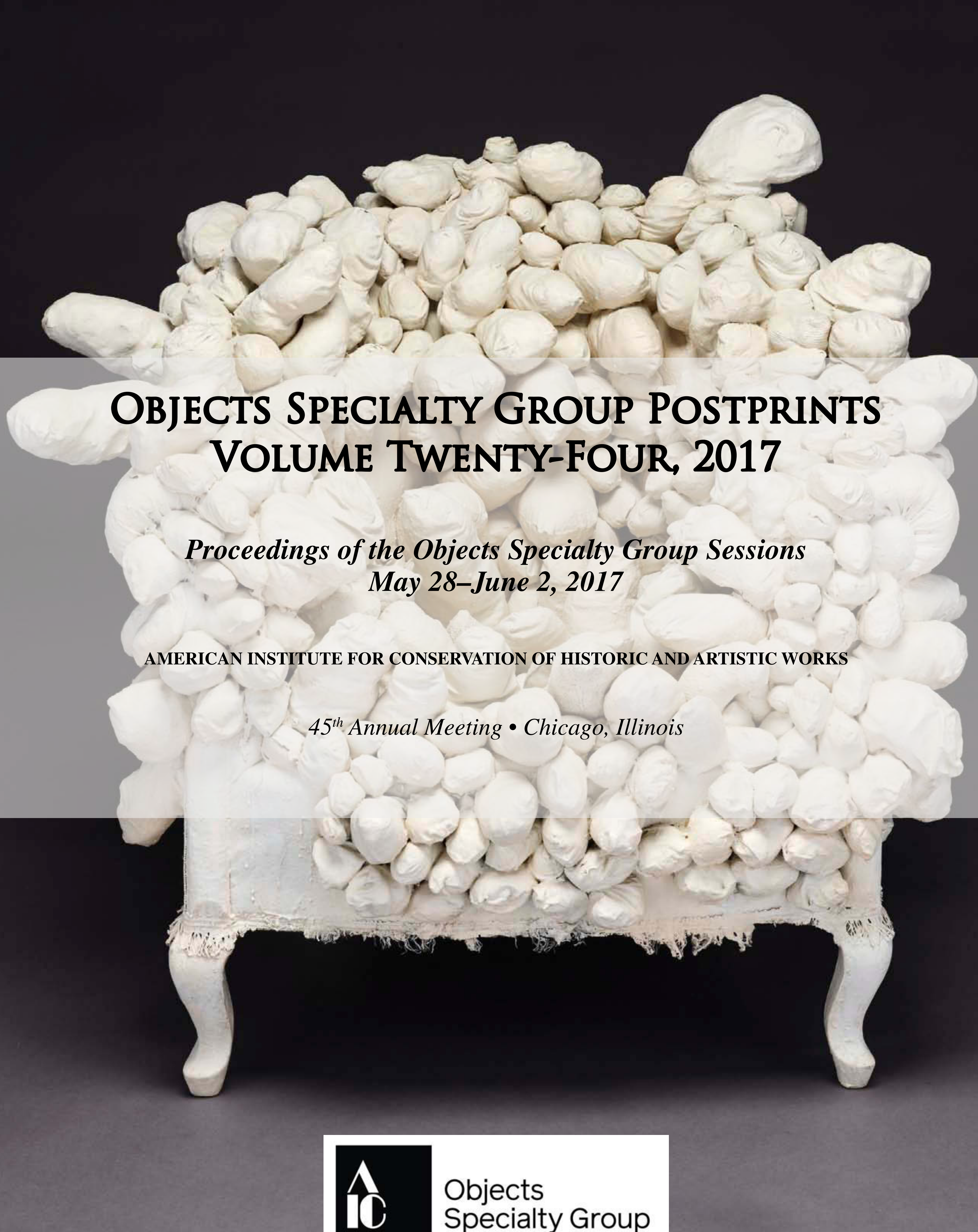

Objects Specialty Group Postprints
Volume Twenty-Four, 2017

Proceedings of the Objects Specialty Group Sessions
May 28–June 2, 2017

AMERICAN INSTITUTE FOR CONSERVATION OF HISTORIC AND ARTISTIC WORKS

45th Annual Meeting • Chicago, Illinois

AIC Objects Specialty Group

Objects Specialty Group Postprints Volume Twenty-Four, 2017

Edited by Kari Dodson and Emily Hamilton
with Tony Sigel, Program Chair

Proceedings of the Objects Specialty Group Sessions
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Cover photographs by Brad Flowers. Front and back views after treatment. Yayoi Kusama, *Accumulation,* 1962–1964, sewn stuffed fabric with paint on wooden chair frame, 87.63 × 96.52 × 83.82 cm. The Rachofsky Collection and the Dallas Museum of Art through the TWO × TWO for AIDS and Art Fund, 2008.41 (Courtesy of Dallas Museum of Art)

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Group Chair's Foreword

As Objects Specialty Program Chair for the 45th American Institute for Conservation's 2017 annual meeting in Chicago, Illinois, May 28-June 2, 2017, I am very pleased to present the Postprints for the Objects Specialty Group session. The meeting theme was Treatment 2017: Innovation in Conservation and Collection Care, and the talks presented reflected the OSG's increasing focus on practical, treatment technique and materials-based information. The program was organized and papers selected by OSG Assistant Program Chair Ariel O'Connor, myself as Program Chair, and Group Chair Laura Lipcsei.

Thanks are due to our speakers for taking the time to transform their talks into full, peer-reviewed papers for publication. These presenter/authors have taken the time and care to distill and present their knowledge, skills, and thoughts for us all to learn from. Individually and cumulatively, these meetings, talks and papers are the engine of the forward progress of our specialty group, which itself embraces the widest spectrum of materials and types of objects imaginable. Equally important has been the continuing efforts of the OSG Postprints Editors, Kari Dodson and Emily Hamilton, and the group of peer reviewers that aid them in bringing these papers to completion and publication. Remarkably, this entire process is voluntary, from the presenter's willingness to be "out there" on the podium, to the editors and reviewers shouldering the task each year of coaxing busy authors into timely completion, lining up volunteer reviewers, organizing visual material into completed documents.

This OSG annual meeting program focused on the practice of treatment: the materials and techniques, the what, how, and importantly the why. Included in the session was a special group of seven talks focused on the Conservation of three generations of the della Robbia family and related workshops. Two complementary della Robbia talks were given in the General Session and RATS groups, and another in the Poster session. Over the past dozen years, there has been a tremendous interdisciplinary interest in these works among conservators, scholars, curators, and private collectors which culminated in the exhibition *Della Robbia: Sculpting with Color in Renaissance Florence* at the Museum of Fine Arts, Boston, and the National Gallery of Art. The exhibition, the first ever devoted to the della Robbia in the United States brought together 46 works from 21 American collections, as well as several important Italian loans.

Outside of the della Robbia initiative, the talks were also highly practical while also considering the ethical considerations of the treatments undertaken. Materials addressed included the novel use of resins, adhesives and fill materials, the structural uses of carbon fiber and paper, and coatings and waxes for outdoor sculpture. Cleaning and stain reduction were featured in several talks, focusing on marble and ceramics and included chelation, poultices, lasers, dry ice blasting, and others. The diverse object materials and treatment-based papers focused on glass invertebrate models, modern furniture, wax sculpture, ancient wood coffins and human remains, and the ethics of conserving modern sculpture made of mud! The tips session was also rich this year, with updates on familiar materials, and the introduction of several new techniques and tools. These papers should be considered required reading for the practicing objects conservator. Congratulations to all involved!

Tony Sigel, 2017 OSG Program Chair

THE CONSERVATION OF DELLA ROBBIA SCULPTURE: AN EXHIBITION AS INITIATOR OF WORK

ABIGAIL HYKIN

There has been a resurgence of interest in glazed terracotta sculpture from the Italian Renaissance. This article provides an overview of work of the della Robbia and related workshops, summarizing the history, technique, and observations gleaned from the 2016 to 2017 exhibition, *Della Robbia: Sculpting with Color in Renaissance Florence*.

KEYWORDS: Conservation, Sculpture, Terracotta, Clay, Glaze, Technique, Italian Renaissance, della Robbia, Buglioni, Rustici

1. INTRODUCTION

This article serves as an overview and introduction to a series of articles on the conservation of glazed terracotta sculpture from the Italian Renaissance, presented as a special session on the conservation of della Robbia sculpture in the Objects Specialty Group with related presentations in the General, Research and Technical Studies, and Poster Sessions. Together, this group of articles covers recent studies, treatments, and mounting of important and large-scale works from three generations of the della Robbia and Buglioni workshops. Many, but not all, of these projects were carried out in preparation for the exhibition *Della Robbia: Sculpting with Color in Renaissance Florence*, which opened at the Museum of Fine Arts, Boston (MFA) in August 2016 and then travelled to the National Gallery of Art, Washington, DC, closing in June 2017.

This was the first exhibition in North America devoted to the della Robbia. In Boston it brought together 46 works from 21 collections: 19 museums and 2 private collections, primarily from the United States but also including six key loans from Italy. At both venues, the exhibition opened with Giovanni della Robbia's spectacular relief depicting the *Resurrection of Christ* (fig. 1).

The use of an opaque, bright and shiny tin-opacified glaze applied to terracotta as a sculptural medium was a new form of art developed by Luca della Robbia in Florence in the 15th century. This article presents an overview of della Robbia sculpture: reviewing the different generations, summarizing the technique and its development, and highlighting some of what we have learned from bringing these works together.

The production of della Robbia sculpture in Florence lasted for only a period of about 130 years (fig. 2). Luca della Robbia (1399/1400–1482) invented the technique sometime before 1440, passing the secrets on to his nephew Andrea (1435–1525). Andrea had 12 children, at least 5 of whom became sculptors. His son Giovanni (1469–1529/30) took over the shop in Florence; by the time of Giovanni's death, the other siblings had either died or moved away, working as sculptors elsewhere in Italy or in France, and the della Robbia shop seems to have closed. Also working in Florence, Benedetto Buglioni (1459/60–1521) somehow acquired the workshop methods from the della Robbias, either, as Vasari tells us, with the help of a woman who worked in the household or, more likely, he was employed in the workshop himself before setting out on his own. Benedetto adopted a young relative, called Santi Buglioni (1494–1576), who took over the business and would be the last of this group to work in the "della Robbia technique" until the style was revived in the 19th century. The Buglioni are now being studied as artists

Fig. 1. View of the exhibition in Boston, with Giovanni della Robbia, *Resurrection of Christ*, about 1520–25, glazed terracotta, 156.2 × 349.3 × 29.2 cm. Brooklyn Museum, Gift of A. Augustus Healy, 99.5 (Image © Museum of Fine Art, Boston, 2017)

in their own right. Other Florentine sculptors, such as Giovanni Francesco Rustici (1475–1554), worked occasionally in the technique.

The works of the della Robbias were highly sought after in the 19th and early 20th centuries and are found in many American museums. Some of the earliest examples to come to the United States were collected by Charles Callahan Perkins in the mid-19th century and donated to the MFA upon its founding in 1870 (Cambareri 2016). Tastes changed, however, and what followed was a long period of neglect—even disdain—through much of the later 20th century. Over the past 40 years, there has been a resurgence of interest in the works of the della Robbias, beginning with Pope-Hennessy's monograph on Luca (1980) and especially with the major monograph by Gentilini (1992), as well as exhibitions curated by Gentilini in Florence (1998) and Arezzo (2009), and technical publications, most of which are in written French and Italian (Vaccari 1996; Vaccari 1998; Bouquillon et al. 2004; Bouquillon, Bormand, and Zucchiatti 2011). Our understanding of della Robbia sculpture has been greatly enhanced by this recent work. The renewed appreciation of della Robbia sculpture means that both museum and private conservators may find themselves working on this material in coming years.

2. LUCA DELLA ROBBIA

Luca della Robbia was born in Florence around 1400. His parents were in the textile trade and Luca is believed to have been trained as a goldsmith before becoming one of the most celebrated sculptors of the Renaissance, working initially in marble and bronze. When Luca was in his thirties, and Florence's

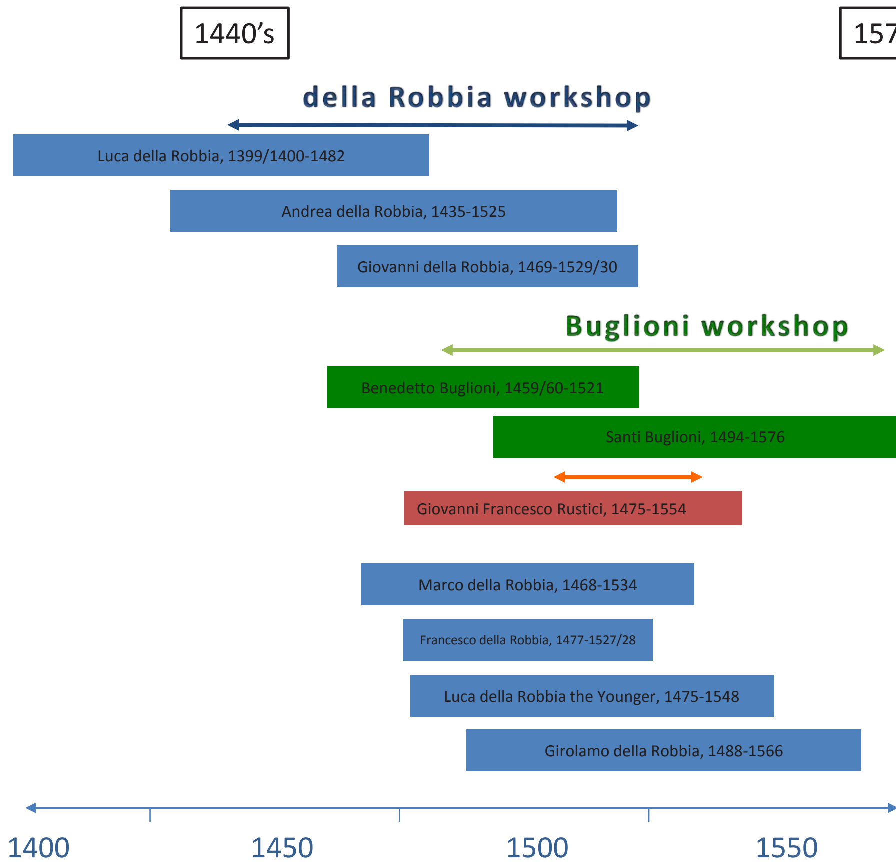


Fig. 2. Timeline showing the production of della Robbia and related workshops (Courtesy of Richard Newman)

cathedral was just completed with the addition of Brunelleschi's dome, Luca was commissioned to participate in several projects for the interior of the cathedral, along with Donatello, Ghiberti, and others. Luca's best-known work in marble—his *Cantoria* (organ loft) depicting children singing, dancing, and making music—was commissioned when he was about thirty years old and placed over the sacristy door at the left side of the crossing opposite another *Cantoria* by Donatello. Both cantorie have been replaced with modern organs in the Cathedral and can now be seen in the Duomo Museum. Luca also created a set of bronze doors for the Sacrestia delle Messe, set under his *Cantoria* (1440s–1470s).

In the 1440s, Luca was commissioned to create two large-scale lunettes to go over the sacristy doors depicting the *Resurrection* and the *Ascension* (fig. 3). These reliefs, which as far as we know have never been removed, are Luca's earliest firmly documented use of glazed terracotta as a sculptural medium. Therefore, they are key to understanding to the development of the technique.

The first of the lunettes to be completed, the *Resurrection*, is glazed primarily with blue and white (and was also partially gilded). Documents indicate that the officials requested more naturalistic colors (i.e., green trees) for the second. Recent art historical work stresses that Luca was paid not just for these commissions but was paid an additional sum in recognition of his invention.[1] It is important to note that this use of glaze on figurative terracotta sculpture was seen, in its own time, as a new material and was

Fig. 3. The interior of the Florence Cathedral in 2016. Luca della Robbia's *Resurrection* (1445) lunette is seen on the left and his *Ascension of Christ* (1446) on the right. Luca also created the bronze door below the *Resurrection*. His *Cantoria* was originally placed on the left, above the *Resurrection*, but is now in the Duomo Museum.

valued for its innovation. The concept of *ingegno*, or innovation, is explored deeply in the exhibition catalog and was highly valued in the Florentine renaissance (Cambareri 2016).

Luca's work was also valued for its permanence—the ability of the glazed terracotta to retain its bright, legible colors even when kept outdoors. A good example of this is at Orsanmichele, the former grain hall transformed into a church of the Florentine guilds. Today, one can see replicas of bronze and marble sculptures created for niches around the exterior of the building (the originals, by Verrocchio, Donatello, and Giambologna, have been moved indoors). In the register above the niches, a series of painted (unglazed) roundels are now faded and illegible, while brightly colored glazed terracotta roundels by Luca della Robbia, such as the *Coat of Arms of the of Guild of Doctors and Apothecaries* (fig. 4) continue to shine over the streets of Florence. Luca's roundels at Orsanmichele are also important reminders of the fact that Luca had the ability to use a wide range of colors, much more than the blue and white with which he is associated.

It is also key to recognize that Luca della Robbia's invention was not only a cheap imitation of marble, as is sometimes claimed, including by Vasari himself (Vasari 1912). Even Luca's monochromatic white figures of the *Visitation* (see Speranza and Afra, in this volume) represent a whole new type of artistic work with its own innate meaning and qualities, such as reflectivity and shine, creating a new and different visual impact versus either marble or painted sculpture.

Fig. 4. Luca della Robbia, *Coat of Arms of the Guild of Doctors and Apothecaries*, ca. 1460, glazed terracotta, diam. 180 cm. Orsanmichele, Florence.

3. WORKSHOP PRACTICES

So what was Luca's new invention? How did he create this new form of sculpture? Terracotta, of course, starts with the clay. The della Robbias used a light-colored, calcium-rich clay gathered from the Arno river. They had property along the river, outside of Florence, which was presumably the source of their clay. The 16th century potter and author, Cipriano Piccolpasso, illustrates the digging of clay from a riverbed in his treatise "The Three Books of the Potter's Art" (fig. 5).

The della Robbia home and workshop, beginning in the 1440s, was in Florence on via Guelfa near via Nazionale (near the present day train station and just inside the city walls)—not far from either the countryside or the center of the city and its cathedral. Luca lived and worked here with his brother and his brother's family, including his nephew Andrea and, eventually, Andrea's many children. Individual authorship of della Robbia works is not always apparent. Andrea began working with Luca when he was a teenager and their work was deeply intertwined. In terms of distinguishing their work, it is sometimes said that Luca's babies are on the left and Andrea's on the right, or Luca does blue eyes and Andrea does yellow eyes, but that is not always the case. They clearly worked together and they also presumably had other assistants in the workshop. Thus, it is not always possible to clearly differentiate their work.

Presumably it was at this workshop that the clay would be prepared and the sculptures formed, followed by two firings in a kiln: the bisque firing and glaze firing, generally cited to be around 950°C (Vaccari 1998; Bouquillon 2011) and discussed further later. We do not have evidence about the form that their

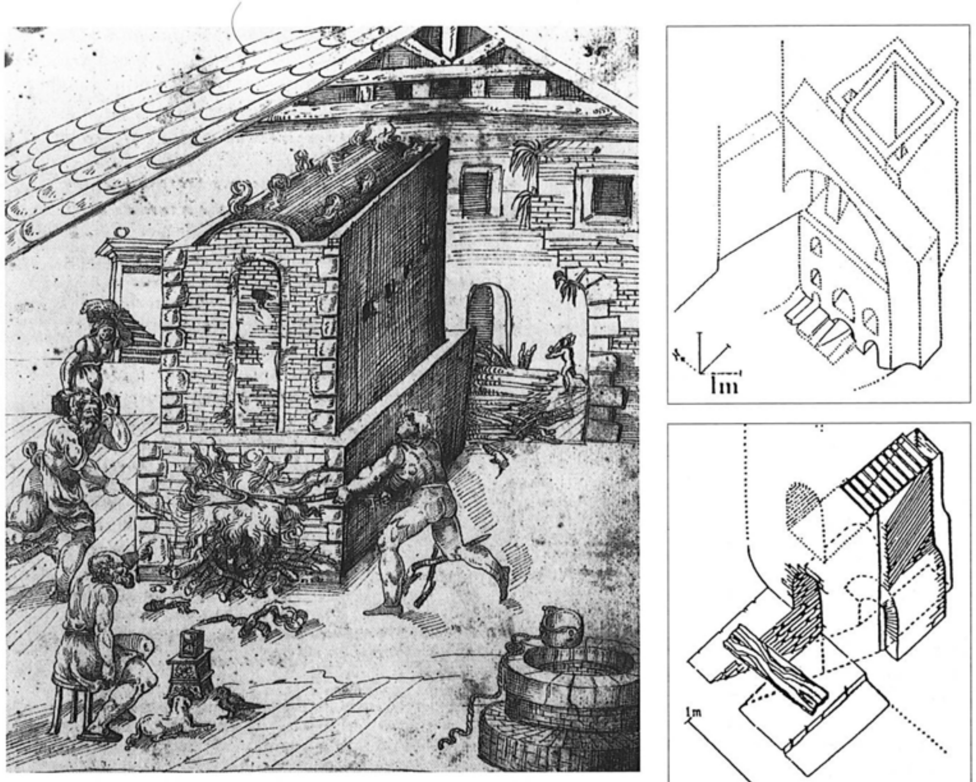
Fig. 5. Digging clay from a riverbed. Cipriano Piccolpasso, *The three books of the Potter's Art/Tre libri dell'arte del vasaio*, translated by B. Rackham and A. Van de Put (London: Victoria and Albert Museum, 1934)

kilns took or whether saggers were used during firing, but they could have been similar to those illustrated by Piccolpasso (fig. 6).

There would be a limit to the size of the works that could fit in the kiln. The largest pieces from the exhibition that were fired in one piece were Luca's freestanding sculpture of the *Madonna and Child* from the Oratory of San Tomasso, approximately 100 cm tall, and the *Madonna and Child* relief from the Toledo Museum of Art, approximately 74 cm tall (figs. 7, 8).

Larger works had to be fired in sections. The MFA's relief of the *Nativity*, created in six sections and assembled after firing, is 89 cm tall (figs. 9a, 9b). This is only somewhat larger than Toledo's relief, but has much greater depth, suggesting that sectioning would also be dictated by what could be handled or fired safely. The *Nativity* and the *Visitation* also demonstrate that Luca was a master of hiding the joins between the individual sections. The joins were well integrated into larger compositions, largely invisible, and are keyed together in such a way that they do not rely on mortar to hold them together.

Another reason for creating works in sections was for ease of transport. During the Renaissance, della Robbia sculptures were commissioned from as far away as Portugal and England and shipped across Europe. Andrea della Robbia created several large-scale altarpieces for the Franciscan Sanctuary of La Verna in the mountains of Arezzo. His *Crucifixion* altar relief, commissioned for the spot where St. Francis received the stigmata, is the largest altarpiece made, at 600 cm tall, and was manufactured in approximately 185 individual sections



"Fornace" durante la cottura. In C. Piccolpasso, *Li tre libri dell'arte del vasaio* (1557-58).
A destra: restituzione ipotetica della *fornace* e del *forno da smalti* dell'atelier
di Bernard Palissy, rinvenuto a Parigi presso Le Tuileries. In "Revue de l'Art", 1987.

Fig. 6. A kiln used for maiolica. Cipriano Piccolpasso, *The three books of the Potter's Art/Tre libri dell'arte del vasaio*, translated by B. Rackham and A. Van de Put (London: Victoria and Albert Museum, 1934).

(fig. 10). These large works would be created in Florence and then transported on carts and on boats, to be installed a long distance away. The treatment of Andrea's relief of *Prudence*, carried out at The Metropolitan Museum of Art for this exhibition, sheds light on how the workshop may have kept track of the arrangement of sections during manufacture and installation (see Riccardelli and Walker, in this volume).

4. GLAZE AND CLAY

In bringing together so many related works, the exhibition provided the opportunity to deepen our understanding of della Robbia sculpture through careful observation and ongoing discussions as well as analysis of the glaze and clay. With repeated examination of the glazed surfaces with the curator and other colleagues, we discovered that many of the glaze surfaces (especially the white glazes of Luca and Andrea) had a particular texture—slightly puckered or rippled, similar to thick cream or cellulite.[2] There was also often a very light craquelure and patches of tiny gray specks due to small air bubbles in the glaze (figs. 11a, 11b). This texture was not seen in pieces that were known to be modern, such as an early 20th century version of Andrea della Robbia's *Adoration of the Child* by the Cantagalli factory (MFA 2016.1463) or in areas of known 19th century restorations on other MFA works.

Glaze analysis was carried out on selected works, building on the extensive work on the della Robbias in France and Italy (Bouquillon et al. 2004; Bouquillon, Bormand, and Zucchiatti 2011) and the MFA's previous work (Hykin et al. 2007). To date, the MFA has gathered approximately 125 samples from 25

Fig. 7. Luca della Robbia, *Madonna and Child*, ca. 1450–60, glazed terracotta, 99 × 47.5 × 37 cm. Oratory of San Tomasso d'Aquino, Florence.

Fig. 8. Luca or Andrea della Robbia, *Madonna and Child*, ca. 1465–70, glazed terracotta, 73.7 × 51.2 × 11.4 cm. Toledo Museum of Art. Purchased with funds from the Libbey Endowment, Gift of Edward Drummond Libbey, 1938.123 (Courtesy of Casey Mallinckrodt)

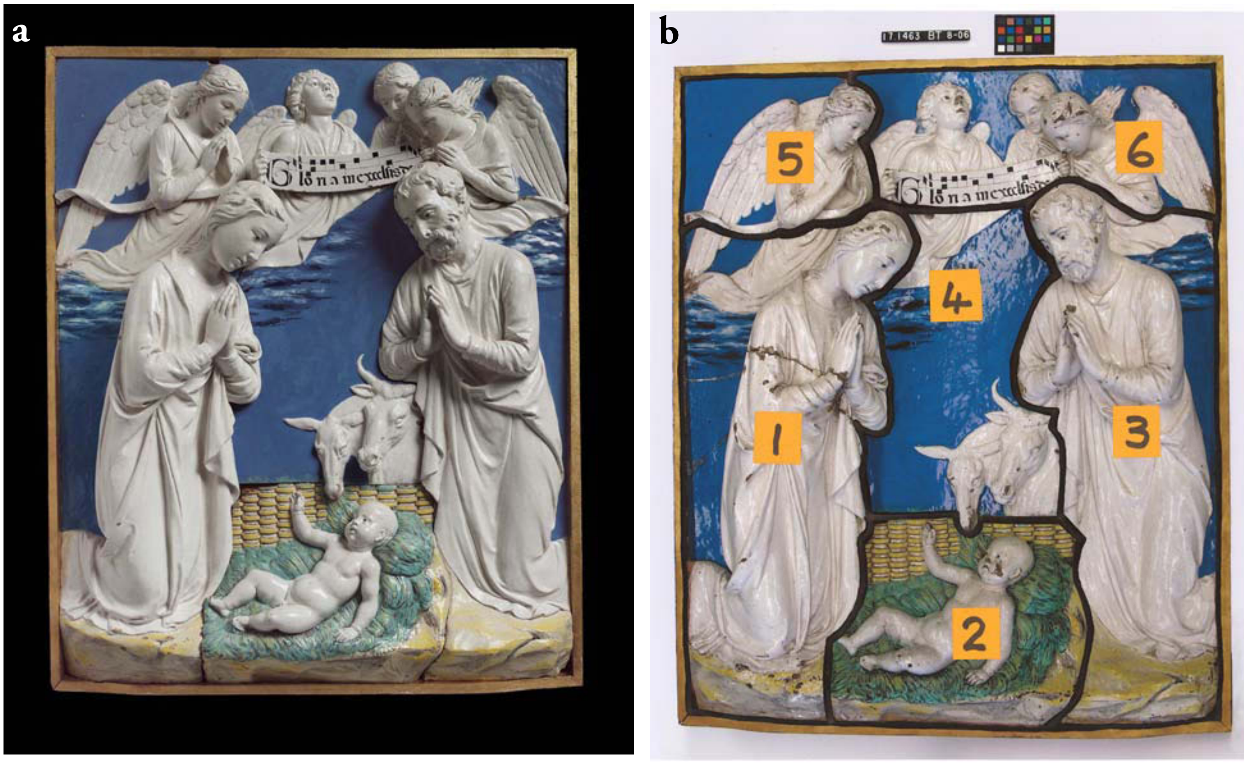


Fig. 9a. Luca della Robbia, *Nativity in Gloria Excelsis*, ca. 1470, glazed terracotta, 88.9 × 73.7 cm. Museum of Fine Arts, Boston, Gift of Quincy Adams Shaw through Quincy Adams Shaw, Jr., and Mrs. Marian Shaw, 17.1463 (Image © Museum of Fine Art, Boston, 2017); 9b. The *Nativity* before treatment in 2006 by Flavia Perugini, with numbers indicating individually fired sections (Courtesy of Flavia Perugini)

sculptures, including those with firm attributions and some that we know to be modern. The glaze samples, taken from areas of existing damage, generally included a small amount of the clay body. These have been prepared as polished cross sections and are being analyzed by scanning electron microscopy/energy-dispersive x-ray spectrometry (SEM/EDS) by Richard Newman, head of Scientific Research at the MFA. XRF was also used in a few cases when samples could not be taken. We owe a great deal of thanks to the lenders who allowed us to sample, or provided samples of, their objects or shared their own data for comparison. This work is ongoing and will be published in detail in a separate publication. Some examples from this research are discussed here.

A beautiful, almost idealized, example of Luca's white glaze can be seen in a cross section from the San Tomasso *Madonna and Child* (figs. 12a, 12b; see fig. 7), believed to be a fairly early example of Luca's use of glazed terracotta. As observed by Richard Newman, bright white spots of recrystallized tin oxide are evenly distributed throughout a single opaque glaze layer measuring approximately 150 microns thick. There is also a well-formed interaction layer of calcium silicate crystals formed between clay and glaze, formed as calcium from the clay body diffused into the glaze during firing.

The calcium-rich, or marly, clay was typically used for lead glazes throughout the Renaissance. This clay has a similar coefficient of expansion to the lead glazes, providing a good glaze fit, and could be fired over a wide range of temperatures, generally cited as between 750°C and 1050°C (Tite et al. 1998; Vaccari 1998; Bouquillon 2011). The light color of these marly clays after firing can be seen clearly on break edges or on the interiors or backs of the sculptures.

Fig. 10. Andrea della Robbia, *Crucifixion*, ca. 1481, glazed terracotta, 600 × 420 cm. Chapel of the Stigmata Sanctuary of La Verna

Fig. 11a. Detail of figure 9 showing glaze texture; 11b. Detail of figure 8 showing glaze texture.

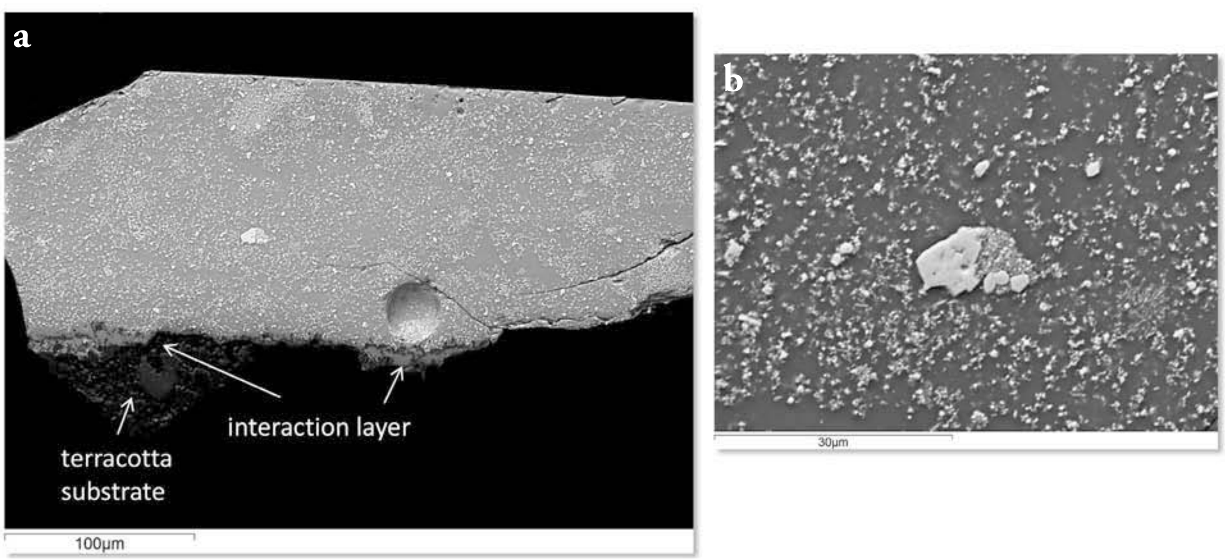


Fig. 12a. Cross section of white glaze (back-scattered electron image) from Luca della Robbia, *Madonna and Child*, San Tommaso (see fig. 7); 12b. Higher-magnification detail showing small tin oxide particles (< 1 μm), with occasional larger ones; overall tin oxide content, approximately 17%. (Courtesy of Richard Newman)

5. GLAZE REPAIRS AND HOLLOWING OUT

While showing the color and texture of the fired clay, the backs and interiors of sculptures also showed a great deal of variety in how the sculptures were hollowed out.

Reliefs and freestanding sculptures were hollowed with a variety of styles, some more rigid and some more free form and organic. These could not be clearly attributed either to one particular generation or type of relief. Barbour and Olson (2011) have published on six versions of a tondo of the *Madonna and Child* by Andrea della Robbia, looking at variations and changes that took place owing to replication with molds and also comparing the backs. With a systematic database, it may be possible to build on this work to compare the different ways that the backs were treated with a larger group of sculpture.

In some cases, the presence of frames or mounts meant that the backs were inaccessible. However, we found only two cases in which the backs were left flat, both versions of Luca della Robbia's *Madonna of the Niche*—held by the MFA (17.1475; figs. 13a, 13b) and The Met (67.55.98)—both generally dated quite early, about 1445 to 1455.

As seen in figure 13b, we discovered a surprising number of examples of glaze being used as a repair material during manufacture, applied after the bisque firing to reinforce firing or drying cracks. The repair glazes could be white or colored (fig. 14). Glaze repairs had been reported in the literature previously but we were not expecting to see how common a practice this was in the della Robbia workshop—we saw it through all generations of the workshop from Luca and Andrea (see Speranza and

Fig. 13a. Luca della Robbia, *Madonna of the Niche*, ca. 1445–55, glazed terracotta, 53 × 44.5 × 7 cm. Museum of Fine Arts, Boston, 17.1475; 13b. Back view showing thick white glaze used to reinforce firing cracks on the flat back of the relief (Images © Museum of Fine Arts, Boston, 2017)

Fig. 14. Back view of figure 8. Luca or Andrea della Robbia, *Madonna and Child*, ca. 1465–70, glazed terracotta, 73.7 × 51.2 × 11.4 cm. Toledo Museum of Art. Purchased with funds from the Libbey Endowment, Gift of Edward Drummond Libbey, 1938.123, Note blue glaze used to reinforce a crack in the hollowed back of the relief. (Courtesy of Suzanne Hargrove)

Afra; and Riccardelli and Walker, both in this volume) to Giovanni (fig. 1; also discussed by Bruno et al. in the General Session (unpublished)). In addition, Walker found a mixture of glaze and clay used as workshop repair in Andrea della Robbia's *St. Michael the Archangel* (Metropolitan Museum of Art, 60.127.2, see Riccardelli and Walker, in this volume).

6. GILDING AND COLD PAINTING

It also became apparent that the use of gilding was much more common and extensive than we had previously realized. Approximately 50% of the pieces in the exhibition had traces of gilding or visual evidence of previous gilding—again, covering all generations. While in some cases the gilding had clearly been strengthened or reinforced in the recent past, particularly on haloes, faint traces of gold or remains of mordants were commonly noted as patterns on backgrounds and drapery (see Mallinckrodt, poster, in this volume). One of the best-preserved examples of an overall gilding pattern, which appears to be original, covers the blue background of Luca della Robbia's *Madonna and Child* relief from the Bargello (figs. 15a, 15b). In many cases, the gilding would have formed large/extensive patterns and had great visual impact.

The use of cold painting over the fired glazes would have also significantly transformed the appearance of these works during the Renaissance, particularly with the addition of red, which could not be made as a glaze. Giovanni della Robbia, the third-generation della Robbia working in Florence, is associated with a

Fig. 15a. Luca della Robbia. *Madonna and Child*, ca. 1441–45, glazed terracotta, 63 × 50 cm. Museo Nazionale del Bargello, Florence. Courtesy of the Ministero dei beni e delle attrivita culturali e del turismo. (Courtesy of Antonio Quattrone); 15b. Detail of gilding remains on background.

much bolder color palette than his father Andrea or his uncle Luca; traces of red paint found on several of his works show that his use of color would have been even bolder than what we see today. One of the clearest examples is found on Christ's brown robes on The Brooklyn Museum's relief of the *Resurrection*, which were originally painted red (fig. 1; also discussed by Bruno et al. in the General Session). Another example, not shown in the exhibition, is found on Giovanni's statuette of *Abundance* at the MFA (46.840), in which traces of red paint under small purple fruit falling from the basket on her head clearly identify them as cherries. In addition, in Giovanni's relief of *St. Donatus* (figs. 16a, 16b), the robe, gloves, and the bishop's hat on his badge should be depicted as bright red, not deep purple. In this case, only one tiny speck of red was discovered on the robe, but the examination was limited by existing restorations and the current mounting of the relief.

Traces of polychromy were also seen on unglazed passages of flesh and hair on works attributed to Andrea, Giovanni, Luca the Younger, and the Buglioni. This suggests that most, if not all, unglazed areas were, in fact, painted at one time.

The loss of gilding, red paint, and polychromy has a significant effect on the way these works are perceived in our time. In 2017, directly after the della Robbia exhibition, there was an exhibition of paintings by Sandro Botticelli and his circle, including Fra Filipo Lippi, at the MFA. The direct comparison of these works—with the same subject matter, from the same time, and exhibited in the same space—was a powerful reminder of the impact of gold and red, driving home what has been lost from these sculptures over the centuries. Thus, while the glazing of della Robbia sculpture has allowed some colors to retain the brightness and shine, we also should be cognizant that this permanence does not apply to all colors.

7. CLAY LAYERING

Another interesting observation about the work of Giovanni is the use of layered clay on two of his largest reliefs, both dating to the 1520s, nearing the end of the workshop's activity in Florence. The edges of the *St. Donatus* relief are unglazed and the clay body is visible around the entire perimeter. Most of the thickness of the slabs that make up the eight sections of the relief are a red-colored clay. The presence of red, noncalcareous clay was somewhat alarming when the piece was first seen prior to the exhibition since red-colored clay is not expected in della Robbia works but is often seen in 19th century restorations (as an example, see Bailey, in this volume). However, in this case, the typical light-colored, marly clay was used on the upper surface, closest to the glaze and where it matters most, while the back of the relief is made with a red-colored clay (fig. 17a). We saw this use of distinctly layered clay on one other work in the exhibition, Giovanni's *Resurrection* relief (see fig. 1; see Bruno et al., in this volume); as yet ,we know of no other examples. We can only guess at the reasons for this use of layered clay. These two works are dated fairly late, toward the end of the della Robbia shop production, and are both large compositions. Was the workshop so busy that they could not keep up with the clay production? Was the red clay cheaper or easier to process? It seems they knew that they needed only to keep the marly clay against the glaze but were perhaps experimenting with how sparingly it could be used.

The glazing of the *St. Donatus* is also very creative and somewhat odd and experimental: the trees on the right, for example, are growing from a rocky cliff, and the rocks are formed by chunks of porous slag that are embedded in the clay (fig. 17b). This is another good indication that the idea of innovation, or *ingegno*, did not stop with Luca's invention but continued through the generations.

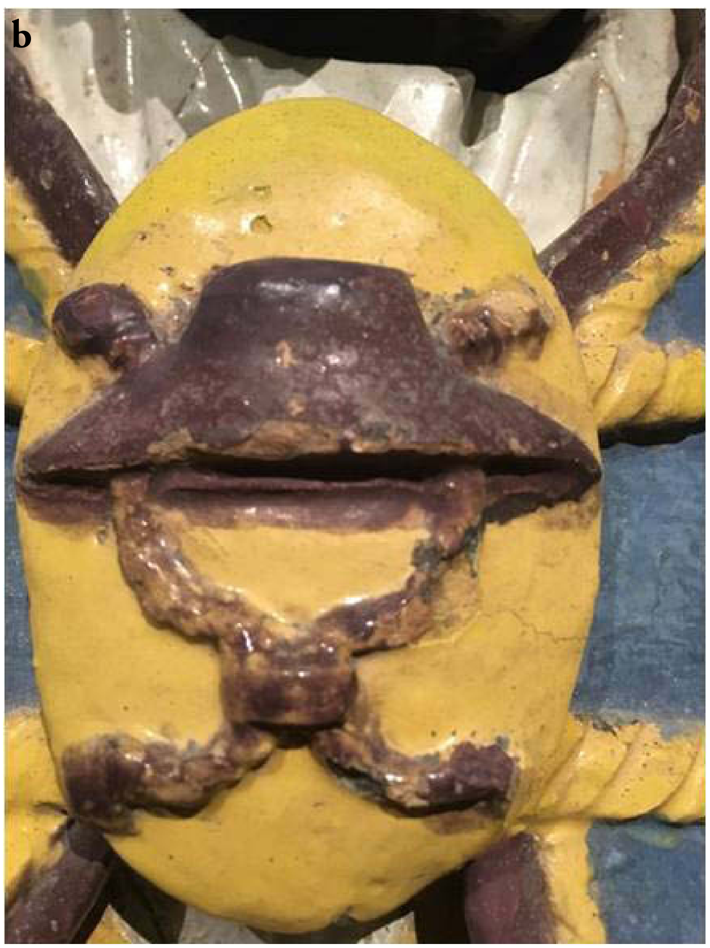


Fig. 16a. Giovanni della Robbia, *Saint Donatus Purifies a Well*, ca. 1520s, glazed terracotta, 86.4 × 144.8 × 33.2 cm. Princeton University Art Museum, 2003-237. (Images © Museum of Fine Arts, Boston, 2017); 16b. Detail of the bishop's hat on his badge. (Courtesy of the author)

Fig. 17a. Detail of figure 16 showing two colors of layered clay at the unglazed edge of the relief; the thickness of clay is approximately 3 cm. 17b. Detail of figure 16 showing the inclusion of slag to depict a rocky cliff. (Both images courtesy of the author)

8. OTHER DELLA ROBBIAS

Several of Giovanni's siblings were also sculptors. Examples of works attributed to Luca the Younger (1475–1548) and Girolamo della Robbia (1488–1566) were included in the exhibition. These sculptors have been less studied and they show a wide range of adaptations as the family moved beyond Florence. The examples by Girolamo included white glazed busts created while he was working in France, where he had to make use of different raw materials than were employed in the Florentine workshop. Three of these busts appear to be related visually and by the fact that they have areas of purple glaze at the edges (*Bust of a Man*, J. Paul Getty Museum, 95.SC. 21; *Bust of a Woman*, Yale University Art Gallery, 1950.138; and *Francis I (1494–1547), King of France,* Metropolitan Museum of Art, 41.100.245). Furthermore, the white glazes all have a visibly stronger craquelure than what is generally observed on della Robbia sculpture, which can be attributed to the use of a sandier clay with less calcium, although restorations can mask these details.

9. OTHER WORKSHOPS – BUGLIONI

The other Florentine workshop making glazed terracotta sculpture was that of Benedetto Buglioni and his young relative called Santi Buglioni. Benedetto was known for his large-scale altarpieces and, although not included in the exhibition, recent treatments at the Art Institute of Chicago (*Adoration of the Shepherds*, 1924.218; see Sabino, in this volume) and at the Cleveland Museum of Art (*Virgin and Child Enthroned with Saints Francis and Giovanni Gualberto*, 1921.1180; Springer, private communication) provide insight into these large-scale works. Works attributed to Buglioni in the exhibition included three white glazed figures: *Hope* and *Charity* (both privately owned) and the Met's bust-length figure of *St. John the Baptist*. Benedetto's work has sometimes been considered a lesser imitation of the della Robbia but his works are very beautiful in their own right and he made use of beautifully naturalistic glazes, particularly grays and mottled browns. His work also tends to show more glaze defects, such as glaze crawling or blisters, although it is possible that some of these were, in fact, intentional effects to suggest rough landscapes, for example.

The exhibition also brought together several works attributed to Santi Buglioni, including a colorful, partially glazed *Madonna and Child* from the Walters Art Museum (27.218) in Baltimore and a grouping of three spectacular life-sized figures of Standing Saints (*Saint John of Capistrano*, Los Angeles County Museum of Art, M.2007.2a-b; *Saint Bernardino of Siena*, private collection; and *Saint Francis(?)*, Uffizi Gallery; see Sigel, in this volume; Gat, in this volume). The most important of Santi's works is the façade of Ceppo Hospital in Pistoia, which was recently cleaned and which also has Giovanni's final commission. The conservation of this monument is beautifully published by Capecchi et al. (2015). As the last practitioner of this technique and a figure who has been relatively little studied, the work of Santi Buglioni provides an important reference point for understanding this work at end of its use during the Renaissance.

10. OTHER SCULPTORS – RUSTICI

The MFA's focus on della Robbia sculpture stems directly from the 2003 rediscovery of a white glazed standing figure of *St. John the Baptist*, which had languished in storage from the time of its acquisition in 1950 until the storerooms needed to be emptied for a large building project in 2003 (fig. 18). The treatment of this important sculpture, now attributed to Giovanni Francesco Rustici, was previously

Fig. 18. Giovanni Francesco Rustici, *St. John the Baptist*, ca. 1505–15, glazed terracotta, 100.3 × 33 × 26.7 cm. MFA 50.2624. (Image © Museum of Fine Arts, Boston, 2017)

published (Hykin 2007), but it is interesting to revisit the findings from that treatment in light of what has been learned since then.

This sculpture is one of the few that was clearly modeled, built up from sausages of clay. It is without an opening at the underside or back, unlike all of the other examples of sculpture in the round in the exhibition. The head and torso were hollowed out by the use of a soft core, or anima, which was removed before firing; vent holes exist at the top of the head and possibly at the back. Separations between the musculature and clothing also suggested that the figure was largely modeled and then dressed, that is, the goat skin was draped over the finished arm. Glaze repairs were not noted, although, as Walker also notes on Andrea della Robbia's *St. Michael the Archangel* (Ricardelli and Walker, in this volume), the sculptor was not overly concerned about careful luting, or joining added sections of clay. Where a section of drapery from the front of the waist was removed at an unsightly old repair, a fingerprint impressed in the wet clay was uncovered, as were crisp tool marks—both clear evidence that the two sections never made contact.

11. CONSERVATION TREATMENTS AND FUNDING

A great deal of conservation was needed to enable the exhibition to go forward. The most significant and large-scale treatments were, coincidentally, for the three major works from each of the three della Robbia generations: Luca's *Visitation*, Andrea's *Prudence*, and Giovanni's *Resurrection of Christ*. Each of these projects is presented as individual papers in this publication (Speranza and Afra; Riccardelli and Walker; also discussed by Bruno et al. in the General Session). While the exhibition budget (including corporate and private sponsors from both of the host institutions) covered most of the conservation costs, including that of Luca's *Visitation*, there were also some more unusual and creative funding sources. For example, the Antinori family supported the conservation of the Brooklyn Museum's *Resurrection*, as this relief was originally commissioned by their Renaissance forebears and includes the life-size donor figure of the Marchese Antinori. The Metropolitan Museum of Art's own funding of the treatment of Prudence also made them a true partner in the exhibition. The nonprofit organization, Friends of Florence, was also a generous supporter of conservation of the *Madonna and Child* from the Oratory of San Tomasso d'Aquino.

Treatment on the MFA's own collection had largely been carried out for the exhibition *Donatello to Giambologna: Italian Renaissance Sculpture at the Museum of Fine Arts, Boston* in 2004 and for a new Italian Renaissance gallery in 2007. An exception was an early 20th century relief by the Cantagalli Workshop, *Adoration of the Child* after Andrea della Robbia, which was acquired by the MFA in 2013 specifically for inclusion in the exhibition. Its treatment by Casey Mallinckrodt provided an opportunity to compare the differences in fabrication and quality of a modern revival piece. MFA conservators also carried out some treatment for seven smaller loans, mostly from private lenders, which were able to arrive a few weeks or months prior to the exhibition. Having some works arrive early also allowed for display mounts, such as clips and inserts, to be made prior to installation.

12. EXHIBITION PLANNING

During the planning phase, as the conservator for the exhibition, I felt that it was important to see as many of the sculptures as possible to gather information about condition, mounting, and installation. Thanks to the curator's long-standing interest in conservation, the catalog would also contain a chapter on "Materials and Technique" and the exhibition included a set of gallery labels with the heading "From the Conservation Laboratory." It would have been ideal to see each of the works prior to writing for the

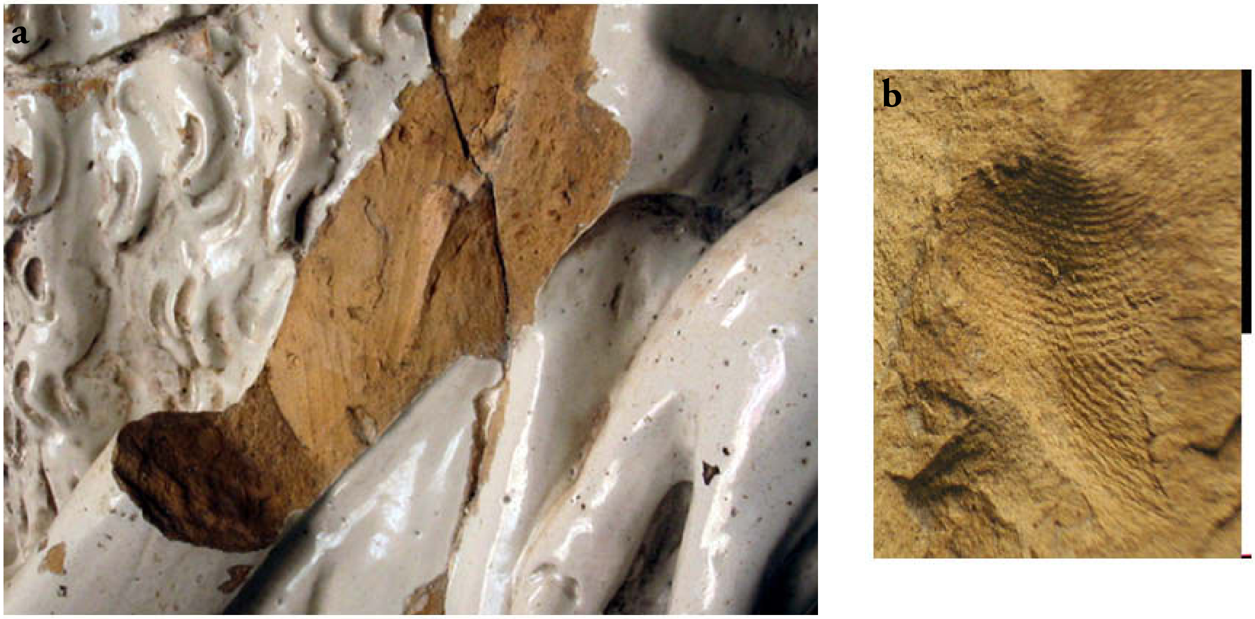


Fig. 19a-b. Detail of figure 18 during treatment in 2004 showing crisp tool marks where a section of drapery has been removed at the waist and a detail of a fingerprint from the removed drapery (Courtesy of the author)

catalog. However, the time frame was extremely tight—catalog writing was due a year before the opening, while some loans were not secured until much later.

In the end, despite the lack of a travel budget for conservation planning, I managed to visit ten of the US museums and private lenders to see most of the loans. But it was only in March, just four months before the opening, that I was able to visit Florence with our curator, Marietta Cambareri, to see these works in situ so that we could make the final arrangements for their inclusion in the exhibition. This trip, for parts of which we were joined by Wendy Walker and by art historians Catherine Kupiec and Rachel Boyd, allowed discussions and observing together, which was profoundly important to my own understanding of della Robbia sculpture and its original context.

In order to relay information about each individual object and its special requirements for planning handling, display, or installation needs, I found it easiest to pull all the relevant information into a PowerPoint document that included dimensions, weight, images of front and back of each sculpture, any existing mount, and any special concerns or needs. This was shared internally and with the venue, providing a clear visual means for understanding the needs of each sculpture.

13. CONCLUSION—FUTURE STUDY

Given the widespread interest in della Robbia sculpture in recent years, it is probable that there will be a continued focus on treatment and research. Many of the works in North American collections were acquired in the late 19th and early 20th centuries and there are many with aged and failing restorations. I am hopeful that the observations gathered in these articles, such as the possible presence of gilding or cold painting, glaze repairs, workshop markings and notations, variations in the use of clay and glaze, and the often subtle surface qualities of the glaze, can help to inform the examination and treatment of more works. Even with all of this added information, there are many secrets of the Renaissance sculptors' workshops that remain a mystery. (Experimental archeology could be a promising direction to attempt to understand questions of production, such as whether saggers were used in the kilns.)

These works are also far removed from their original contexts; thus, comparison with firmly dated works that remain in situ in Italy is key. This would provide fixed data points for comparison of clay and glaze analysis, and may also help clarify questions about original mountings and installations. In depth study of firmly documented monuments in Italy would be extremely useful to create firm points of comparison. Andrea's iconic roundels from Ospedale degli Innocenti have been recently treated and are presented here (see Speranza and Afra in this volume). Specifically, the study of Luca's first commissions in the Duomo from the 1440s would provide a very important earliest reference point as well as his roundels at Orsanmichele, and the recently treated reliefs at Ceppo Hospital by Santi Buglioni dating to the mid-16th century provide the endpoint for this production in the Renaissance.

Building on work being carried out at other institutions, this exhibition provided an exceptional opportunity for conservators, art historians, and scientists to work together to further our understanding and appreciation of these Renaissance sculptors and their contributions. This special session on della Robbia sculpture, with eight related articles, has provided a wonderful in-depth exchange of information, ideas, and questions that I hope we can continue to work on together.

ACKNOWLEDGMENTS

I am extremely grateful to be able to collaborate on this project and many others with Marietta Cambareri, senior curator of Decorative Arts and Sculpture and Jetskalina H. Phillips Curator of Judaica, and Richard Newman, head of Scientific Research at the MFA. None of this work would be possible without the push and pull of the curator's questioning countered by the scientist's caution. We are all grateful to the many lenders to the exhibition who were generous in sharing information about their objects or allowed sampling or other analysis.

I am also deeply appreciative of the very many colleagues whose assistance, treatments, observations, and discussions contributed to this exhibition as well as to my own understanding of della Robbia sculpture: Shirin Afra, Brett Angell, Greg Bailey, Daphne Barbour, Jane Bassett, Monica Berry, Rachel Boyd, Lisa Bruno, Jessica Chloros, Michele Derrick, Leslie Gat, Courtney Harris, Pamela Hatchfield, Catherine Kupiec, Sarah Levin, Adeline Lutz, Casey Mallinckrodt, Maria Christina Masdea, Flavia Perugini, Louis Pierelli, Caroline Riccardelli, Rachel Sabino, Holly Salmon, Matthew Siegel, Tony Sigel, Kim Simpson, Rika Smith McNally, Colleen Snyder, Laura Speranza, Samantha Springer, Melissa Tan, Valerio Tesi, Mei-An Tsu, Dante Vallance, and, of course, Wendy Walker.

Finally, I am very grateful to the organizers of AIC and OSG who welcomed and supported the idea of a dedicated session on della Robbia sculpture.

NOTES

1. As noted by Catherine Kupiec (2017), the final payment to Luca for his *Resurrection* was for his industry and invention (*pro sua industria et invention*).

2. Wendy Walker is to thank for this and many other observations.

REFERENCES

Barbour, D., and R. J. M. Olson. 2011. "New Methods for Studying Serialization in the Workshops of Andrea della Robbia: Technical Study and Analysis." In *Della Robbia: diece anni di studi = dix ans d'*études. Edited by A. Bouquillon, M. Bormand, and A. Zucciati, Genova: Sagep. 56–61.

Bouquillon, A., A. Zucchiati, J. Castaing, and I. Katona. 2004. Les della Robbia: matière et transfiguration. In *Terres Cuites De La Renaissance*. Paris: Centre de recherche et de restauration des musées de France. *Techne* 20: 13–17.

Bouquillon, A., M. Bormand, and A. Zucchiatti, ed. 2011. *Della Robbia: dieci anni di studi = dix ans d'études*. Genova: Sagep.

Bouquillon, A. 2011. Terra, vivi per me cara e gradita. In *Della Robbia: dieci anni di studi = dix ans d'études*. Edited by A. Bouquillon, M. Bormand, and A. Zucchiatti. Genova: Sagep. 24–31.

Cambareri, M., with contributions by Abigail Hykin and C. L. Harris. 2016. *Della Robbia: Sculpting with color in Renaissance Florence*. Boston: MFA Publications.

Capecchi, G., M. C. Masdea, V. Tesi, G. Tucci, and N. Begliomini. 2015. *Avvicinatevi Alla Bellezza: Il Fregio Dello Spedale Del Ceppo*. Pistoia: Giorgio Tesi.

Gentilini, G. 1992. I Della Robbia: La scultura invetriata nel Rinascimento. 2 vols. Florence: Cantini.

Gentilini, G. 1998. I Della Robbia e l' "arte nuova" della scultura invetriata. Exh. cat. Basilica di Sant'Alessando, Fiesole, Florence: Giunti Editore.

Gentilini, G., ed. with L. Fornasari, 2009. I Della Robbia: Il dialogo tra le arti nel Rinascimento. Exh. cat. Museo Statale d'Arte Medievale e Moderna, Arezzo. Milan: Provincia di Arezzo and Skira Editore.

Hykin, Abigail. 2007. "The Conservation and Technical Analysis of a Glazed Terracotta Figure of St. John the Baptist Attributed to Giovanni Francesco Rustici." In *Riconoscere un patrimonio, la statua e la sua pelle: artifici tecnici nella scultura dipinta tra Rinascimento e Barocco*, edited by R. Casciaro. Galatina (Lecce): M. Congedo. 81–99.

Hykin, Abigail, Flavia Perugini, Richard Newman, and M. Cambareri. 2007. "An Overview of the Treatment and Analysis of Italian Renaissance Sculpture at the Museum of Fine Arts, Boston." In *Glass and Ceramics Conservation 2007: Interim Meeting of the ICOM-CC Working Group 27-30 August 2007, Nova Gorica, Slovenia*, edited by Lisa Pilosi. Nova Gorica: Goriški Muzej [u.a.]. 120–129.

Kupiec, C. 2017. Luca della Robbia: A Portrait of the Artist as Inventor. Presentation at Renaissance Society of America, Chicago, March 30, 2017.

Piccolpasso, C. 1934. *The Three Books of the Potter's Art / Li tre libri dell'arte del vasaio*. Translated by B. Rackham and A. Van de Put, London.

Pope-Hennessy, J. 1980. *Luca della Robbia.* Oxford: Phaidon.

Tite, M. S., I. Freestone, R. Mason, J. Molera, M. Vendrell-Saz, and N. Wood. 1998. Review article – "Lead Glazes in Antiquity—Methods of Production and Reasons for Use." *Archaeometry* 40 (2): 241.

Vaccari, M. G. 1996. *La scultura in terracotta: tecniche e conservazione*. Firenze: Centro DI.

Vaccari, M. G. 1998. Tecniche e methodi di lavorazione. In *I Della Robbia e l'"arte nuova" della scultura invetriata,* ed. G. Gentilini. Fiesole: Basilica di Saint'Alessandro. 97–116.

Vasari, G., and de Vere, G. C. 1912. *Lives of the Most Eminent Painters, Sculptors & Architects*. London: Macmillan and Co. & The Medici Society, Vol. 2, 116–128. Internet resource. https://archive.org/details/cu31924020574129.

FURTHER READING

Belland, A. 1998. *Altre sculture invetriate del Rinascimento*, in *I Della Robbia e l'"arte nuova" della scultura invetriata*, edited by G. Gentilini, Firenze.

Gentilini, G. 1996. La scultura Fiorentina in terracotta del Rinascimento: tecniche e tipologie. In *La Scultura in terracotta: tecniche e conservazione*, edited by M. G. Vaccari, Firenze.
Kingery, D. and M. Aronson. 1990. "The Glazes of Luca della Robbia." *Faenza* 76: 221–225.
Tite, M. S. 1991. "Technological Investigations of Italian Renaissance Ceramics." In *Italian Renaissance Pottery*, edited by T. Wilson, London.
Tite, M. S. 2009. "The Production Technology of Italian Maiolica – A Reassessment." *Journal of Archaeological Science* 36: 2065–2080.

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THE COMPREHENSIVE RETREATMENT OF A RENAISSANCE TERRACOTTA ALTARPIECE BY BENEDETTO BUGLIONI

RACHEL C. SABINO

This article describes the treatment of a monumental Renaissance glazed terracotta altarpiece that included disassembly of segments, cleaning, reassembly, aesthetic integration, and remounting. The primary focus of the article is the problematic nature of displaying these types of architectural objects in a museum context far removed from the original and the inevitable compromises that accompany the resultant choices. Some of the prosaic but often unexplored factors are considered, such as the working practices of the masons who originally installed these objects. The significance of these factors in developing a rationale for presenting the altarpiece with unfilled gaps between individual ceramic segments is a topic of special focus.

KEYWORDS: Renaissance, Buglioni, Florence, Glazed terracotta, Ceramics conservation, Relief sculpture, Masonry

1. BACKGROUND

Adoration of the Shepherds (1924.218) was sculpted in the Florentine workshop of Benedetto Buglioni (1459–1521) sometime around the year 1520. Significant in scale, standing at nine and a half feet tall, the altarpiece is made up of 46 individual segments of glazed, buff terracotta. It consists of a lunette and primary altarpiece bordered with a vegetal garland and footed by a predella (fig. 1). The altarpiece was given to the Art Institute of Chicago in 1924 by Kate S. Buckingham, one of three siblings whose gifts lay the foundation for the museum's collection. The altarpiece remained on display until it was removed from the galleries and consigned to storage in 2006. During its tenure in the museum's collection, the altarpiece received no significant treatment until it was designated as one of nearly 700 objects to be installed in the newly designed Deering Family Galleries of Medieval and Renaissance Art, Arms, and Armor that opened in the spring of 2017.

The initial scope of treatment had been confined to making cosmetic improvements: surface cleaning, smoothing fills, and correcting aged and discolored retouching. During a preliminary rigging to inspect the verso and evaluate the structure and condition of the existing support, it became immediately apparent that such a limited treatment would be insufficient to address the many issues that came to light, making it necessary to completely disassemble and remount the altarpiece.

1.1 Condition

The altarpiece had been mounted in two disarticulating sections using vertical wooden boards as a support, the poor-quality wood of which had become entirely desiccated. A number of the garland segments were loose, and detached ovoid fragments of ceramic associated with what appeared to be mechanical fasteners remained trapped between the backs of the segments and the backboard. Other breakages across the segments appeared to be intimately related to their points of attachment on the support. Finally, a bituminous material applied behind several of the loose lunette segments in a subsequent campaign of repair confirmed the tenuous nature of their attachment.

The ceramic segments themselves were extraordinarily unsightly. Heavy, opaque and discolored overpaint was visible uniformly throughout; it was most extreme in sections of the garland where large swathes of turquoise paint sat atop the emerald glaze of the leaves. Chips, cracks, lacunae, and steppes of varying magnitude were present alongside more serious and significant misalignments, breaks, and losses. The glazed surfaces and exposed ceramic fabric alike were stained and dirty. Important traces of manufacture,

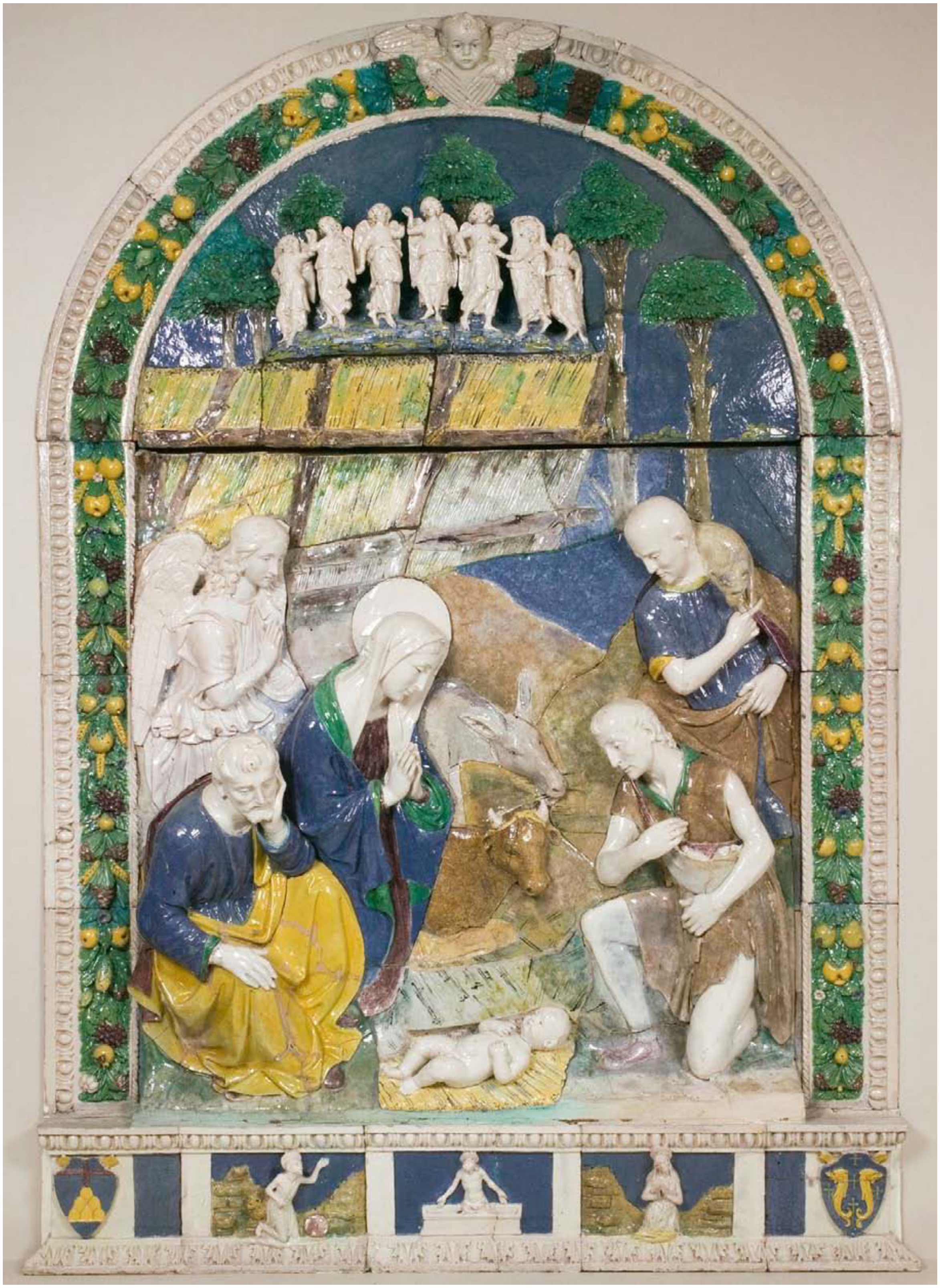

Fig. 1. Overall view of the altarpiece before treatment. Benedetto Buglioni and workshop, *Adoration of the Shepherds*, ca. 1520, glazed terracotta, 289.6 × 200.7 cm. The Art Institute of Chicago, 1924.218 (Courtesy of the Art Institute of Chicago)

such as firing and drying cracks, had been overfilled and painted. In addition, several key geometric sight lines had been aligned in a problematic way: the verticals along the outside edge of the garland, the join between the lunette and the altarpiece, and the join between the altarpiece and the predella. Not least, a lumpy fill material had been used between all of the segments, often in the place of missing areas. This material did not lend itself to smoothing or polishing and had been covered with heavy paint, which had aged and discolored, lending the object an overall dull, poorly textured surface. The material was analyzed and found to consist of rosin (colophony) bulked with chalk; rosin is commonly encountered in 18th and 19th century restoration.[1]

1.2 Display

In the former gallery installation, the altarpiece had been displayed level with the ground. In the new galleries, the altarpiece would be installed at height in a wall cavity five feet from the floor atop an altar-like plinth in an effort to suggest its original context.

2. DISMANTLING

Dismantling was done with the altarpiece in a vertical position. During this process, it became clear what the previous restorers had done. With the support lying flat, pools of colophony were ladled onto the surface. The segments were pressed into position, using colophony bulked with hair to fill gaps between the segments and the board, until the solidifying colophony produced sufficient “tack.” Once this placement was reasonably secure, they drove screws through the backboard into the segments without benefit of predrilling (fig. 2).

Fig. 2. The lunette during disassembly (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Unsurprisingly, in many places the ceramic had been riven along planes of existing manufacturing flaws and localized areas of weakness by the force of the penetrating fasteners. The segment comprising St. Joseph's yellow mantle—the largest and heaviest, but also the most delicate due to a complex network of drying and firing cracks—had given way along fault lines from the strain, essentially rendering the segment a conglomeration of at least 10 separate fragments all bound by an assortment of screws and rosin.

The segments were mechanically removed one by one from top to bottom, starting with the lunette and, finally, the predella. Alarmingly, many segments could be lifted or coaxed off quite easily once the screws were removed. Many had been broken prior to attachment; these fragments were bonded with colophony prior to being screwed down. Still other breaks had been secured with iron cramps and rivets, but it was not evident whether these interventions were contemporaneous with the most recent restoration, with a previous restoration, or with the original fabrication.

3. TREATMENT OF INDIVIDUAL SEGMENTS

The treatment of the individual segments followed well-established protocols in the conservation of ceramics. The use of high-pressure steam was essential during the cleaning phase, as was a methylene chloride–based stripper for breaking down and removing heavy overpaint. Paraloid B-72 (50% w/v in acetone) was used to bond all broken segments and was bulked with glass beads to promote adhesion in cases where break edges displayed poor fit or limited surface area. Fills were done mindfully to leave manufacturing defects and glaze flaws visible, using fine casting plaster left white for larger missing areas and acrylic putty tinted with powder pigments for smaller losses. Missing ornament, most frequently within the egg-and-dart frieze, was recreated using a polyvinyl siloxane impression material. Fills of all sizes were consolidated after shaping with a 5% to 10% w/v solution of Paraloid in acetone after shaping and the backs of the segments with polyvinyl butyral (5% w/v in ethanol). Knowing that the segments would be handled copiously during subsequent stages, the majority of the retouching took place after the altarpiece was remounted. At that time, inpainting was done using acrylic paints and mediums and occasionally aldehyde colors and alkyd resin.

3.1 Evidence of Manufacture, Workmanship, and Construction

Handling the segments during these phases of work made it possible to note many aspects of their fabrication. The texture on the backs of the altarpiece and lunette segments indicates that they had been prepared on beds of sand. Each of the sculptural segments had been hollowed out at the back in an effort to achieve a uniform wall thickness for firing. To pack the forms into their molds, the craftsmen scooped with hands, punched with fists, pinched, crimped, and squeezed (fig. 3). Knife or chisel-like implements had been used to either remove or build up material or to freehand model the sculptural elements. The overlying glaze obfuscated evidence of luting or seams—particularly within the fruits, leaves, and other embellishments on the garland segments. Nonetheless, these seemed to have been made up of compositions created from smaller molds of individual fruits, vegetables, and leaves rather than unique, individual molds for each segment. Yellow glaze is present on the interfaces between a detached fragment on the waistband of St. Joseph's mantle and is the only such glaze repair found on the altarpiece (fig. 4).

Most remarkable was the technical virtuosity of the glazing and modeling. The glaze fit was superb, with hardly any fly ash, specks, orange peel, or crawling. The variety of colors, subtlety and painterly quality of the glaze application were masterful. As evidence of the sculptural ability and artistic merit, consider the figure of St. Joseph (fig. 5). There are no actual biblical accounts of St. Joseph. Thus, it is only through

Fig. 3. The artist's working methods visible on the backs of the segment depicting the Virgin Mary (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 4. A glaze repair on St. Joseph's waistband (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 5. The remarkable sensitivity demonstrated in the face and posture of St. Joseph (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

the lens of personal experience and empathic insight that his state of mind materializes: his confusion, disappointment, discomfiture, but also his resolve and dedication. These emotions are skillfully conveyed in the face and posture; the rendering is striking not just for its technical merit but also for the sensitivity of contemplation that it reflects. Received wisdom holds that Bugloni is the lower-quality alternative to della Robbia. However, this altarpiece would seem to contradict that generalized assessment. Moreover, the quality of the Buglioni oeuvre is more likely related not to deficits in the firm's technical ability but rather to its differing goals and ambitions or to the nature of the individual commissions.

No marks or notations were found impressed into the ceramic itself, save for two rather large instances of the letter "S" stamped or incised in the garland on the bottom and top outside corners of the proper left upper and middle garland segments, respectively. However, a cryptic notation system of red numerals and symbols had been painted on the side edges of the segments. A diagram plotting the notations helped to establish somewhat of a pattern: each numeral or symbol mirrored that on the edge of the segment opposite. The purpose of these notations (i.e., a possible bonding sequence) could never be ascertained. Ultimately, their presence between break edges that had been repaired using colophony would seem to place them closer to a more recent intervention rather than to the original craftsmen.

Eroded remains of gilding in the form of heavy, flat overpaint was found behind the wings on the choir of angels. This gilding strongly resembles bronze powder, making it more likely a 19th century addition.

4. TOWARD A NEW PRESENTATION

Throughout the process of treating and preparing the segments, wherein their individual peculiarities, vulnerabilities and specific needs became apparent, much ruminating and planning toward the next steps took place.

4.1 Trial Assembly

After treatment, the individual segments were staged in a mock-up. A platform was constructed and leveled with shims. After snapping out a series of vertical chalk lines, the segments were placed on the platform in accordance with these established verticals, proceeding from the lunette down, aiming for a centerline passing through the cherub at the top of the lunette and the risen Christ in the predella. During this process, inasmuch as was allowable, the segments were placed directly against each other with virtually no space left between.

4.2 Constraints and Unknowns

The trial assembly immediately demonstrated that the original relationships of all three components would be difficult, if not impossible, to recreate.

To begin with, the unglazed bottoms of the lowermost figures projected forward from the front edge of the predella by as much as 3 in. (fig. 6). Examination, albeit not exhaustive, of comparanda yielded no other exemplar in which this lower register, particularly with unglazed bottoms, projects forward so emphatically from this plane. Indeed, a palimpsest on top of the predella quite clearly highlights the original placement of the figures, which was, in actuality, quite far back from the predella's front edge (fig. 7). Placing the figures in this original position would have meant pushing the predella forward by as much as 8 in. or more. In turn, this would have meant pushing the garland forward in order to maintain its appropriate contact and alignment at the top of the predella.

This precipitated the second major problem: several elements along the proper right side (the angel's wing, the shepherd's elbow, a piece of fabric on St. Joseph's mantle, and a small tree branch) project over the garland, preventing it from moving forward. This raised the possibility that the figures had originally been somehow situated behind the garland. And yet, the inside edges of the garland segments were unglazed. It was unlikely that these raw edges would have been exposed in the final presentation and equally unlikely that mortar would have been applied on a diagonal to bridge the unglazed garland segments and the figures behind.

Fig. 6. Following trial assembly, the lowermost segments projected forward from the front edge of the predella by as much as three inches. (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 7. Palimpsest atop one of the predella segments indicating the original position of the figures (top) and the compromise position of the bottom segments and predella in the current configuration (bottom) (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

The garland surrounding the lunette also contained one odd short segment whose top edge indicated that it was constructed from a straight rather than an arched segment. Only half of it contained original fabric and the other half was modeled in plaster (fig. 8). The segment immediately adjacent to this truncated segment— the center segment with the cherub—was chiseled away on the proper right side.

These inconsistencies and problematic relationships began to cast doubt on whether the garland was related to the altarpiece at all or whether it had been repurposed from one of any number of garland segments in circulation within the art market.

With respect to the verticals established by the sides of the garland, the previous restorers had mounted the object askew, leaving the width at the top a full inch narrower than the bottom. With the aid of framing buttresses screwed into the platform, it was possible to ensure that in the new presentation both the top and bottom garland segments would be placed 76 in. across. Geometrically speaking, at a width of 76 in., the height of the lunette should have been 38 in. on center, but the previous mounting was also 1 in. off that dimension. Examination of the lowermost garland segments in the lunette revealed that the bottom ends had been chiseled away at an angle to achieve this flatter radius (fig. 9).

4.2.1 The Problem of Context

Very little is known about the original context, history, or trajectory of the altarpiece save for the fact that the coats of arms link its commission to Bartolomeo Buondelmonti and Alessandra Pazzi, who were

Fig. 8. Midtreatment image of the truncated lunette segment with its missing half reinstated in plaster (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

married in Florence in 1483 (fig. 10). More than likely, the altarpiece was intended for a domestic shrine or a family chapel in a church. But even with a generalized sense of context, many questions remained unanswered. Did it originally sit in some kind of concave niche that would have allowed for a shoulder or curve to accommodate the overlapping segments and the discrepancies flagged during trial assembly? Was there any stone masonry, such as cornicing or molding, that had been incorporated into the altarpiece but was discarded or lost when it was extracted? What sight lines had been imposed on the object by the

Fig. 9. Chiseled ends on the terminal segments of the garland around the lunette (left) and their reinstatement in plaster (right) (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 10. Earliest documentary photograph of the altarpiece, date and location unknown (Photograph courtesy of the Art Institute of Chicago)

architecture? How constrained was the vantage point? Did the presence of an obstacle, such an altar or table, establish a minimum viewing distance?

The impending presentation in the new gallery added yet another challenge. As visitors make their way through the space, they approach the altarpiece from a three-quarters angle and are then free to maneuver around it in an almost unlimited number of angles and distances. This unconstrained vantage point most certainly would not have been how it was viewed originally.

4.2.2 The Unknown Masons

Complicating things still further, although many of the segments were planar, many others displayed pronounced warps and distortions. These are not technical deficiencies but rather natural features of the firing process governed by where the segments were placed on the kiln shelves. Nonetheless, when placed on a flat board, these dislocations sat considerably proud of the surface. This begs the question, how had these irregularities been addressed in situ? The masons certainly would have been accustomed to these kinds of anomalies and would have had a host of tricks and techniques at their disposal to rectify them (if, in fact, doing so was a priority). Surely with benefit of the amorphous back provided by a mortar, a slight impact, perhaps with a fist or mallet, would help adjust a wayward segment in relation to its neighboring segments or set the segments against each other at a slight angle.

The presence of a single hole in the top edge of each segment, with no corresponding bottom or side holes, may provide a clue as to how the masons worked. The masons likely worked from bottom to top, using iron pins or cramps in these holes to engage with the mortar bed or the masonry substructure. Anchoring each segment from the top thus creates a very flexible pivot point that would have allowed them to be adjusted in any number of directions in response to a corrective tap or blow. Such in situ adjustments surely were common practice, ultimately signifying that the masonry itself—in particular, these "job site" level adjustments and decisions—exerted considerable influence on the final presentation. The presence of a cramp or pin also meant that the segments were not placed directly against one another but rather set apart sufficiently to accommodate the breadth of the pin between them.

Remarkably little is known about this phase of the commission. Did the della Robbia and Buglioni workshops subcontract to outside masons or was the installation process managed in-house? Did a representative from the "design" side of the firm accompany the masons in every instance or did it vary according to the importance of the commission? In the case of the latter scenario, a tremendous degree of variation is to be expected. In either scenario, were the masons given a great deal of latitude in making these on-the-spot decisions or were strict parameters enforced? The knowledge gap with respect to this essential technical aspect of the work is significant.

5. DECISIONS AND RATIONALE FOR PRESENTATION

It is extremely difficult to interpret these types of objects devoid of their architectural context, but close interaction with them in the course of a treatment like this one suggests that flat backboards are not the ideal means to express much of the missing context. As a result, the most appropriate presentation is at best an educated guess. Thus, given all of the aforementioned factors and variables, how to proceed? How to arrange the segments without imposing personal judgments or creating a false presentation? How to deal with the warped segments without benefit of mortar? How to sidestep or at least not actively contradict the series of decisions that the original craftsmen and masons made? And how to make the altarpiece look acceptable from all the possible vantage points?

5.1 Garland and Predella

By the time it became clear that the arrangement would benefit from greater depth, the blueprints for the gallery were already finalized. It would not be possible to deepen the niche or make structural modifications to the wall. It would also have been unwise to try to deepen the structural assembly of the restored altarpiece. As it was, the altarpiece demonstrated a pronounced forward pitch and exacerbating that pitch would place an irregular load across the bearing surface. There was no option but to deal with a flat backboard. The predella was blocked up from behind to the minimum allowable distance wherein the figures would be set as close to the front edge of the predella as possible (see fig. 7). There was no way to avoid a resultant gap at the shoulder where the garland should have met the predella. To help camouflage this void, a strip of acrylic sheeting was laid between the figures and the predella and painted with *trompe l'oeil* to mimic the unglazed ceramic (fig. 11).

Because the altarpiece would be sited against an architectural surround with prominent and mathematically precise frames of reference, it made sense to return the garland to its true geometric proportions. The vertical segments were quite painlessly returned to parallel at 76 in. top and bottom. As for the lunette, it was possible that the original craftsmen had chiseled away the bottom edges of the lowermost segments, but improbable that they would have been improvising to this degree on a

Fig. 11. Left: Strip of acrylic in its correct position above the predella at proper left prior to painting. Right: Acrylic installed after painting. The back of the strip was painted black to mask the mount infrastructure below. The front was painted to match the unglazed ceramic in line with its actual depth.

commission of this stature. It seems more likely that they would have been guided by the overarching principles of Renaissance art—a period hallmarked by mathematical principles, balance, and harmony. The missing material was therefore reintegrated on both segments; the resulting arch did, in fact, result in an upper measurement of 38 in. on center (see fig. 9). This same logic was applied to two garland segments on the proper right side whose rope braids had also been chiseled away. A visual disruption of this magnitude within the decorative elements was unlikely to have been acceptable to the Buglioni craftsmen or their surrogates; thus, the missing braids were reinstated.

The predella segments were not uniform in height; thus, it was necessary to evaluate whether it was more critical to harmonize the sight line established by the top in relation to the altarpiece or the bottom in relation to the plinth. In the end, the upper sight light appeared more crucial. Therefore, an epoxy putty cast, set back slightly from the front edge and painted to match the glaze, was used to help camouflage the resultant discrepancies between the bottom of the predella and the plinth.

5.2 Interior Segments

With the position of the garland and predella established, the next task was to orient the segments within the available space inside. A diagram illustrating how the previous restorers chose to arrange the segments reveals a considerable amount of empty space to navigate, even when factoring the inch of space consumed along the top edge by the downward movement of the lunette in the arch compression (fig. 12). A considerable gap ran along the proper left side, but the most significant gap was left underneath the lower figures. These segments had been built up on a pad of colophony that held the figures up on a diagonal, extending up 2 in. on the proper right and 3 in. on the proper left (fig. 13). Once again, a search for comparanda yielded not a single instance in which the lowermost segments sit above the predella without benefit of some kind of lifts or platforms. Does this mean there were other ceramic segments now missing? Or would the masons have placed some ad hoc structure in the void during installation that got destroyed when the altarpiece was extracted from its original position?

The massive gaps around the perimeter (including the large gap that the restorers left between the lunette and the altarpiece) belied a shortage of available space. Yet, material had been reduced and chiseled away from the edges of several segments along the proper right side: from the angel and from the tree on the uppermost segment. Why did the previous restorers struggle to achieve a decent fit?

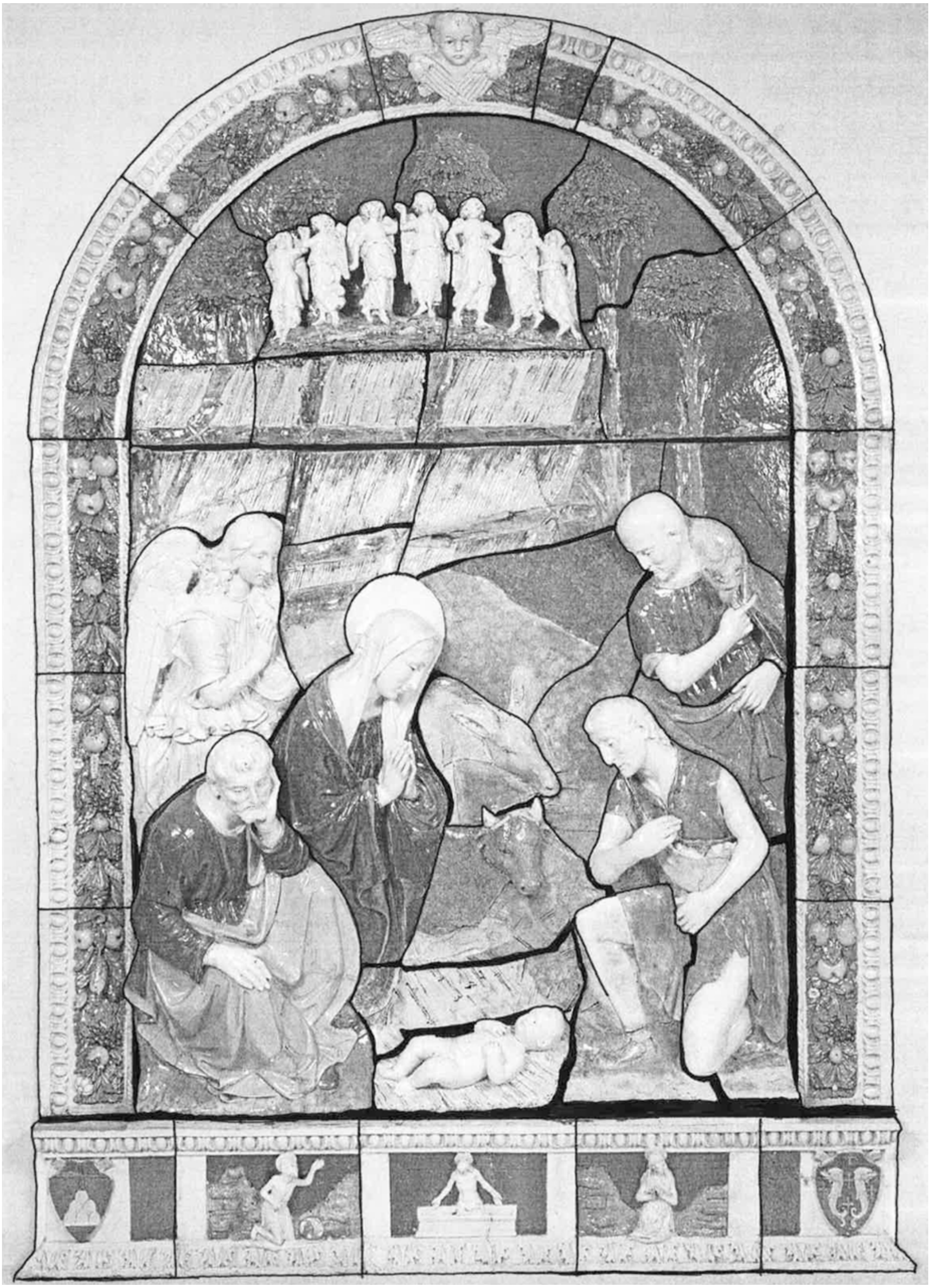

Fig. 12. Diagram showing placement of the segments in the previous restoration (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

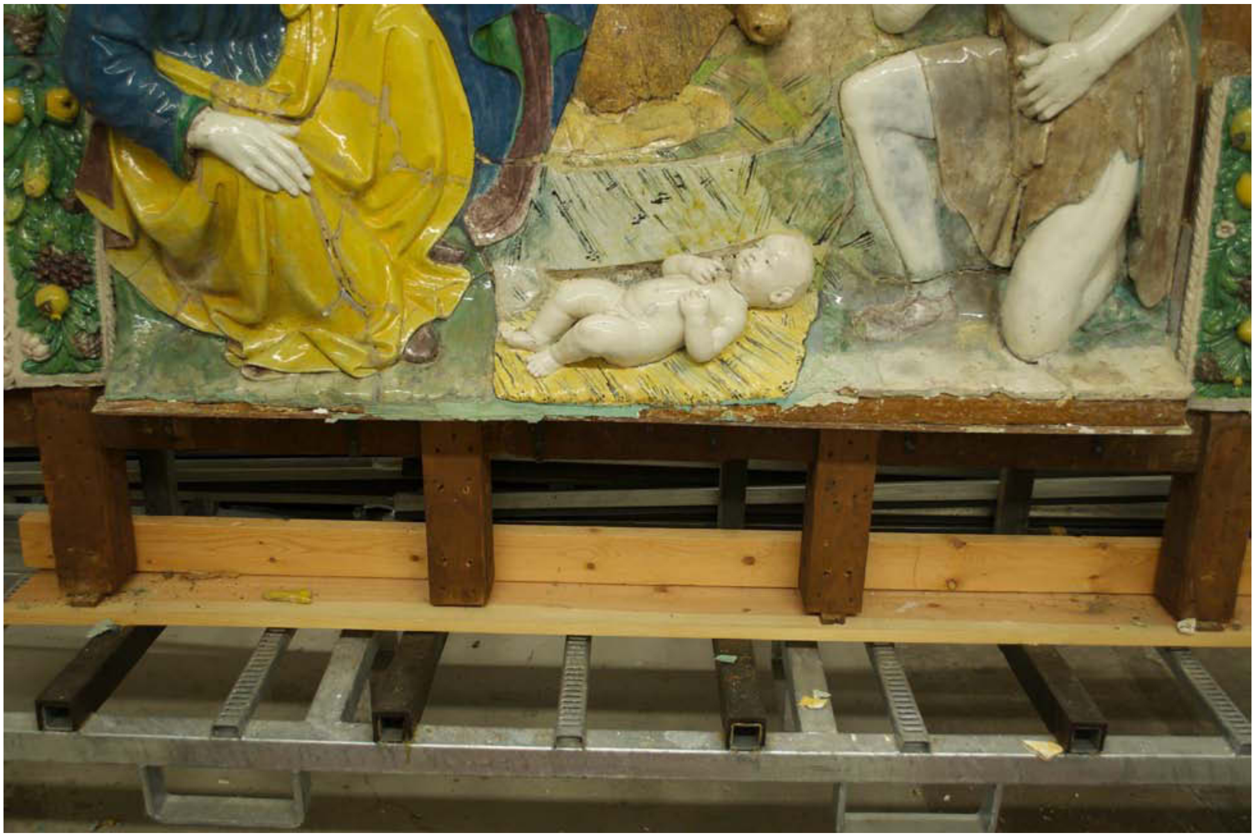

Fig. 13. Massive pad of colophony below the figures in the previous restoration (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

This question became all too apparent with increased handling and repeated efforts to achieve a satisfactory placement. So often, a virtually inconsequential segment exerted a disproportionate amount of influence in the placement of the surrounding segments. For instance, one small, dumbbell-shaped segment with a pronounced convex distortion exclusively governed the interrelationship between St. Joseph and the kneeling shepherd. Once again, these material problems begged the question, "What would the masons have done?" They no doubt would have had strategies to more effectively set the segments against one another to achieve a satisfactory presentation even if it meant setting them together slightly out of plane—strategies that were unavailable on a flat, rigid backboard.

Weighing everything, the best course of action was to abstractly explode the segments within the available space to create as harmonious and regular a presentation as possible and, to the extent that the many sight lines would accommodate it, displace the most egregious of the gaps up into the shadows created by the projecting figural segments (fig. 14). There was no choice but to leave somewhat more space beneath the figures relative to the rest of the gaps, but they were arranged in balance with the flow of the gaps elsewhere. Unlike in the previous presentation, this gap was regularized, siting the figures along a level rather than diagonal plane. As for the void between the figures and the predella itself, it seemed unethical to fill the space with some kind of invented, extrapolated feature, particularly when the new sight line at eye level would lend it undue prominence. Instead, casts of epoxy putty were made to support the bottom segments and to bridge the space between them and the predella. The casts were recessed slightly from the outermost edge and painted a neutral color similar to the glaze on the predella (fig. 15).

Fig. 14. The altarpiece at the close of treatment, installation, and finishing (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

5.3 The Question of the Gaps

The issue of how to deal with the gaps remaining between the segments was the leading question not only from visitors, internal colleagues, and curators who visited the *Adoration* over the course of its treatment but also from exterior colleagues and curators working contemporaneously on similar objects across the country.[2] Over the course of the year, the collective group of people immersed in Renaissance glazed terracottas had come to a generalized consensus to leave the gaps open and that doing so constituted a new vernacular for the presentation of these objects. However, this rationale was never formally or fully

Fig. 15. The casts beneath the lowermost figural segments (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

articulated, which made justifications awkward when presented to people outside this small community. After all, it is somewhat of an unorthodox idea; in the original context, there is something between the gaps—mortar.

Whether or not those mortars were originally tinted to create a seamless field is debatable. The majority of the mortars remaining in situ do not appear to be tinted, but this does not mean that they were not tinted originally. Systematic analysis and cataloguing would be necessary to clarify that question with any certainty. However, the mortar joins are rougher than the adjacent glazes. This texture would have stood in contrast with the segments even if they had been tinted, especially where they do not follow the contour of a figure or feature but instead appear across comparably flat areas, such as within an expanse of sky. Was this, too, another aspect over which the masons had control? Did they use finer mortars for some gaps and courser mortars for others? Were they given any latitude to tint the mortars to aid in blending them with the surrounding area? Was the appearance of the mortar lines a determining factor in how the segments were placed during installation? Whatever the answers to these questions may be, examination of assemblages remaining in situ demonstrate that an entirely smooth, unsegmented presentation was not the desired aesthetic or was simply not attainable.

Architectural terracottas that are no longer in context, essentially all of those on view in museums today, have most often been filled and tend to reflect a 19th century sensibility for completion. On these types of objects, it is possible to see a great deal of overfilling and overpainting, frequently done over misaligned, misshapen, or stepped segments, to create a uniform presentation.

So—how to answer this question of the gaps, not just for the benefit of the niche professional but, more importantly, for the lay visitor who has been conditioned one way or another to expect the gaps to be filled? Devoid of context and devoid of all of the secondary workmanship that is actually crucial to their ultimate appearance, these objects cease in some way to be what they once were; they are no longer technically altarpieces. They are abstractions: a collection of ceramic pieces that once constituted an altarpiece. The distinction is subtle but important. The material between the segments is not just a mere functional substance holding the object together but rather a symbolic material, cementing the object into a specific moment in time. The lowly and insignificant mortar and the unglamorous work done by an unknown mason is every bit as essential to the object's history, vision, interpretation, and perception as are the segments themselves.

By way of analogy, consider a pilot's flight plan. For every one degree of deviation, the destination is missed by 92 feet for every mile traveled off course. Therefore, the key to success is recognizing an off-course trajectory at the earliest opportunity. Extrapolating to treatment decisions on the altarpiece, if the plan was to fly from New York to Los Angeles, that first "one-degree" moment came in placing the figures relative to the predella. Each subsequent decision thereafter was a step further removed from the original appearance and context. Thus, the question of whether to fill the gaps is essentially the difference between landing in Burbank and floating in a life vest 40 miles out in the Pacific Ocean. Neither of the outcomes is the same as landing in Los Angeles, but one is considerably safer. Had it somehow been possible to recreate the exact context of the *Adoration* and guarantee the original position of the segments, filling between them with a rough material to simulate mortar might have been a responsible option. Failing that, the other option would have been to fill the gaps but perhaps recess them slightly from the surface. However, this approach raises questions of its own and, quite possibly, interjects an incongruous and inappropriate sensibility.

6. ASSESSMENT

Many of the segments did seem to relate to one another masterfully: the interrelationship between St. Joseph's shoulder and Mary's cloak and between the kneeling shepherd's arm and the background segment, for example. Losing those relationships was a painful sacrifice in achieving alignment in other areas that would have caused severe dislocations and jarring gaps throughout. More time to evaluate and consider different placement options would certainly have been welcome.

The unfilled gaps between segments are jarring—it is ironic that the most cautious and conservative option for compensation actually yielded the most radical presentation. Were it possible to have the opportunity to "do it all again" only with more planning available at the conceptual stages of the gallery design, it would have been interesting to construct an architectural framework within the wall itself that more closely approximated the original architectural context. Working along these lines, it would have been fruitful to partner with a historic masonry specialist, preferably one with a background in the use of lime mortars to guarantee a certain sensibility of material selection and application. In so doing, the gaps between the segments could have been filled in the same manner and with the type of material originally specified.

7. FURTHER DIRECTIONS

With respect to the unfilled gaps, it is essential to find some way to effectively relate the conceptual decisions underpinning the visual outcome of this and other recent retreatments to audiences who, more than likely, have difficulty interpreting the works in their new contexts. Conservators should work alongside their curatorial colleagues to produce expansive didactic information to accompany these objects while on display.

Most importantly, collaboration with archival specialists, researchers and historians is crucial to unearth as much information as possible about the little-understood structure, involvement, and working relationships of the related professionals who collaborated with the della Robbia and Buglioni firms, namely: stone masons, brick and block masons, material suppliers, architects, project managers, and other laborers.

ACKNOWLEDGMENTS

A project of this scale by definition involves a large number of people. I am appreciative of the collective effort by so many to assist me in my work. Among this group, a few individuals deserve particular commendation. My friend and erstwhile colleague, Elena Valentinova King, paintings conservator in private practice in Chicago, graciously volunteered her time during the onerous process of taking down and smoothing fills. For their unflagging support and encouragement, I am extremely grateful to Wendy Walker and Carolyn Riccardelli at The Metropolitan Museum of Art; Lisa Bruno at the Brooklyn Museum; and Abigail Hykin, Richard Newman, and Marietta Cambareri at the Museum of Fine Arts, Boston. At the Art Institute of Chicago, I wish to recognize Frank Zuccari, Grainger Executive Director of Conservation and Senior Paintings Conservator, for backing the myriad expeditions and fact-finding missions associated with my background research, and curators Rebecca Long and Martha Wolff for their consistent enthusiasm and trust in me. Jann Trujillo submitted endless orders for crucial materials, often at the last minute. Wholehearted gratitude to Lauren Schultz, Director of Communications, for giving the treatment a much-deserved public face. Above all, I am indebted to mount maker Andrew Talley, of Talley & Talley in Chicago, without whose immeasurable talents, experience, and resilience this project would not have been possible.

NOTES

1. The rosin and chalk were identified by Ken Sutherland using FTIR spectroscopy and pyrolysis gas chromatography mass spectrometry with thermally assisted hydrolysis and methylation (THM-Py-GCMS). For FTIR analysis, representative portions of the sample were mounted on a Specac diamond compression cell. Data were collected in transmission mode between 4000 and 400 cm^{-1} at 4 cm^{-1} resolution and 128 scans per spectrum using a Bruker Hyperion microscope with MCT D315 detector, interfaced to a Tensor 27 spectrometer bench.

   For THM-Py-GCMS, a portion of the sample (≈ 10–20 µg) was placed in a Frontier Lab stainless steel sample cup and 2 µL of a 25% solution of tetramethylammonium hydroxide in methanol added prior to insertion into a Frontier PY-2020iD vertical microfurnace pyrolyser, with the furnace at 550°C. The pyrolyser was attached to a Varian 3800 GC, with Restek Rxi-5ms column (30 m, 0.25 mm i.d., 0.25 µm film), interfaced to a Saturn 2200 MS; transfer line temperature 300°C. The oven was programmed from 40°C, with a 2 min. hold, then increased at 20°C/min. to 300°C and held isothermally for 10 min.; total runtime 25 min. The inlet was operated with a split ratio of 1:10. Helium was the carrier gas, with a constant flow of 1 mL/min. The MS was run in scan mode (*m/z* 40–600) with the ion trap at 210°C.

2. The treatment of *Adoration of the Shepherds* happened during the same period of time that wholesale retreatments of other architectural glazed terracotta objects were in progress at The Metropolitan Museum of Art and the Brooklyn Museum in preparation for an exhibition organized by the Museum of Fine Arts, Boston. Both of these treatments are described in this volume.

FURTHER READING

Cambareri, M. with contributions by A. Hykin and C. Harris. 2016. *Della Robbia: Sculpting with Color in Renaissance Florence*. Boston, MA: MFA Publications, Museum of Fine Arts, Boston.
Cipriani, A., and L. Cipriani. 2013. *Lo Spedale del Ceppo: Storia, Arte, Cultura*. Pistoia: Gli Ori.
Cooper, D., and M. Leino. 2007. *Depth of Field: Relief Sculpture in Renaissance Italy*. Bern: Peter Lang.
Marquand, A. 1921. *Benedetto and Santi Buglioni*. Princeton, NJ: Princeton University Press.
Vasari, G. 1912–1914. *Lives of the Most Eminent Painters, Sculptors, and Architects*. Translated by Gaston du C. de Vere. London: Philip Lee Warner.

SOURCES OF MATERIALS

Acetone, Ethanol
Thermo Fisher Scientific
81 Wyman St.
Waltham, MA 02451
800-766-7000
http://www.fishersci.com

Acrylic Medium, Golden Porcelain Restoration Glaze (Gloss), Acrylic Paint, Golden Fluid Acrylics
Golden Artist Colors, Inc.
188 Bell Rd.
New Berlin, NY 13411
607-847-6154
https://www.goldenpaints.com/products/

Acrylic putty, Modostuc
Plasveroi International
Via Camussone 38
Frazione Giovenzano
Vellezzo Bellini (PV) Italy
+39 382 926895
http://www.antichitabelsito.it/schede/stucco_modostuc.pdf

Acrylic Resin, Paraloid B-72
Dow Chemical
800-331-6451
https://www.dow.com/en-us/pdp.paraloid-b-72-100-resin.154799z.html

Aldehyde Colors, Gamblin Conservation Colors, Alkyd Resin, Galkyd Medium #1
Gamblin
323 SE Division Pl.
Portland, OR 97202
503-235-1945
https://conservationcolors.com/

Epoxy Putty, Apoxie Sculpt Modeling Compound
Aves Studio
PO Box 344
River Falls, WI 54022
https://www.avesstudio.com/shop/apoxie-sculpt/

Glass Beads, Very Fine #59832
Kremer Pigmente
247 W. 29th St.
New York, NY 10001
212-219-2394
http://shop.kremerpigments.com/en/fillers-und-building-materials/fillers-made-of-glass/5647/glass-beads-very-fine

Paint Stripper, Zip Strip Premium Paint Finish and Remover
Recochem Inc.
550 Hills Dr., Suite 106
Bedminster, NJ 07921
800-361-6030
http://www.recochem.com/us/products/solvents_cleaners/zip_strip_premium_paint_finish_remover

Plaster, Fine Casting Plaster
Sculpture House, Inc.
3804 Crossroads Pkwy.
Fort Pierce, FL 34945
772-210-6124
https://www.sculpturehouse.com/p-236-pristine-white-casting-plaster-25-lbs.aspx

Polyvinyl Butyral, Butvar B-98
Eastman Chemical Company
200 South Wilcox Dr.
Kingsport, TN 37660
423-229-2000
http://www.eastman.com/Products/Pages/ProductHome.aspx?Product=71095422&list=products

Polyvinyl Siloxane Putty, Aquasil Soft Putty
DENTSPLY DeTrey GmbH
De-Trey-Str. 1
D-78467 Konstanz Germany
+49 7 531 5830
https://www.net32.com/ec/aquasil-soft-putty-regular-set-standard-includes-d-111697

Steam Cleaner, Derotor GV6
Preservation Equipment Ltd
Vinces Rd.
Diss, Norfolk IP22 4HQ UK
+44 1379 647400
https://www.preservationequipment.com/Catalogue/Equipment-Tools/Instruments-Meters/Derotor-Steam-Cleaner

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TRUTH VERSUS BEAUTY: MAINTAINING VISUAL UNITY IN THE TREATMENT OF FLORENTINE POLYCHROME TERRACOTTA SCULPTURE

ANTHONY SIGEL

Loss compensation in sculpture can pose treatment questions that can be resolved in many different ways. Different genres, materials, and surfaces call for different treatment responses, and different pressures may come to bear when the project involves privately owned works. This article describes the visual compensation issues affecting two sculptures from the Italian Renaissance, a life-size glazed terracotta of *S. Giovanni da Capistrano* and a smaller *Plaque with Winged Putto*, both by Santi Buglioni. Both were privately owned when originally treated. The *S. Giovanni*, now in the collection of the Los Angeles County Museum of Art, is one of a group of three near life-size figures of saints by the Florentine sculptor, a relation of the della Robbia family.

I will discuss my approach to compensation for the Buglioni *Plaque with Winged Putto* and the *S. Giovanni da Capistrano* figure, which were severely damaged and suffered a variety of condition issues. My approach to treatment was guided by a set of principles and practices that include visual coherence, selectivity, minimization, and—yes—subterfuge and deception. I also discuss avoiding overtreatment and the concealment of important signs of age, composition, and inherent vice, which contribute to critical patina and signal originality. Approaches are presented for balancing the preservation of evidence of the state of technology of the time with preserving the visual unity and coherence of the work. By taking the work in stages, making careful selections, and maintaining close communication with the owner/curator, these tensions may be successfully negotiated. I present the practical treatment methods to illustrate my work and whether I would do things differently now.

KEYWORDS: Loss, Compensation, Inpainting, Patina, Originality, Visual coherence, Selectivity, Minimization, Subterfuge, Deception

1. INTRODUCTION

Loss compensation—how far to go when filling and inpainting—is the subject of this article. I will be showing examples of how I solved compensation questions on glazed terracotta sculpture that arose from the need to be efficient with time and stay within budget (the works were privately owned) but also to manage the aesthetic challenges caused by damages from the original fabrication processes, later accident, and aged, poor quality restorations. These are works of decorative arts and sculpture, not archaeological objects; I felt that they must be given a sufficient degree of interpretive restoration where needed in order to function artistically. On the other hand, over-restoration—cleaning, filling, and inpainting away all vestiges of original patina and loss—can kill a work of art. Balancing these often-competing claims and maintaining close communication with the owner/curator of the work is essential to arrive at a satisfactory solution. Retrospectively, I find that I followed these principles and practices:

> Visual coherence: My goal throughout was not total restoration but rather visual coherence—to reduce distractions and let the piece function as intended.
>
> Balance: The level of damage, if any, allowed to remain needs to be brought into balance throughout the work.
>
> Selectivity: It is important to be selective—to know when to limit the treatment, let the work breathe, and not kill it by over-restoration. I know that these are somewhat abstract and subjective concepts, but they have been borne out by my experience. I find that in cases of severe damage and loss, there is generally a threshold after which further restoration may detract from, rather than improve, an object.

To achieve these goals, I employed these practices, among others:

Minimization—reducing a loss or defect, rather than eliminating it completely

Subterfuge—leaving some obvious, unrestored damage to mask or distract from adjacent restorations

Deception—disguising instances of damage as original defects

2. WORKING METHODS, MATERIALS AND TECHNIQUES

For the treatments that I will be discussing, both carried out over a decade ago, I used similar materials and techniques. When possible, I reworked existing stable but poorly shaped plaster fills, recarving the plaster after dampening it with water. I augmented these old fills and created new ones with plaster of Paris and acrylic spackle such as Flügger Acryl. I used wood carving tools, such as curved and "V" gouges, to recreate the appearance of tool marks similar to those left by the original sculptor's clay modeling tools. After creating new or reshaping existing fills, I consolidated them with 10% to 15% Paraloid B-72 in acetone/ethanol 80:20.

After shaping and consolidating the fills, I applied several rather liquid coats of Golden acrylic gesso before inpainting. This technique recreated the "drape" of the original glaze over the surface and the way it pooled in the recesses of the underlying modeling. To recreate "orange-peel" glaze textures, thickened gesso was stippled on with a brush held vertically to the surface. I inpainted losses with Golden fluid acrylic paints, using Golden Gloss UVLS Polymer Varnish as a glazing medium. To simulate glaze pin-holing, I spattered darker colors with a fine stencil brush, controlling for size and position with varying paint viscosities, distance, and masking. I mixed and preserved my paints on a Masterson Sta-wet Handy Palette, premixing small batches of the basic glaze tones in small polyethylene containers (fig. 1).

To achieve a realistic-appearing "liquid" glaze surface, I used multiple layers of thinned paint followed by layers of clear medium, also thinned to flow out after application. Where a glossy surface free of brush strokes was needed, I sanded the paint with Micromesh coated abrasives before the next coat.

3. PLAQUE WITH WINGED PUTTO, BY SANTI BUGLIONI

This *Plaque with Winged Putto* by Santi Buglioni is privately owned. When brought to our lab in 2004, it had a very old restoration, its surface broadly covered with extremely darkened and deteriorated overpaint. The older assembly joins were stable. Most losses had been restored with poorly shaped, now deteriorated plaster fills (fig. 2). The budget was not unlimited, and the owner wished to preserve "an appearance of age and use." An initial exploratory removal of overpaint was done first with a scalpel to assess the overall condition and extent of the losses. This revealed massive losses of original terracotta elements and glaze (fig. 3). Major losses of terracotta elements included both upper corners of the plaque, the blue-glazed projecting swags, the nose, portions of both cheeks, brow and hair of the putto, portions of the wings, and many large elements in the hanging garland and fruits. Smaller glaze losses were too numerous to count. With such massive damage, the question of what to do and what to leave—how far to carry the restoration—was the principal issue. Because of the massive losses of original elements and surface glaze, it would be impractical to restore all of the losses. Time and expense were considered, but my principal concern was that such massive restorations might well have left an over-restored looking, visually "dead" object. Aiming to create visual coherence while retaining a sense of the history and materiality of the sculpture called for minimizing damage rather than eliminating it completely.

Fig. 1. Inpainting set-up, including Golden fluid acrylic paints, small polyethylene jars, and Masterson Sta-wet Handy Palette

The plaque was cleaned of soiling and overpaint with Orvus nonionic detergent and a Derotor steam cleaning unit was particularly valuable for removing overpaint, fill material, and ingrained soiling from glaze abrasions and loss areas. Organic solvents, such as acetone and ethanol, and mechanical cleaning with a scalpel were also employed (fig. 3). Poorly shaped fills were recontoured and selected losses were filled as described earlier and primed with acrylic gesso (fig. 4).

The face and wings of the Putto offer a good example of the selectivity I employed throughout the treatment regarding what to treat and what to leave. I restored enough of the losses to return visual coherency to the face while leaving other losses to allow the original materials—the glaze layer and underlying terracotta—to show through and provide balance. Working in stages, I judged that re-creating selected losses in the chin, right cheek, nose, right eyebrow, and upper left wing was enough to restore coherence and a sense of the underlying beauty of the piece while allowing other damage to remain and give a sense of the history and condition, the "life" of the plaque (figs. 5a, 5b). I began with a few of the obvious, very large losses first, then paused to review and reassess those remaining, always looking for visual balance. I frequently consulted with my colleagues in the lab, along with curators and other nonconservators. The client was pleased with this approach and the results.

The blue-glazed swags and hanging fruit on each side of the relief and the garland below sustained an exceptional amount of damage and loss. The amount of restoration needed was correspondingly higher to bring it into balance with other areas. Note that there are still numerous chips and losses on most surfaces, albeit smaller and less obtrusive (figs. 6a, 6b, 7a, 7b).

Fig. 2. Before treatment (detail)

Fig. 3. During treatment, partially cleaned

Fig. 4. During treatment, with selected losses filled and primed

With the older restorations removed, if left untreated the large losses of both upper corners of the plaque would have been extremely disfiguring and distracting. I substantially reused the existing plaster restorations, which I reshaped and consolidated. Restoring the restorations included resurfacing the fills, consolidating, imitating glaze defects such as bubbling and pin-holing, and re-creating small chip losses to harmonize with the overall surface, an example of deception (figs. 8a, 8b).

The final result presented the appearance of a damaged but "cared for" sculpture, which showed the still considerable amount of glaze spalls, chips, and losses that I left remaining or created in the larger losses—an example of subterfuge (fig. 9). Through the remaining losses, the viewer can still encounter the color and texture of the original clay body, and the thickness and opacity of the fractured glaze. Did I do too much restoration? Or too little? One could argue the pros and cons about my choices, but I feel that the overall effect is harmonious and the presentation honest, preserving hopefully something of both the truth and considerable beauty of the plaque.

4. SAN GIOVANNI DA CAPISTRANO, SANTI BUGLIONI

When I originally treated this sculpture, it was privately owned; it is now in the collection of the Los Angeles County Museum of Art (accession number M.2007.2 a-b). During its long and occasionally difficult life, it had been subjected to several extensive campaigns of restoration. Executed in glazed and

Fig. 5. a. The face during treatment; b. The face after treatment.

Fig. 6. a. At left, the proper left swag and hanging fruit, during treatment, showing the areas of fill. b. On the right, after inpainting. Though losses remain on most surfaces, they are fewer, smaller and less obtrusive—minimization of the damage.

unglazed terracotta, the figure was originally made in six pieces; it now divides in half in the drapery at the belt line. The head and hands—the areas representing flesh—were made separately and left unglazed but show remnants of a gesso-like preparation, suggesting that they may have been painted originally. The proper right arm was attached at the shoulder. Though substantially complete except for the missing proper right forefoot, there were numerous small and larger losses in the drapery, banner, beads, and rope—some poorly filled and inpainted, some only toned, and many without any compensation. The remaining overpaint was discolored severely (figs. 10a, 10b).

What is most notable about the condition, however, are the original defects arising from its original fabrication and glazing. That is to say, the visual coherence of the sculpture was challenged not only by later damage but also by damage from its original creation. This complicated treatment decisions about minimization, deception, and subterfuge. The surfaces show numerous firing cracks, fractures, and losses as a result of the original drying and bisque firing of the clay. Many such areas, as are found in the yellow banner, were repaired during the glaze firing using the glaze as an adhesive (fig. 11). Firing damage (breakage in the kiln) was widespread and resulted in losses—for example, when a broken piece fell to the floor of the kiln and shattered. Substitute pieces, such as are found in the banner (see fig. 11, *arrows*) and

Fig. 7. a. The opposite side, where rather more restoration was carried out on the fruit to bring it into balance; b. Another view of the opposite side.

drapery over the left foot (fig. 12), were replacements—modeled, dried, and glazed later, after the original firing. They were then attached with a tree-resin adhesive, almost certainly within the original workshop.

The purple glazed surfaces have many defects and differences in color and texture—artifacts of the glaze application and firing process, emblematic of the development of these technologies in Italy in the mid-16th century. They include the network of cracks from glaze shrinkage away from underlying breaks in the terracotta, orange peel, fish eye, separation of blue and red glaze color components, and a vast amount of air bubbles (fig. 13).

The previous treatments had reconstructed the figure using large metal staples and a thick, sisal-reinforced layer of tinted plaster throughout the interior from head to toe (fig. 14). This material had exuded out through cracks in the terracotta body in places, and had been either shaped and overpainted, or left as discolored blobs in less visible areas.

I will now present several treated areas to illustrate the challenges and solutions I found to render the figure more presentable and legible while preserving the important artifacts of its original fabrication.

Fig. 8. Before (a) and after (b) restorative inpainting on the surfaces of the plaque corners

Fig. 9. After treatment

Fig. 10. a. Before treatment; b. After treatment. San Giovanni di Capistrano, Santi Buglioni, ca. 1550, Glazed terracotta, 61 × 30 × 14 in. (154.9 × 76.2 × 35.6 cm) Los Angeles County Museum of Art, M.2007.2 a-b, Gift of The Ahmanson Foundation (Courtesy of Anthony Sigel, Angela Chang)

Fig. 11. Banner before treatment. Breakage and blind cracks in the bisque firing were rejoined in the original workshop using glaze as an adhesive. Substitute pieces at arrows.

Fig. 12. Substitute piece of drapery over the left foot

Fig. 13. Glaze applied over damage after the initial firing; glaze defects including bubbles, orange peel, and a replacement sherd at the join line.

Widespread darkened overpaint appeared to be covering a badly broken upraised right arm. I removed the overpaint to find that the restorations covered both undamaged original surface and reconstructed fractures and losses that occurred during the original manufacture of the piece and from later accident. The existing tinted plaster fill material was stable and could be reused by recarving, augmenting with

Fig. 14. Interior of figure covered in thick tinted plaster mixed with sisal reinforcement

additional fill, and texturing with acrylic gesso. To rationalize the fill and inpainting of the losses required a strategy of imitation and deception. I used the existing network of blind cracks, creating imitation blind cracks in some loss areas where needed for continuity, while filling and inpainting other losses to appear continuous and undamaged, and merge invisibly with the surrounding surfaces (figs.15a, 15b, 15c).

Original workshop repairs of breaks in the drapery illustrate how I chose to minimize, but not eliminate, distracting gaps. Removing the darkened overpaint revealed where the glaze had "crawled," or shrunk away, from these edges and cracks, leaving a distracting pattern of break-lines over the purple glaze. In some areas, I chose to make the gaps and break lines smaller and less obtrusive by imitative filling and inpainting along their edges (figs. 16a, 16b).

Throughout the treatment, I toned the fills terracotta color before inpainting to subtly show through, mimicking the interaction of the original glaze and substrate. After treatment, the blind cracks, repairs, and glaze defects are still there and visible but are minimized and less distracting (figs. 17a, 17b, 17c).

Fig. 15. a. Right arm before treatment, with broad areas of excess fill and darkened overpaint; b. Overpaint and excess fill removed or reshaped; c. After treatment, with extensive losses filled and inpainted. (Courtesy of Anthony Sigel, Angela Chang)

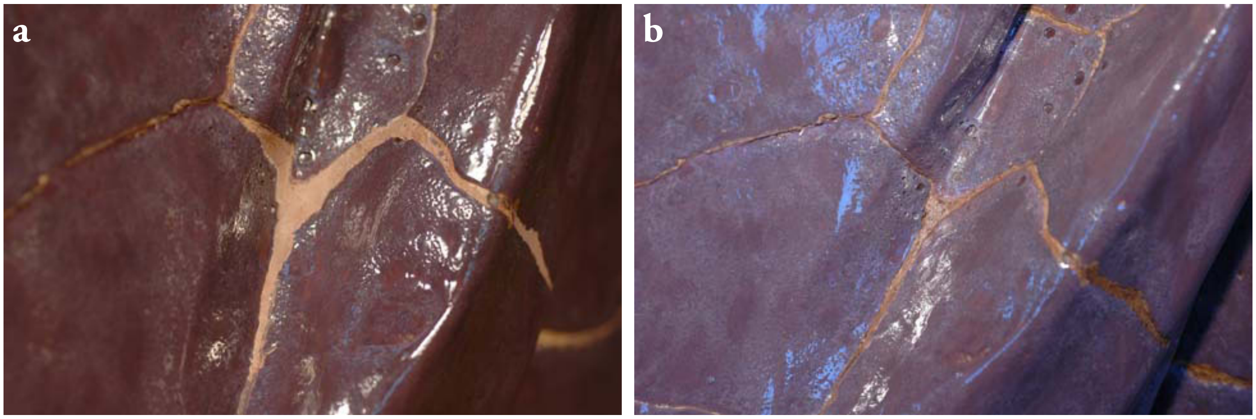

Fig. 16. Imitative fill (a) and inpainting (b) along loss edges reduces their prominence.

Selective restorations were carried out in areas of the back drapery (figs. 18a, 18b).

Some of the distracting losses in the banner were completely filled and inpainted. For others, I used deception—imitating the adjacent surfaces to suggest an original glaze-adhered repair (fig. 19).

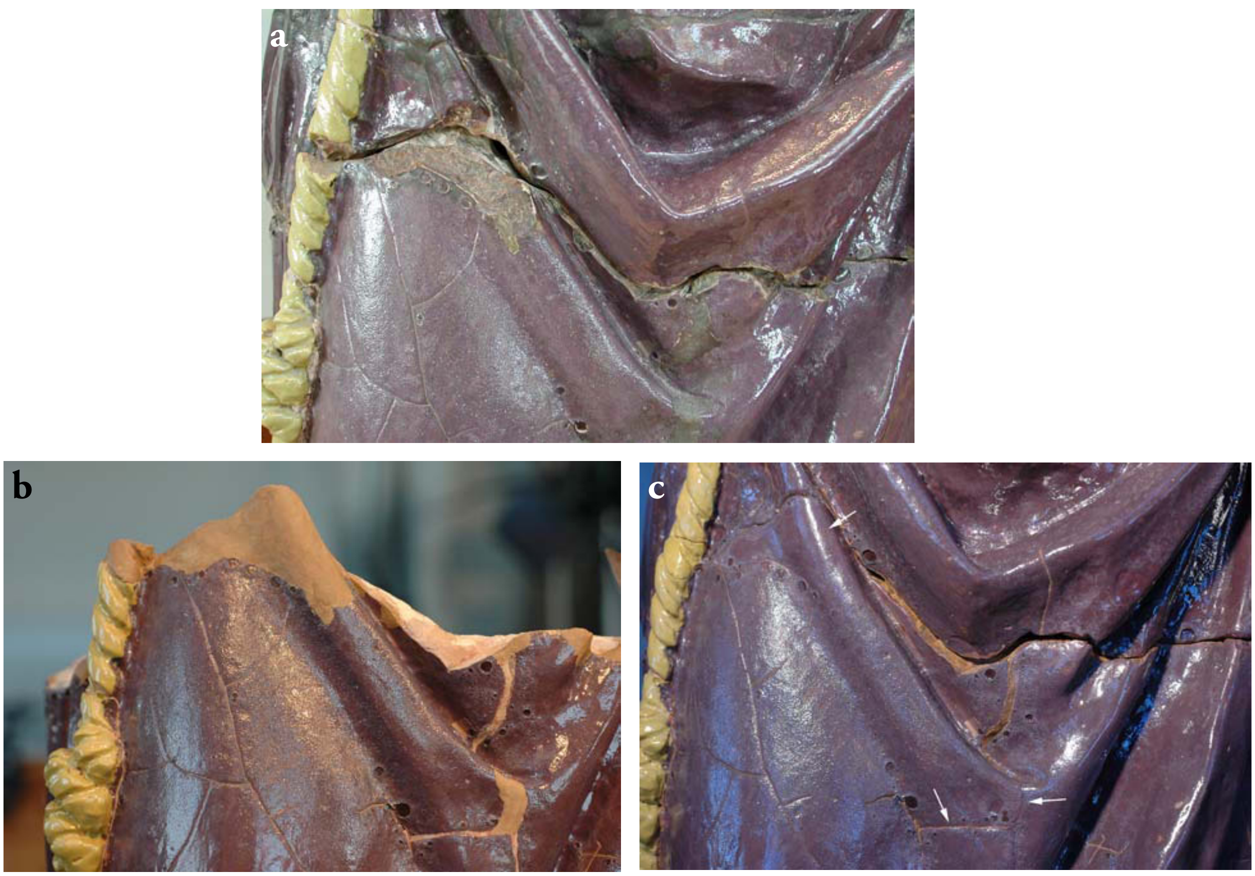

Fig. 17. a. Before treatment showing extensive losses along the join between top and bottom halves of the figure, darkened overpaint and overfills; b. During treatment (upper section removed), cleaned and losses filled and toned; c. After treatment, with losses inpainted, including minimized cracks below waist join (arrows). (Courtesy of Anthony Sigel, Angela Chang)

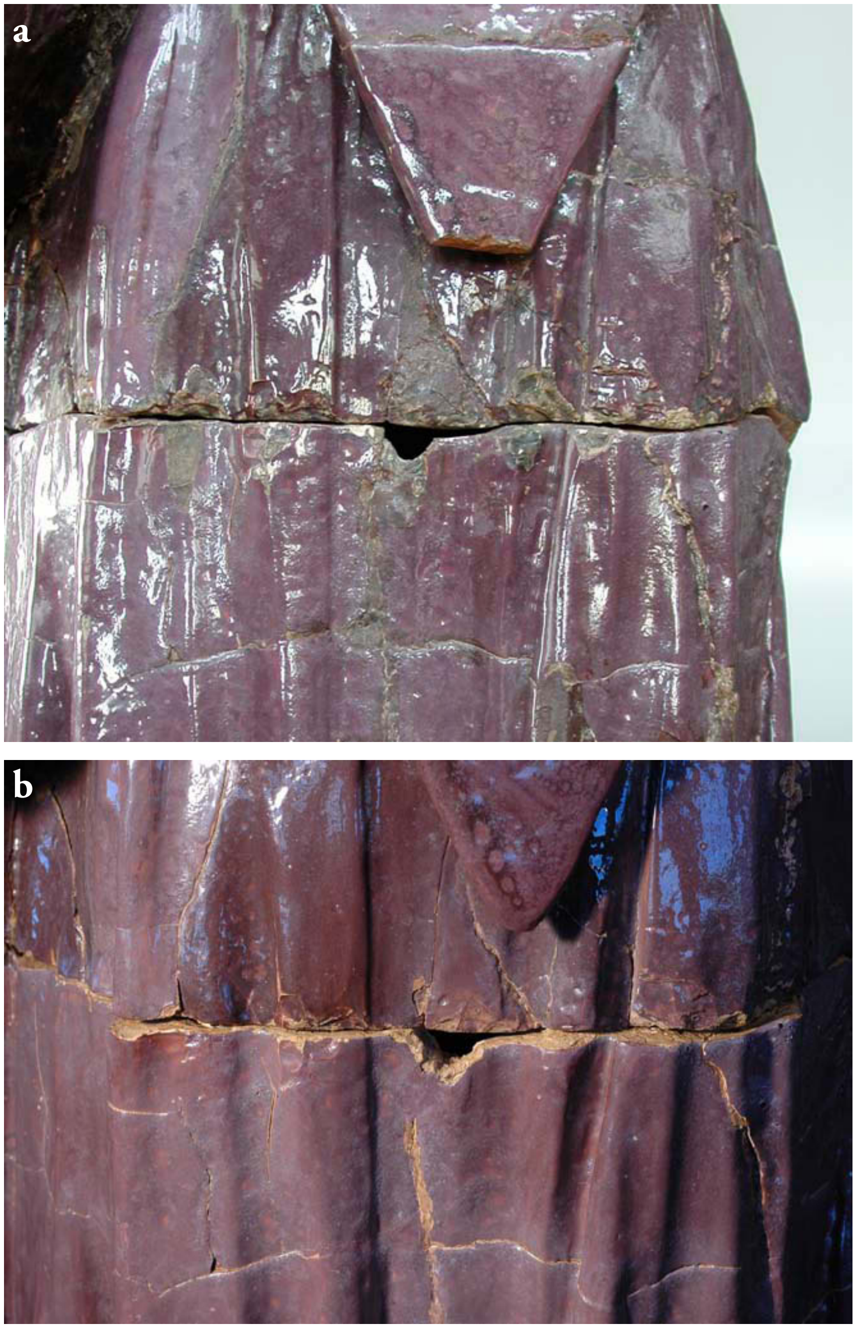

Fig. 18. Before (a) and after treatment (b), surfaces cleaned of fill and overpaint with only the missing tip of the drapery element re-created. (Courtesy of Anthony Sigel, Angela Chang)

5. CONCLUSION

For each sculpture, my aim was to limit the scale of the treatment and to preserve patina and areas of original damage, which were intrinsic to the technical genesis, history, and character of the sculpture. By selectively addressing small and larger losses, minimizing the visual impact of others, and leaving many as found, I was able to restore visual coherence or, to drop the conservation jargon for a moment, restore the "beauty" to the whole. I feel that the damage that I left untreated or partially treated added a great deal of

Fig. 19. After treatment, with an imitation of an original glaze-adhered repair join on the flag at arrow.

truth and authenticity to the works that might have been lost to a more “truthful,” minimal archaeological approach or smothered by its opposite—a “leave no loss unfilled” approach. Thirteen years later—would I make the same choices? Yes.

ACKNOWLEDGMENTS

I am indebted to the generous and patient clients who entrusted these works to my care and to my teachers: my colleagues and friends.

SOURCES OF MATERIALS

Derotor Steam Cleaner
Manufactured by PLYNO S.A.S
Via Lipparini 12/B
40128 Bologna, Italy
Available from conservation and dental equipment suppliers (often rebadged)
https://www.preservationequipment.com/Catalogue/Equipment-Tools/Instruments-Meters/Derotor-Steam-Cleaner

Flügger Acryl Acrylic Spackle
Flügger A/S, Denmark
Conservation Resources International, LLC
5532 Port Royal Road
Springfield, VA 22151
http://www.talasonline.com

Golden Fluid Acrylics, Matte and Gloss, and Gloss, Satin, and Matte Golden Polymer UVLS varnishes
Golden Artist Colors, Inc.
188 Bell Rd.
New Berlin, NY 13411-9527
http://www.goldenpaints.com

Masterson Sta-wet Handy Palette
Masterson Art Products Inc.
PO Box 11301
Phoenix, AZ 85017
Available at Dick Blick
http://www.dickblick.com/products/masterson-sta-wet-handy-palette/

Micromesh Coated Abrasives
Micro-Surface Finishing
1217 West Third St., PO Box 70
Wilton, IA 52778
800-225-3006
Micro-Surface Finishing Products, Inc.
http://www.micromark.com/Micro-Mesh-Finishing-Kit

Orvus WA Detergent
Procter & Gamble Professional
2 P&G Plaza
Cincinnati, OH 45202
800-332-7787
pgsds.im@pg.com
http://www.conservationsupportsystems.com/product/show/orvus-wa-paste/detergents-soaps

Paraloid B-72 Acrylic resin. 70/30 Polyethylmethacrylate/polyethylacrylate copolymer
(Rohm & Haas Co.)
Conservation Resources International, LLC
5532 Port Royal Rd.
Springfield, VA 22151
http://www.conservationresources.com

Small Polyethylene Containers: 5 ml sample vial, LDPE
Thermo Scientific/Nalgene
75 Panorama Creek Dr.
Rochester, NY 14625-2385
https://www.thermofisher.com/order/catalog/product/6250-0005

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CONSERVATION OF 15TH AND 16TH CENTURY ITALIAN GLAZED TERRACOTTA: THOUGHTS FROM CONSERVATORS IN PRIVATE PRACTICE

LESLIE RANSICK GAT AND ERIN TOOMEY

Art Conservation Group has worked on more than a dozen glazed Italian terracotta sculptures. All have come to us after purchase from the market or auction house. One of the glories of glazed ceramics is that beneath the layers of grime and old restoration, the surfaces are often beautifully preserved. Though there are often multiple areas of damage, adjacent surfaces largely inform the viewer as to how the whole would have looked. As a studio in private practice, beyond our mandate to treat each object within the AIC code of ethics, our choices for the aesthetic outcome of our treatment are also directed by the clients' needs. While always appropriate to preserve some sense of an object's visual antiquity, we consider the context in which the piece will be placed when determining our goal(s). Our part of a joint presentation with Anthony Sigel discusses our general approach to the treatment of these terracotta sculptures. We include a review of the general materials that we use and discuss some of our choices in light of our work in the private sector.

KEYWORDS: Della Robbia, Renaissance, Glazed terracotta

1. INTRODUCTION

Over the last 20 years, Art Conservation Group has examined or worked on more than a dozen Renaissance era glazed terracottas. On occasion, the studio has been brought works that are structurally sound, with restorations that are virtually invisible. It has been our practice to leave such a restoration in place as long as it did not appear to be covering an extensive amount of good surface. However, well-executed restored pieces are not what we routinely encounter. Our experience has most often been with glazed works that exhibit the clear presence of at least a few, if not many, heavy-handed restorations that show significant age.

That a glazed terracotta object from the 15th or 16th century has made it to the 21st is exceptional. In its 500 or so years, a given piece has most likely lived in many locations and passed through the hands of multiple custodians. While these fired works are strong, for the most part, they are also inherently vulnerable. As such, virtually all have suffered at least minor damages and surface losses—and most have seen at least one major "breakage event." Enter the generations of restorers, with their agendas and materials that age and discolor, and the custodians for whom they worked, whose aesthetic and budgetary whims have driven the restoration process.

We see the results: restorations on top of restorations and large swaths of discolored overpaint that cover ever-smaller swaths of earlier fixes, often with minor actual damage beneath. While this phenomenon is seen on all sorts of materials that we conserve, we have found that it is particularly egregious with the della Robbias.

One gets the distinct impression that there is a tendency for these pieces to be "atticed"—set aside, or stored for an extended period, once the restorations have degraded. Certainly many, if not most, of the glazed terracotta Renaissance era pieces we have worked on have been in the so-called attic condition, in some cases made all the more challenging by the presence of a highly compromised, yet still holding on, mounting system. It is usually a "fresh" owner or custodian who brings the piece to us to examine and treat.

Treatments are driven by consideration of condition, desired aesthetics, installation context, and budget. When a project is particularly large or complex, we communicate with our clients throughout the process; clients are updated as to our own emerging understanding of their piece. While we typically start by giving the client a ballpark estimate, we provide reports and invoices several times over the course of these projects. As we progress through the treatment in phases, including the client in decisions at the different phases helps them understand and be comfortable with the costs.

First, we assess the condition of a given piece. When restorative material is widespread, the assessment happens largely through examination paired with surface cleaning. On some of the large glazed works, this can require the careful removal not just of dirt and degraded coatings but also the deconstruction of tenacious old mounting and framing systems. After initial cleaning, we carry out any required stabilization or repair work in a second phase of treatment. The need for repairs is far more common than the need for consolidation/surface stabilization, as the glazes tend to be very sturdy and coherent. Because the original surfaces are so often sound, finding them below layers of restoration is not typically the main challenge. The process of stabilization also tends toward a clear-cut goal. Far less automatic, however, is the question of surface integration during the final phase of treatment.

Our goal for the final appearance of the surface typically begins to take shape once cleaning and stabilization are completed, and its true condition can be more fully understood. We would say that a range of integrated surfaces can be considered appropriate for a Renaissance glazed piece—a balance between what its likely original appearance was, its current condition, and a consideration of what might be appropriate signs of age or damage. Within this idea, the wishes of the custodian/owner and the object's intended context can also play a role in defining our goal. In some cases, we have worked toward achieving more of a pristine look, while other treatments have leaned toward more of a natural "scratch-and-dent" aesthetic, depending in part on the context into which we anticipate it entering.

We will describe aspects of five projects as they moved through the cleaning (reversal of old restoration), stabilization, and integration phases of treatment. Ultimately, we will discuss how some of the integration decisions were made. A section at the end will outline some of the techniques we often use in our work on these objects.

The five projects are:
della Robbia, *Madonna and Child*
A workshop-grade[1] della Robbia, *Roundel* 2016-146
della Robbia, *Fruit and Vegetable Basket*
della Robbia, Wall Plaque 2015-068
Santi Buglioni, *St. Bernadino* 2013-278

2. CLEANING PHASE

We have encountered several old mounts and frames that have been a challenge to remove. A 16th century Madonna and Child (fig. 1), one of the so-called atticed objects, arrived with mobile cracks, a torturous frame, and extensive deteriorating restorations.

There were several bolts in the back; we were optimistic that their removal would free the various elements. However, in addition to bolts, we found that the glazed elements had also been attached to the back panel with beds of adhesive and mortar paired with iron nail catches (fig. 6). Thankfully, these adherents were only applied locally. Each element was loosened by mechanically separating the adherents

Fig. 1. After treatment, della Robbia, *Madonna and Child*, 16th century(?), glazed terracotta, 121 × 90 cm. Private collection (Courtesy of ACG)

Fig. 2. After treatment, della Robbia Workshop, *Roundel*, 16th century(?), glazed terracotta, Diam: 74 cm. Private collection (Courtesy of ACG)

Fig. 3. After treatment; della Robbia, *Fruit and Vegetable Basket*, 15th/16th century, glazed terracotta, H: 6 cm, Diam: 25 cm. Private collection (Courtesy of ACG)

Fig. 4. After treatment, della Robbia, *Wall Plaque*, 15th/16th century, glazed terracotta (Courtesy of ACG)

Fig. 5. After treatment, Santi Buglioni, *St. Bernadino*, mid-16th century, glazed terracotta, 152 × 58 × 43 cm. Private collection (Courtesy of ACG)

from the wood back panel. Once freed from the wood panel, the elements were ready for the cleaning and stabilization phases of treatment.

A workshop-grade roundel also arrived in a degraded mount (fig. 2). The bricks were attached with several different types of thick cementitious mortars onto a now-rusted iron frame.

A mirror, not original to the roundel, had been attached with a bituminous material, still soft and with a slight smell of tar. The mortars and bituminous restorative material were mechanically carved away in order to separate the bricks from the rusted frame.

Fig. 6. *Madonna and Child* during removal from frame (Courtesy of ACG)

The various mortars, such as the ones found on both the roundel and the *Madonna and Child*, can be as hard as cement and may cover original surfaces. Removal requires tenacity and patience. We have found that old plaster and some of the cementitious materials can be carefully softened with water for easier mechanical cleaning; we typically use cotton wadding or dampened paper towels.

Once the bulkier remains of mortars and other mounting materials have been removed, the individual elements can be cleaned. The bricks associated with the *Madonna and Child* remained encapsulated within layers of discolored varnish, very stubborn old paint that covered wide passages of original glaze, and extensive grime.

Acetone, ethanol, and benzyl alcohol generally suffice to take down discolored paint and varnish layers. Most often, the aged restorative materials are markedly dull compared with the gloss of the original glaze; their removal is typically a great improvement.

A dark bituminous material found on the surface of the roundel reduced with benzyl alcohol and ethanol. As increased dwell time improved the result, we choose to poultice with solvent-saturated cotton wadding under a foil cover. Had the passages of the relief been lower and less detailed, we might have been more inclined to employ solvent gels.

In addition to organic solvents, we have used saliva or water, of course. When a surface is very dirty, yet hearty, we have on occasion used steam and stencil brushes, which can help get grime out of the interstices that are found in detailed passages. Ammonium citrate solutions, pH 9, have also been

Fig. 7. *Fruit and Vegetable Basket* during treatment (Courtesy of ACG)

employed—always well cleared with water. With these fired-clay materials, water can soften unglazed areas; aqueous cleaning, especially soaking of any kind, requires caution.

3. STRUCTURAL PHASE

The *Madonna and Child* required significant structural work. Manufactured in two sections and joined along the horizontal with pins, the join was distinctly mobile (fig. 5).

In addition, the upper part of the two sections was broken and had a highly mobile crack down its center. Our concerns for reversibility were mixed with the need for added join strength; both the horizontal join and the break in the upper portion were adhered using a combination of Epotek 301 thickened with fumed silica to a gel state and placed as dots in strategic locations and a 3:1 mixture of Paraloid B-72/B-48N applied more generally across the break edges. The Paraloid B-72/B-48N mix has become our go-to structural adhesive for projects such as these (Riccardelli et al. 2014).

For structural fills, we commonly use plaster as a subfill and then seal with shellac or Paraloid B-72. Occasionally, an epoxy putty fill is used and then surfaced with another material. With the epoxies, it is our standard practice to apply Japanese tissue with dilute Paraloid B-72 in acetone as a barrier over the join face, which should facilitate removal in the future. We have also used Japanese paper infused with adhesive to fill losses along joins. We generally surface fills with Flügger, as it dries harder and with a denser surface than some of the other vinyl spackles we have used (including Modostuc and DAP).

Structural issues can also fall under integration concerns. A 15th century fruit and vegetable basket (fig. 3) exhibited damages that were severe but not unexpected for a piece of its composition, one of the

Fig. 8. *Wall Plaque* before (left) and after (right) treatment (Courtesy of ACG)

most visually and materially delicate della Robbia baskets that we have seen. It had lost most of the leaf points. The leaf tips were remade with plaster and consolidated with thin solutions of Paraloid B-72 in acetone before adhering them to the object with the Paraloid B-72/B-48N adhesive (fig. 7).

It was a challenge to make the joins between our leaf-tip additions and the break edges sufficiently hearty, as the break edges are extremely thin, with very little surface area for the added plaster to cling to. We were concerned that our repairs would not hold up since the object is a centerpiece on a low table in a private home. The owner is an active collector; when new objects are brought home, things are moved about until any new acquisition has been incorporated into the overall installation. Within months, several of our added leaf tips had fallen off.

It was decided to strengthen the joins with Japanese tissue "band-aids": small strips of paper adhered over the undersides of the joins with Paraloid B-72. While the tissue tabs cover original material, they are on the undersides of the leaves, and are not readily visible. This solution has proved effective so far: while the basket continues to be moved about by the owner, no leaves have fallen off for many years.

4. INTEGRATION PHASE

Once a piece has been cleaned and stabilized, we can address integration aesthetics. Our preference is to visually minimize areas of damage so that the object can be taken in as a whole—so that these changes to the piece do not interfere with our experience of it. Within this guiding concept, however, a range of surface appearances can be considered acceptable. Even among those in the know (curators at a museum, savvy dealers and owners, or different conservators), there does not seem to be agreement in the art world as to ideal condition; it seems to boil down to taste. Some expect a surface closer to perfect, and have collections that reflect this ideal, while others prefer the signs of wear and tear natural to an old glazed ceramic.

While we would argue that some sense of an object's visual antiquity should always be preserved, we do not find it objectionable to consider the context into which the piece will be placed when determining our aesthetic goal(s), provided that we exercise some measure of restraint in our use of restorative materials. In the case of the della Robbia basket, the majority of the object was in pristine condition, providing ample information to fill the losses that truly undermined the original intention. In the market place and—we believe—in most museums, such an object would be restored. This was the owner's expectation.

A decorative plaque (fig. 4) we worked on needed less treatment than any of the others discussed so far. It was in good condition, with scattered minor surface losses and the larger loss of a fruit element near the outside edge. The initial proposal agreed to by the client was for a selective decrease in damages, including some cleaning and relatively minor fills and inpainting. With this approach, our original inclination was to leave the side fruit loss, as such. However, after the clients lived with it for several months, they felt it to be incomplete. Thus, the piece was returned to us for the addition of some fruit (fig. 8).

Many objects that we see on the market are frequently left with a combination of visible areas of minor damage in select locations with more highly restored areas in others. The highly restored areas are often difficult to find even under close examination; in some cases, there has been select use of UV-blocking coatings. This is, simply, manipulative. Because we work in the private sector, we at times lean toward more integration or replacement of losses than a museum conservator may; however, we refrain from heavy-handed work and are committed to staying within the lines of loss. If looked for, the fills can be found without difficulty.

Three mid-16th century saints by Santi Buglioni on view at the Boston Museum of Fine Arts (MFA) in 2016 were exhibited together perhaps for the first time since inception, or ever, presenting a unique opportunity to compare different conservation approaches. Each of the three saints had different owners and conservators; we worked on *St. Bernadino* for a private client (fig. 5); *St. John of Capistrano* was worked on by Anthony Sigel and discussed in his article in this volume; and *St. Francis*, on loan from the Uffizi, was conserved by an Italian institution. Our approaches to loss compensation and integration varied quite markedly.

All three had lost their proper right foot, likely due to the geometry and weight distribution of the sculptures. Additionally, *St. Bernadino* had also lost his proper right thumb; a photograph from the 1940s indicates that *St. Francis* had suffered a loss to his left arm. On arrival at our studio, the statue of *St. Bernadino* exhibited dull restorative paint over much of his robe, due in part to old restoration that sought to cover the seams between the blocks. The overpaint on the seams had been leveled with fill before inpainting; thus, the old fill had to be brought down following paint removal. Once removed, stable bright glaze was revealed.

In the treatment of the *St. Giovanni da Capistrano*, Sigel decided to leave the loss to the foot and the seams between the blocks minimized but left a terracotta color, in accordance with his specific goals. The conservators of the Uffizi *St. Francis* decided to replace both the foot and lost arm, and the seams were well integrated. They also added a base with a white glaze finish.

Our integration decisions for *St. Bernadino* were made based on the known eventual location of the sculpture: the owner's living room. It is a somewhat minimalist room as far as furnishings are concerned, but filled with 16th century Italian sculpture and paintings. It is intimate and often visited by scholars. Because of this context, the replacement of the proper right thumb and foot was ultimately considered essential, as their absence would be a distraction from the overall object. Also, because of the install location, more sculptural than architectural in feel, it was decided that the very visible joins between the blocks that make up the sculpture would be toned—but not filled—such that they would visually recede.

5. FAVORITE TIPS

Baggie Method for Applying Fills: We often apply fills by loading the fill material into small polyethylene baggies. A corner of the baggie is cut off; you can then "shoot" the material into cracks or hard-to-reach gaps by sticking the clipped corner into the loss and squeezing, run a bead along longer cracks, or simply hold the baggie in one hand and squeeze successive tiny amounts on to your spatula. The ability to squeeze bits of material directly into losses can be especially helpful when they are surrounded by sensitive surfaces and the usual clean-up would likely be damaging. Between uses, you can tape the corner or put a spring clip on it. An added benefit is that, by decanting into a baggie, less crust builds up on your mother container.

Tools for sculpting fills: We frequently use silicone tip spatulas in addition to the usual steel ones (Color Shaper by Royal Sovereign Ltd).

Della Robbia blues and whites: We use Golden Archival Varnish with dry pigment, especially when della Robbia blues or whites need to be matched—or when the surrounding glaze is particularly thick and rich looking. For matching blues, rottenstone is used to dull a mixture of ultramarine and Prussian blue pigments. Add titanium white and, in some cases, add a bit of a magenta element. For della Robbia white—titanium white works if you add rottenstone—often with a blue or magenta component. The key to both is the rottenstone; it dulls back the white or blue without overdarkening or turning cloudy as it dries.

Inpainting terracotta: We use Flügger as both the medium and white pigment in combination with matte acrylic paints. The "tooth" lent by the Flügger acts as a matting agent and allows for mechanical manipulation of the surface; you can easily create convincing scuff marks, for example. Rottenstone is, once again, a helpful colorant.

Watercolor pencils (we use Caran d'Ache) have a number of benefits. With no drying time, the final color is immediate and the range of colors is quite extensive. Freed from the brush, you can apply color in scumbling or other nonbrushmark manners. Also, if Flügger or another textural agent is in the underlying paint layer, the pencil lines will catch nicely on the tooth.

Brushes: We have found the SeppLeaf gilding brushes to be far superior to any others, especially when working with solvent-based varnishes. They keep their points for a very long time and stand up to solvent well. In addition, they hold a lot of paint; thus, you do not have to reload as often. Note that these brushes are also our first choice for consolidation—again, for their high load capacity, durability, and nice point.

Proprietary Epoxy Putties: WoodEpox (Abatron), Pro Poxy (Hercules) and Magic Sculpt (WESCO).

ACKNOWLEDGMENTS

We would like to thank the owners of the works of art discussed in this article for allowing us to use images of objects from their collections.

NOTE

1. Based on a visual assessment of the piece; less detail and depth of relief; more likely to have been mass produced and cast from molds.

REFERENCE

Riccardelli, Carolyn, Jack Soultanian, Michael Morris, Lawrence Becker, George Segan Wheeler, and Ronald Street. 2014. "The Treatment of Tullio Lombardo's *Adam*: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49: 49–116.

SOURCES OF MATERIALS

Acetone, Ethanol, Benzyl Alcohol, Ammonium Citrate, Fumed Silica, Paraloid B-72, Paraloid B-48N, Shellac, Japanese Tissue Paper, Flügger, Modustuc

Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Plaster, Rottenstone, Dry Pigments

Kremer Pigments
247 W. 29th St.
New York, NY 10001
212-219-2394
www.kremerpigments.com

Color Shaper/Royal Sovereign Ltd. Silicone Tip Spatulas, Magic Sculpt

The Compleat Sculptor
110 West 19th St.
New York, NY 10011
212-243-6074
www.sculpt.com

Sable Pointed Quill Brushes

SeppLeaf Products, Inc.
381 Park Avenue South
New York, NY 10016
212-683-2840
www.seppleaf.com

Golden Archival Varnish, Golden Acrylics, Caran d'Ache Watercolor Pencils
Blick Art Materials
PO Box 1267
Galesburg, IL 61402
800-828-4548
www.dickblick.com

Wood Epox
Abatron
5501 95th Ave.
Kenosha, WI 53144
262-653-2000
www.abatron.com

Epo-Tek 301
Epoxy Technology
14 Fortune Dr.
Billerica, MA 01821

Pro Poxy 20
HCC Holdings
4700 West 160th St.
Cleveland, OH 44135
800-321-9532
www.Oatley.com

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TEMPTING FATE: TREATMENT OF GIOVANNI DELLA ROBBIA'S *ADAM AND EVE*

GREGORY BAILEY

Recent examination and treatment of the Walters Art Museum's relief *Adam and Eve* (27.219), attributed to the workshop of Giovanni della Robbia and dated to circa 1515, shed new light on the complex history of this object. In 2013, an incident of damage provided the impetus for a year-long effort to examine, document, and treat the relief. The project was completed in close collaboration with Dr. Joaneath Spicer, the James A. Murnaghan Curator of Renaissance and Baroque Art.

The relief is permanently installed on a stairway landing in a high-traffic area, hindering access and photography. Examination and treatment were conducted largely in public. Consequently, cleaning methods were restricted to mechanical, aqueous, and low volatile organic compound solvent methods. Examination of cleaned surfaces and glaze analysis by x-ray fluorescence spectrometry provided evidence that many sections of glazed terracotta were manufactured in the 19th century. Provenance research suggests that they were made in Italy in 1870 or before, possibly with the intent of sale to the South Kensington Museum in London (now the Victoria & Albert Museum). Losses and prior restorations were inpainted with only minimal additional filling or resurfacing. As a result, the appearance is unified at a distance; however, damages, restorations, and differences between the two types of terracotta are visible on close inspection.

KEYWORDS: Della Robbia, Glazed terracotta, XRF, Restoration

1. INTRODUCTION

This article focuses on a large glazed terracotta relief in the Walters Art Museum depicting Adam and Eve in a scene of the Temptation, attributed to the workshop of Giovanni della Robbia and dated to circa 1515 (fig. 1). Based on the inscription on the predella together with the crests of Leo X and the Buondelmonti and Salviati families (Marquand 1911, 1912, 1920, 1928), the relief is associated with the triumphal entry of the Medici Pope Leo X into Florence on November 30 of that year. The relief has been on continuous display in Baltimore since 1909, when Henry Walters completed his private art gallery, and is currently located on a shallow stair landing between floors. Prior to the present study, little was known of its history before its arrival in Baltimore.

In 2013, a palm-size section of the fig leaf at Adam's waist was accidentally damaged and lost. Despite a thorough search of gallery spaces, the fragment was not located. In preparing a damage report and initial examination, it quickly became clear that many other small fragments were loose or partly detached and at risk of loss. Surfaces had last been cleaned superficially 10 years before, and accumulated dirt and grime obscured the original glazed ceramic. There were remnants of a discolored, nonoriginal wax coating left in many areas, trapping dirt and contributing to the uneven appearance. Multiple campaigns of fill and restoration paint had been added to the surfaces over the years, which no longer harmonized well with each other. Additionally, the large size, extreme complexity, and location of the relief had limited prior documentation efforts, and contributed to some difficulties in assessing and responding to the new damage. I consulted with Dr. Joaneath Spicer, the James A. Murnaghan Curator of Renaissance and Baroque Art on the piece. We decided to address the immediate damage in an efficient and reversible way, revisiting other issues at a later date.

At the time, we hoped that the missing fragment would eventually be located; thus, I designed a fill that could be easily removed. I quickly consolidated the loose fragments along the break edge using dilute Paraloid B-72 in acetone/ethanol and spent the afternoon fabricating a laminated paper fill. To do so, a negative mold of the break edge was taken with Zhermack Elite HD dental putty; a positive replica of the

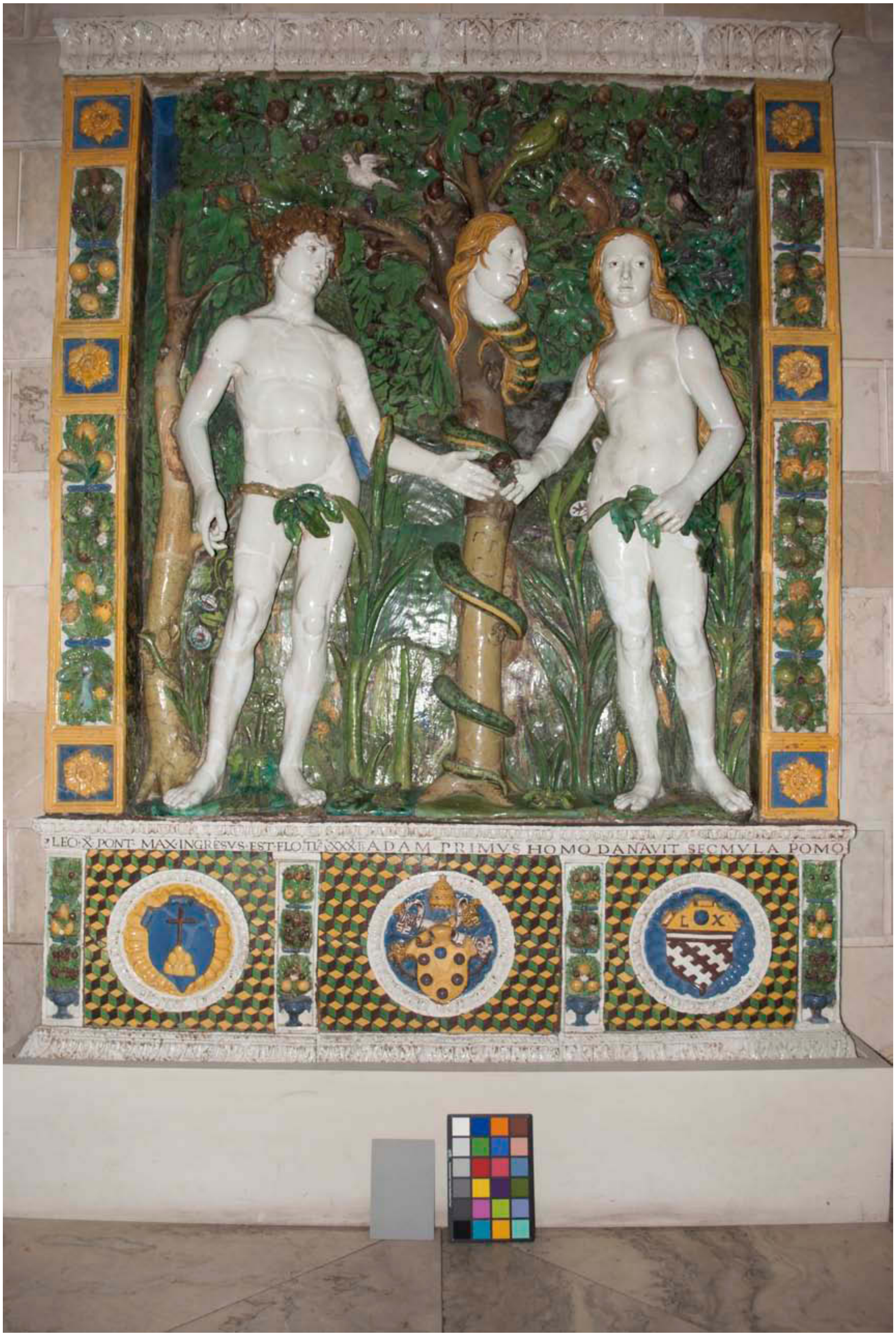

Fig. 1. Before treatment. Attributed to the workshop of Giovanni della Robbia, *Adam and Eve*, ca. 1515, terracotta with glaze, 2.795 × 2.12 m. Walters Art Museum, 27.219

surface was then cast in the same material. Layers of Japanese paper were built up over the replica surface with a 4% mass-to-volume aqueous solution of sodium carboxymethyl cellulose. After drying overnight, the fill was burnished, trimmed, and tacked in place on the relief with several dots of thicker Paraloid B-72 in acetone/ethanol. Inpainting was completed using Golden Fluid Acrylic paints. Unfortunately, the fragment was never found, necessitating that this fill remain in place.

As I prepared my own documentation of this damage and treatment, I delved into prior treatment records. This documentation revealed that the relief, despite its monumentality, is a fragile, compromised object. It was treated at least eight times between the 1950s and 2000s to repair damage, consolidate joins, remove excess restoration material, and improve the aesthetic appearance. The rich written accounts of treatment were instrumental in understanding the 20th century history of this complex object. I am grateful to the many conservators whose work informed my own, including Elizabeth Packard (1958), Peter Michael (1959, 1960), Carol Aiken and Terry Weisser (1974), Carol Snow (1988), Donna Strahan (1998), and Meg Craft (2001, 2003). Yet photographic and diagrammatic records of condition were scant, leaving considerable ambiguity as to the location and extent of issues noted in the written reports.

Using my time as a Mellon Fellow in Conservation, I embarked on a more thorough campaign to document the condition of the relief through photographs and written reports. On further discussion with Dr. Spicer and others, it was decided to undertake a surface cleaning to reduce dirt and grime, remove traces of the uneven and nonoriginal wax coating, and reduce excess restoration material with the goal of increasing overall cleanliness and revealing as much of the original as possible.

2. DOCUMENTATION AND INITIAL TREATMENT

Before treatment, extensive photography was performed both overall and in detail to capture the current state of the object. This proved difficult in execution as well as in organization; the very large number of photographs and complex surface of the relief, with some portions rendered fully in the round, made it difficult to accurately record the condition of all surfaces. Serendipitously, I had the opportunity to work with technicians from Direct Dimensions Inc., a 3D scanning and printing company, to record a medium-resolution scan of the relief overall as well as a high-resolution scan of the central panel of the predella. Three-dimensional scanning has been used in the conservation and preservation of architecture and monuments for some time. The ever-declining cost and increasing portability of scanning equipment and software has rendered it increasingly appropriate for large, complex art objects such as this relief.

The size and location of the relief presented a number of unusual challenges when designing a plan to clean the glazed surfaces and reduce excess restoration material. A ladder and additional lamps were necessary, and the nearest power source was located on the next floor, requiring power cords securely taped down to the outside of the stairwell. Because the landing remained open to foot traffic, a stanchion was needed to guide visitors around the work area. All tools and materials had to be packed up and removed each day, as the space at the foot of the stairs was frequently used for after-hours special events. Owing to space restrictions, no fume extraction equipment could be used, which prevented the use of volatile organic compounds (VOCs) during treatment. Furthermore, because the object remained on continuous display, the curator was keen to ensure that it remained in "visually acceptable condition" during the course of treatment.

I completed initial tests and tried out equipment configurations on Mondays and Tuesdays, when the museum is closed to visitors. After settling on materials and procedures and further discussions with Dr. Spicer, I continued treating the relief several additional days per week during the museum's open hours.

To reduce dirt, grime, wax, and excess plaster and paint, surfaces were first poulticed for several minutes with Webril nonwoven cotton pads wetted with tap water adjusted to pH 9 by the addition of sodium hydroxide. The increased contact time of the poultice meant that less mechanical action and a smaller volume of water were necessary to begin the cleaning process, which were both important factors when working atop a ladder on a stairwell. Poulticing softened the restoration materials on glazed terracotta surfaces, allowing mechanical reduction using scalpel blades or micro-spatulas. Excavating the excess material proceeded slowly, as the goal was to reveal as much of the original surface as possible while leaving fills in place rather than removing all of the restoration materials. In many areas, three or four campaigns of plaster and spackle fill were evident, covering the glazed surfaces with as much as an inch of excess material.

Wax was reduced by rolling swabs dampened with Shellsol 71, so-called "odorless" mineral spirits, a mixture of aliphatic solvents with a very low VOC content. Solvent and waste containers were kept covered to limit exposure.

Dirt and grime were reduced by rolling cotton swabs dampened with sodium citrate adjusted to pH 8.5. Surfaces were cleared by rolling with swabs or washing with cotton pads wetted with tap water. In part because setup and cleanup each day was laborious and time-consuming, completing the cleaning process required approximately 12 months of working several days per week.

Though not initially accounted for in planning the project, interaction with the public came to occupy a considerable portion of my time. Given the prominence of the relief's location and the fact that there were several other concurrent opportunities to interact with conservators in gallery spaces at the Walters, many visitors were extremely interested in my work, eager to learn more about the object and the process of conservation. Through informal interactions over time, many security officers and volunteer docents became familiar with the project and were often willing to answer questions from visitors. Though informal, this cooperation proved to be a valuable strategy for my own time management.

Interacting with the public also yielded some surprising and nuanced insights into the materials, techniques, and context of this complex artwork. I had the opportunity to speak at length with physicians who commented on the anatomy of the figures, sculptors and ceramists with observations on the construction of the relief, seminary students on the narrative of the Temptation, and botanists who speculated on the species of flora represented in the border and background. Often, interaction with the public is presented as an extra service provided by conservators—sometimes to the detriment of treatment and examination—when, in reality, it can enhance our knowledge and appreciation of artworks by drawing on diverse fields of expertise and experience.

As I worked to reduce the restoration materials, it became clear that the central scene was assembled from many sections of severely damaged terracotta at some point in the past (fig. 2). Most fragments were repaired by pinning or stapling with iron rods, though many appeared to align along original joins. Some joins were loose or very poorly aligned, such as the vines around Adam's waist and the digits of the figures' hands. These were disassembled either mechanically, by cutting through the pins with a narrow file, or by softening the plaster fill material. Working away from the object, corroding iron pins were removed, the sections were cleaned and repaired with Paraloid B-72, and fills were made in Modostuc, an acrylic-bound calcium carbonate material. After reattaching the fragments to the relief with Paraloid B-72, inpainting was again completed using Golden Fluid Acrylic paints and Acrysol WS-24 acrylic medium to adjust gloss as necessary.

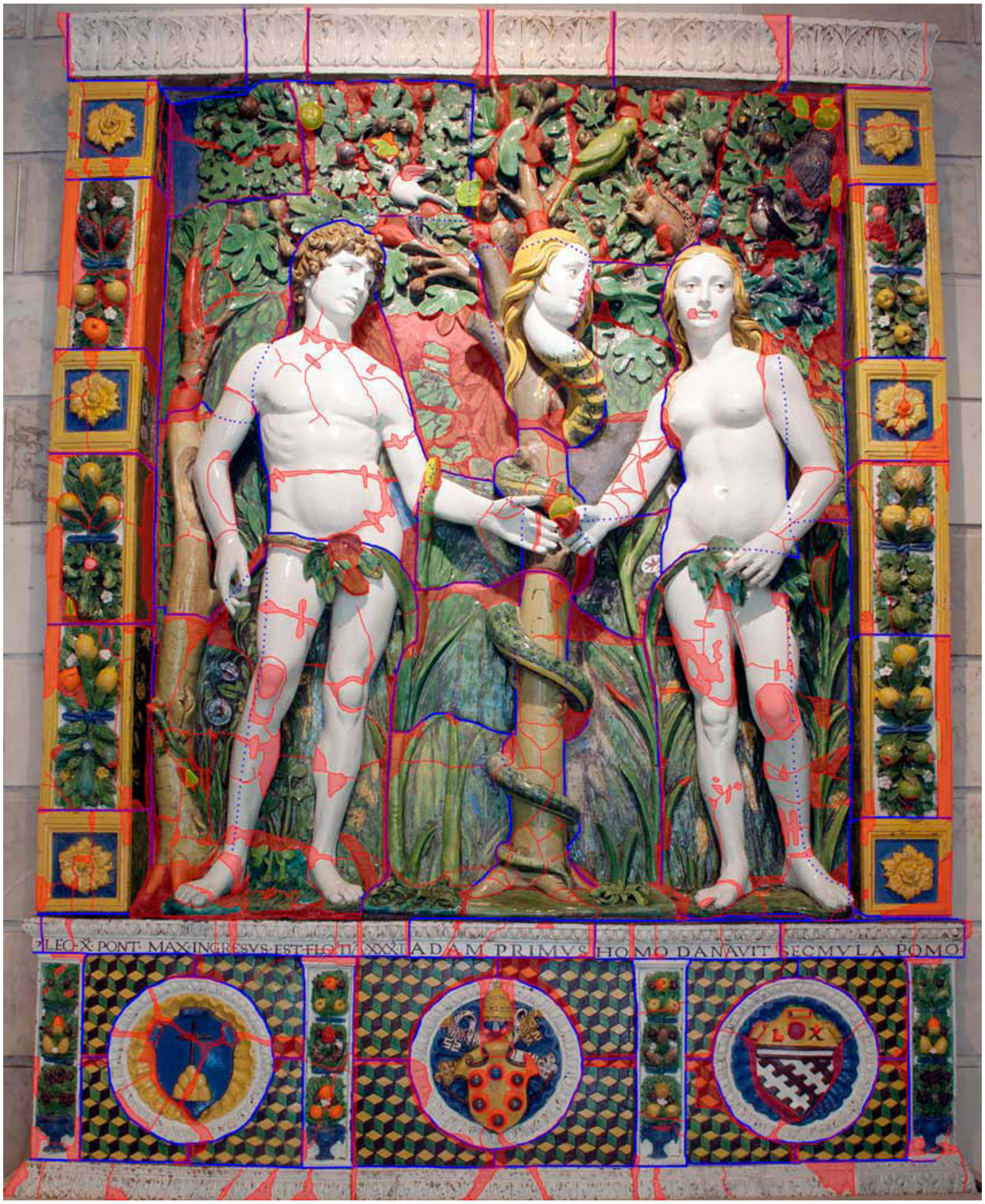

Fig. 2. During treatment, after cleaning. Breaks, losses, and fills are highlighted in red.

The center of the relief and the upper register of leaves consist of misaligned fragments with no clear join edges. These appear to be held in place with plaster alone; the gaps between them have been filled with additional plaster and integrated with paint. Several fragments of original glazed terracotta are clearly out of place; they seem to have been inserted merely to fill gaps among the larger pieces. Similarly, the text on the predella includes gaps and dislocations that had previously been obscured by overpaint, indicating that it should be read as fragmentary and incomplete.

3. ANALYSIS AND IDENTIFICATION OF PRIOR RESTORATION

As cleaning and reduction of restoration material progressed, it became apparent that two different types of glazed terracotta fragments were incorporated into the relief. The majority of the fragments consisted of buff-colored terracotta covered with a single opaque layer of glaze. On the whole, these were visually consistent with glazed terracotta produced in the della Robbia workshops (Gentilini 1992).

A smaller, but still substantial, number of fragments were made from a reddish terracotta that had undergone two glaze firings. These pieces were first glazed overall with a white ground, over which a second layer of semi-translucent glaze was applied in a brushy, impressionistic manner and fired again. In both materials and technique, these broadly resemble descriptions of 19th century restorations of della Robbia works, such as those believed to have been added to a large retable of the Ascension (now at the Museé du Louvre) by the firm of Alfred André between 1885 and 1890 (Lepeltier and Labbe 2011).

Working with Dr. Glenn Gates, Research Scientist at the Walters Art Museum, I performed XRF spectrometry on the two different types of glazed terracotta using portable instrumentation loaned by the Baltimore Museum of Art (a Bruker Tracer III-V) and Elio XRF (Elio XRF unit). Using the Bruker Tracer III-V, 12 sites of similarly colored glazes on each of the two types of terracotta were analyzed (120-second acquisition time at 40 kV and 4.75 µA with no filter, in contact with the surface and under vacuum, average counts per second ~2.5k). Spot analysis on the same 24 sites was performed with the Elio XRF unit under varying parameters.

Analysis by XRF identified consistent differences between the two visually distinct glazed terracotta sections. The composition and colorants used for the glazes on the buff-colored terracotta fragments are consistent with published data on della Robbia glazes (Zucchiatti and Bouquillon 2011), whereas those used for the glazed surfaces on the reddish-colored terracotta were more consistent with 19th century manufacture. In particular, the identification of chromium in green glazes provides strong evidence for the 19th century origins of these fragments, as chromium is not known to have been used as a colorant for vitreous materials before approximately 1800 (Hornig-Sutter 1985; Wypyski 2004).

4. PROVENANCE RESEARCH AND EARLY RESTORATION HISTORY

Concurrent with my documentation, treatment, and analysis of the relief, I pursued provenance research in an effort to unravel its complicated treatment history. Henry Walters purchased the relief in 1902 at auction in Paris, from the estate of the widow of the Parisian art collector Camille Lelong (*Le Bulletin de L'Art*, 1902). The sale catalog includes an image of the relief, which appears damaged and visibly grimy. The text of the inscription on the predella is presented in a different configuration, and the catalog entry notes that it is incomplete (Lelong 1902).

Lelong had successfully purchased the relief in 1886 from Adele Ristori, a woman from Valdarno, despite efforts by Italian authorities to bar its export (Gentilini 2012). Ristori had acquired it sometime during or after 1884, when it was in the shop of the antiques dealer Angelo Cappelli, located in the Borgo Ognissanti, Florence (Marquand 1920).

In December 1870, the relief had been in the hands of "V. Cappelli," who shipped it to South Kensington Museum in London (now the Victoria & Albert Museum). The relief was offered for sale at the considerable price of ₤1000 (Victoria & Albert Archives RP/1870/48677 1870/12/20). No photographic records of its condition are known to survive. However, it is described in detail in a technical report written for the South Kensington Museum by Matthew Digby Wyatt (Victoria & Albert Archives MA/3/35 RP/1870/49059). It is also described in the 1871 January and February issues of *The Art Journal* (London), leaving no doubt as to the identity of the relief (*The Art Journal*, 1871). The written accounts of the appearance and condition of the object reveal that the newly made glazed terracotta restorations were in place at that time as well as the initial campaign of tinted plaster fills and paint (fig. 3).

Digby Wyatt had the benefit of examining the object while it was disassembled in several pieces for shipping. He summed up his observations thus: "I think a little of this is old and a great deal *quite modern* [emphasis in the

Fig. 3. During treatment, after cleaning. Sections of glazed terracotta made in the 19th century are highlighted in bright green. Archival research suggests that these restorations were made as part of a concerted campaign to reconstruct and restore the relief in Italy in 1870 or before.

original]…. It is much made up with plaster and coloured (not fired) in many places. The various pieces are made with… two different kinds of clay—and colour has been applied in many places to make new material appear old" (Victoria & Albert Archives MA/3/35 RP/1870/49059). The South Kensington declined to purchase the relief, and it was returned to Florence in 1871 (Victoria & Albert Archives RP/1871/12407 1871/03/13).

Based on this evidence, it seems likely that the relief was reconstructed in the 19th century, probably in Italy in 1870 (or slightly before) from an incomplete collection of fragments from a larger 16th century monument. The restorers created a reduced version of the original that strongly privileged the sculptural qualities of the two figures, working from the largest to the smallest sections and completing the assemblage with newly made pieces of glazed terracotta. The application of colored glazes over a white ground on these pieces approximates the look of the original della Robbia glazes. However, this technique is borrowed from maiolica vessels (Piccolpasso 1980) and represents a fundamental misunderstanding of the techniques of the della Robbia workshop on the part of the restorers.

The restoration materials and techniques employed in the assembly and completion of the relief borrow equally from traditional repairs to both ceramics and marble statuary.

The 19th century restorations in glazed terracotta are remarkably well fitted to the break edges of the original fragments, suggesting that they were modeled on the original surfaces in a low-shrinking clay, then separated for firing and glazing before securing them to the relief with tinted plaster or iron pins. Nineteenth century restorers employed such methods for completing fragmentary ceramic vessels as well as marble sculptures. For vessels, restorers would throw or build a section of new clay directly on the original and fire it separately. For sculpture, clay modeled in situ was detached and restorers carved precisely fitted pieces of new marble with the aid of pointing machines (Carradori 1802).

The techniques used to integrate the glazed terracotta restorations are likewise similar to those used by Italian restorers of marble sculpture during this period. This includes the iron staples and pins used to secure the restorations in place as well as the overall wax coating, which was commonly used to disguise repairs and additions (Bourgeois 2003).

A close examination of the restorations thus suggests that the overall effect was calculated to appeal to Victorian tastes in collecting and that the materials and techniques themselves seem to be predicated upon an understanding of the glazed terracotta works of della Robbia as partaking of both the craft of maiolica and the art of marble sculpture (Bailey 2018).

5. COMPENSATION APPROACH

Recognizing that the *Adam and Eve* relief is a hybrid object—one that combines fragments of a 16th century monument with 19th century restorations in the same material—presented a significant challenge for the aesthetic reintegration of loss and damage. Previously, layers of paint and wax had been applied to disguise differences in the two sets of terracotta, obscuring the true nature of the object to create an aesthetically unified whole. The opposite approach, which would privilege authenticity over aesthetics, might lead to disassembling the relief and removing the 19th century additions. Neither approach is quite satisfactory. It would be difficult to justify either returning the relief to the state of a deceptive but alluring pastiche or reducing it to a pile of disarticulated but authentic rubble. Indeed, we never seriously considered disassembling the relief, not least because of the prohibitive costs in time, labor, and resources needed to free the terracotta sections from the concrete, plaster, wooden beams, and iron rebar in which they are embedded.

Recognizing that it was not possible to either return to the relief's 19th century appearance or restore the still unknown original appearance, I devoted considerable time to discussing the nature and goals of aesthetic reintegrations with Dr. Spicer and my conservation colleagues. Ultimately, the unique physical location of the relief within the museum came to guide the approach to compensation.

Because of its location on the stair landing, the relief is visible from long distances in many locations within the 1909 building. Most people, most of the time, experience this artwork from a distance. We thus decided that damages and losses should be toned or inpainted in order to present a unified appearance overall. This approach necessitated little additional filling and minimal resurfacing of the old fills to bring them closer to surface level with surrounding areas of glazed terracotta. This helped to ensure that damages, losses, and prior restorations remained evident on close inspection, bearing witness to the history and hybrid nature of the object.

Virtually all areas of existing fill and damage were retouched using Golden Fluid Acrylic paints. Though not all prior inpainting was removed, much of it had either discolored over time or had been painted to match dirty glazed surfaces, appearing dark and murky after cleaning. Though many areas had been toned with washes of color during the 12 months that it took to clean the relief, the final process of retouching required more than three weeks to complete.

Some areas of prior fill that stood proud of the surface were mechanically reduced and resurfaced using scalpel blades. Some small losses along joins, such as those on the figures' hands, were filled and leveled using Modostuc or Flügger spackle.

Several more speculative fills were deemed necessary for the aesthetic reintegration of damage and loss. Removal of overpaint on the proper right arm of Eve revealed a broken ridge of terracotta outlined in dark-purple glaze with traces of yellow glaze along the edges. Close inspection suggested that the ridge was evidence of an additional lock of hair that had originally been glazed to the arm but was later damaged and lost. In its cleaned state, the arm appeared disfigured, if not outright necrotic. Dr. Spicer therefore agreed to recreating a lock of hair, which, while speculative, would conform as closely as possible to the physical evidence of the location and position of the lost original. To do so, a thick double layer of Japanese tissue impregnated with Paraloid B-72 was cut to shape and adhered with acetone over the ridge on the arm to serve as a release layer. Milliput fine white epoxy putty was then molded by hand in situ, taking care to restrict the form only to the Japanese tissue release layer. After setting, the epoxy locks were painted with Golden Fluid Acrylic paints.

At the end of treatment, photographic and diagrammatic documentation were performed overall and in detail. While it has not yet been possible to capture an after-treatment 3D scan, this remains a possibility.

6. CONCLUSION

The initial plans for examination, documentation, and limited treatment evolved to encompass the previously underappreciated complexity of this object. Ultimately, the treatment—aesthetic compensation in particular—was considerably more difficult and time-consuming than expected. Furthermore, though scientific analysis and provenance research were beyond the scope of the original plan, they proved essential to understanding the complex physical state revealed during treatment (fig. 4). Thus, while I was tempted to conceive of this treatment as a linear process with clearly defined steps and

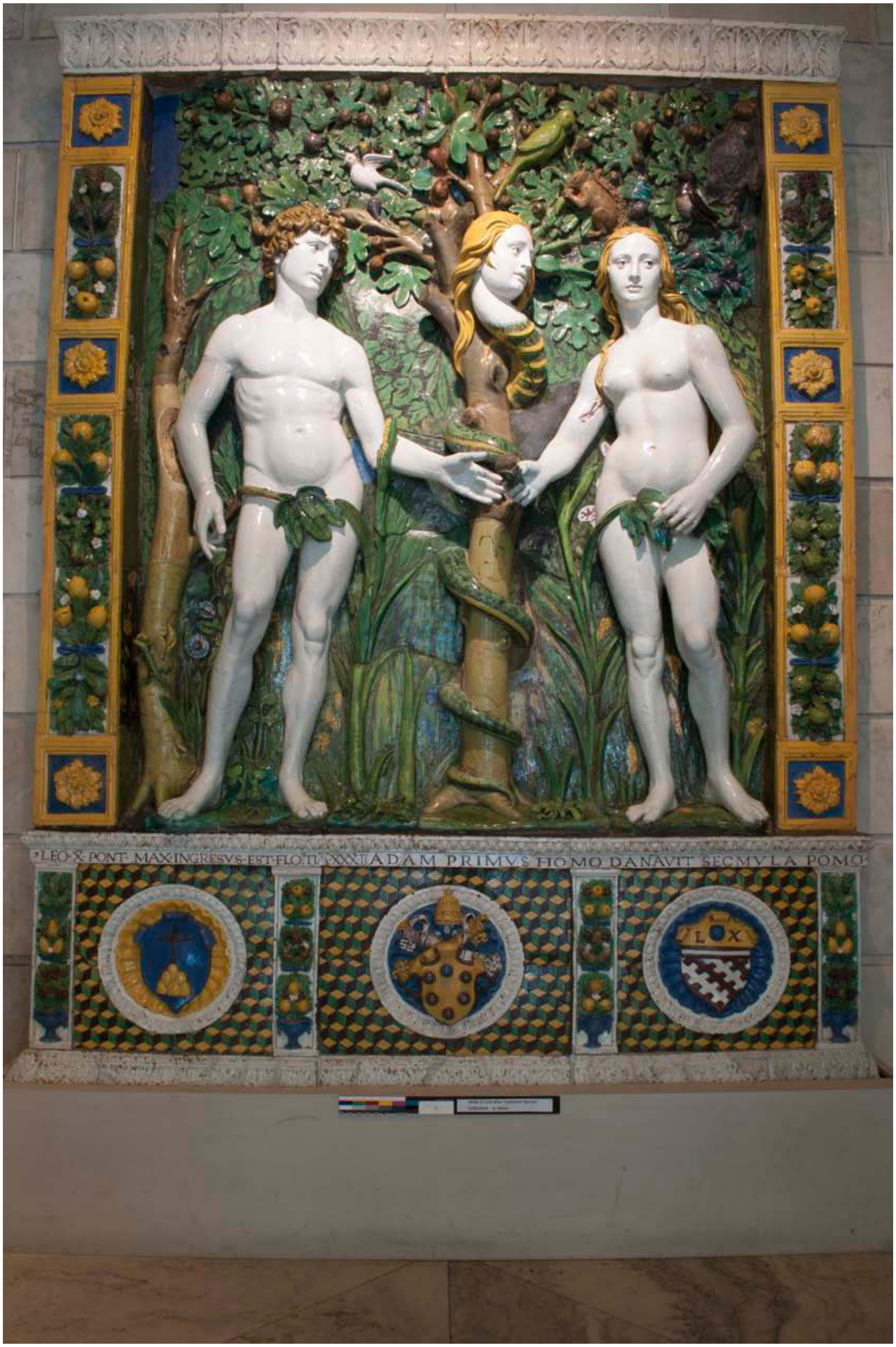

Fig. 4. After treatment. After completing cleaning, filling, and inpainting, gallery lighting was adjusted to better show the figures' forms.

goals, it proved to be a recursive exercise, requiring a multi-pronged, collaborative approach to achieve negotiated outcomes.

As a result of this process, the *Adam and Eve* relief is more structurally stable and cleaner, with improved documentation. More of the glazed terracotta surfaces are now visible, and the multi-layered history and physical state of the object are better understood. Much work remains, however, to discover the origins of the object and attribute the 19th century restoration to a particular workshop. As with any conservation treatment, this process has revealed more questions—and a greater multiplicity of prior states—than could have been anticipated.

ACKNOWLEDGMENTS

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REFERENCES

The Art Journal: The Illustrated Catalogue of the Industry of All Nations. 1871. London: Virtue & Co. Vol. 18 (Jan., 1871). 17.

Bailey, Gregory. 2018. "The Nineteenth-Century Reconstruction of Giovanni Della Robbia's Adam and Eve." *Journal of the Walters Art Museum* 73: 70–76.

Bourgeois, Brigitte. 2003. "'Secure for Eternity': Assembly Techniques for Large Statuary in the Sixteenth to Nineteenth Century." In *History of Restoration of Ancient Stone Sculptures*, edited by Janet B. Grossman, Jerry Podany, and Marion True. Los Angeles: Getty Publications. 149–162.

Carradori, Francesco. 1802. Istruzione elementare per gli studiosi della scultura. Florence. 27–30.

Craft, M. 2003. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Craft, M. 2001. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Gentilini, Giancarlo. 2012. *A Parigi "in un carico di vino": Furti di Robbiane nel Valdarno.* Città di Figline Valdarno: Assessorato all Cultura.

Gentilini, Giancarlo. 1992. *I Della Robbia: La Scultura Invetriata nel Rinascimento.* Florence: Cantini & Co.

Hornig-Sutter, Monika. 1984. "Meißener Porzellane des 18. Jahrhunderts im Visier von Kuntgeschichte und Naturwissenschaft. Teil I." *Welkunst* 54 (23): 3654–3658.

Le Bulletin de L'Art. 1902. Chronique des ventes: Collections de Mme. Lelong, Premiere vente. Paris. No. 158. Dec. 13.

Lelong, C. 1902. *Catalogue de objets d'art de haute curiosité de l'antiquité, du moyen-age, et de la renaissance, etc.* Paris: Galerie Georges Petit.

Lepeltier, C., and L. Labbe. 2011. "Etude du retable de l'Ascension d'Andre et Giovanni della Robbia." In *Della Robbia, dieci anni di studi*, edited by A. Bouquillon, M. Bormand, and A. Zucchiatti. Genoa, Italy: Sagep Editori. 90–95.

Marquand, Allan. 1928. *The Brothers of Giovanni Della Robbia.* Princeton, NJ: Princeton University Press.

Marquand, Allan. 1920. *Giovanni Della Robbia.* Princeton, NJ: Princeton University Press.

Marquand, Allan. 1912. *Della Robbias in America.* Princeton, NJ: Princeton University Press.

Marquand, A. 1911. "A Memorial of the Entry of Leo X into Florence." *The Burlington Magazine for Connoisseurs.* 20 (103): 36–38.

Michael, P. 1960. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Michael, P. 1959. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Packard, E. 1958. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Piccolpasso, Cipriano [1548] 1980. *I Tre Libri dell'Arte del Vasaio.* Translated by Ronald W. Lightbown and Alan Caiger-Smith. London: Scholar Press.

Snow, C. 1988. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Strahan, D. 1998. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Victoria & Albert Archives. MA/3/35 RP/1870/49059. Technical report on the object written by Matthew Digby Wyatt.

Victoria & Albert Archives. RP/1870/48677 1870/12/20. Note on correspondence of "Ferrario, C. enqs. respecting Mr. Cappelli's Della Robbia & calls attention to some objects in his possession."

Victoria & Albert Archives. RP/1871/12407 1871/03/13. Draft of a letter written January 1, 1871.

Weisser, T., and C. Aiken. 1974. Treatment report. Walters Art Museum Conservation file for 27.219. Baltimore, MD: Walters Art Museum.

Wypyski, M. T. 2004. "Identification of 19th c. Limoges Painted Enamels in the Metropolitan Museum of Art—Characterization of Enamel Compositions." In *Proceedings of the International Colloquium on New Research on Limoges Painted Enamels*. Braunschweig, April 18–20, 2002. 123–131.

Zucchiatti, A, and A. Bouquillon. 2011. "Les Glaçures: atout maître des Della Robbia." In *Della Robbia, dieci anni di studi*, edited by A. Bouquillon, M. Bormand, and A. Zucchiatti. Genoa, Italy: Sagep Editori. 32–43.

SOURCES OF MATERIALS

Zhermack Elite HD+ Putty Soft Normal Set: a-silicone two-part dental putty.
Manufactured by Zhermack SpA
Via Bovazecchino
100 45021 Badia Polesine (RO)
Italy +39 0425 597611
web@zhermack.com
www.zhermack.com/en/

Sekishu Japanese Paper: heavy weight, machine-made kozo fiber paper
Hiromi Paper, Inc.
469 Jefferson Blvd., Suite 117
Culver City, CA 90232
310-998-0098
washi@hiromipaper.com
www.hiromipaper.com

Sodium carboxymethyl cellulose. Manufactured by Dow Chemical, www.dow.com
Available from Sigma Aldrich
800-325-3010
www.sigmaaldrich.com

Paraloid B-72: ethyl methacrylate and methyl acrylate copolymer. Manufactured by Rohm and Haas, a subsidiary of Dow Chemical, www.dow.com
Available from Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Golden Fluid Acrylics: pigments in aqueous acrylic dispersion
Manufactured by Golden Artist Colors, Inc.
188 Bell Rd.
New Berlin, NY 13411-9527
800-959-6543
help@goldenpaints.com
www.goldenpaints.com
(Available from Dick Blick at www.dickblick.com)

Modostuc: calcium carbonate spackle material bound with a polyvinyl acetate copolymer in an aqueous dispersion
Manufactured by Plasveroi S.p.A.
Via Camussone 38
Franzione Giovernenzano, Vellezzo Bellini, PV, Italy
+390 382 926895
www.plasveroi.it
(Available from Talas, www.talasonline.com)

Flügger: calcium carbonate spackle material bound with butylmethacrylate in an aqueous dispersion.
Manufactured by Flügger A/S
Islevdalvej 151
2610 Rødovre, Denmark
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(Available from Conservation Resources at www.conservationresources.com)

Milliput Superfine White: two-part epoxy putty
Manufactured by Milliput
Unit 8, The Marian
Dolgellau, Gwynedd, LL40 1UU United Kingdom
01341 422562
info@milliput.demon.co.uk
www.milliput.com

Acrysol WS-24: aqueous emulsion of acrylic copolymers
Manufactured by Rohm and Haas, a subsidiary of Dow Chemical, www.dow.com
(Available from Talas, www.talasonline.com)

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THE GAP BETWEEN ETHICS AND AESTHETICS IN ITALIAN RESTORATION: EXPERIENCES IN THE LABORATORIES OF THE OPIFICIO DELLE PIETRE DURE IN FLORENCE—DELLA ROBBIA SCULPTURE CASE STUDIES

LAURA SPERANZA AND SHIRIN AFRA

The question of the gap (the loss of materials and colors) is perhaps the most debated argument in the philosophy of restoration to this day. Although the numerous theories on filling the gap were sometimes contradictory, all are still current and applicable. How do we deal with the gap in Europe and especially in Italy? How much of it do we fill? Does the restoration have to be recognizable, should it hide the pictorial retouch, or should it stand out? Is there a common criterion that is applicable to all types of support? In other words, does ethics or aesthetics prevail? This article examines some exemplary cases of restoration of polychrome sculptures, including della Robbia works, at the restoration laboratories of the Opificio delle Pietre Dure in Florence. We analyze the discussion around the reconstruction of the gap in modeled works, including the use of three-dimensional scanning technique, and the pictorial retouching of the color gap. We also address what we call the "dual gap," that is, the presence of both the modeling gap and pictorial gap, which opens the way for a new philosophical debate between ethics and aesthetics of restoration.

1. THE OPIFICIO DELLE PIETRE DURE CERAMIC AND PLASTIC MATERIALS DEPARTMENT

The Ceramic and Plastic Materials Laboratory is part of the National Institute of Restoration and Conservation at the Opificio delle Pietre Dure (OPD). The Opificio delle Pietre Dure (literally meaning "workshop of semi-precious stones") is a public institute of the Italian Ministry for Cultural Heritage based in Florence. It is a global leader in the field of art restoration and serves as one of two Italian state conservation schools. The institute also maintains a specialist library, an archive of conservation, and a museum displaying historic examples of pietre dure inlaid semi-precious stone artifacts. A scientific laboratory conducts research and diagnostics and provides preventive conservation service (see appendix 1 for further information on the OPD). The OPD Ceramic and Plastic Materials Department has restored important artworks by Donatello, Iacopo della Quercia, Benedetto da Maiano, and Michelangelo. In recent years, we have focused our restoration and research on important glazed terracotta works related to the artists of the della Robbia family.

In this article, we will present the restoration of the first large statuary group modeled by Luca della Robbia (1399/1400–1482) representing the *Visitation*, the biblical encounter between the Virgin Mary and her cousin Elizabeth, before the births of Jesus and John the Baptist (fig. 1).

Additionally, we will discuss the restoration of the 10 *Putti* by Andrea della Robbia (1435–1525; fig. 2), located on the façade of the Ospedale degli Innocenti—the Hospital of the Innocents—one of the most representative historic buildings in Florence, designed by Filippo Brunelleschi (1377–1446), who received the commission in 1419. The hospital was originally a children's orphanage and is regarded as a notable example of early Italian Renaissance architecture. The hospital, which features a nine-bay loggia facing the Piazza SS. Annunziata, was built and managed by the Arte della Seta, or Silk Guild of Florence. That guild was one of the wealthiest in the city and, like most guilds, took upon itself philanthropic duties. The façade is made up of nine semi-circular arches, upon whose spandrels are glazed blue terracotta roundels by Andrea della Robbia. They feature reliefs of babies, hinting at the function of the building.

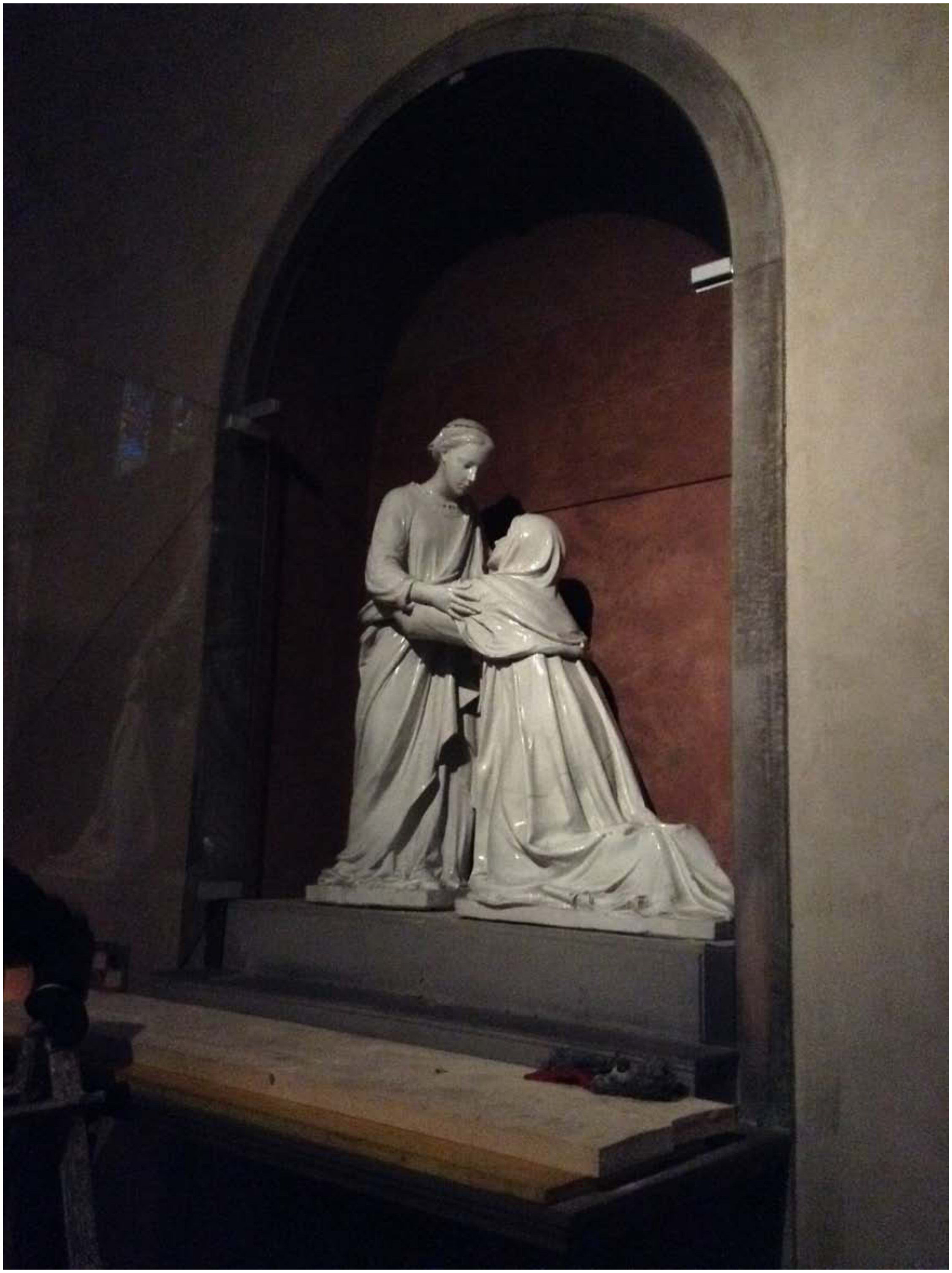

Fig. 1. Luca della Robbia, *Visitation,* 1445, glazed terracotta. Church of Saint Giovanni Fuorcivitas, Pistoia (Courtesy of Opificio delle Pietre Dure)

Both works gave us the opportunity to experiment with and deepen our knowledge of new conservation solutions, especially the use of static stabilization systems, three-dimensional (3D) technology, and carbon fiber wall anchoring systems. The restoration has been divided into several different phases, but

Fig. 2. Andrea della Robbia, *Putti,* 1487, Ospedale degli Innocenti, Piazza SS. Annunziata, Florence (Courtesy of Opificio delle Pietre Dure)

this article will discuss how we tackled and solved both the aesthetic and technical aspects associated with the gaps in glazed terracotta works located outdoors. It will also touch on the concomitant issues related to exposure to atmospheric agents, stress caused by temperature changes, condensation, and pollution present in both air and rain water.

2. DELLA ROBBIA SCULPTURE CASE STUDIES

2.1 The *Visitation* of Luca della Robbia, 1445, Church of San Giovanni Fuorcivitas, Pistoia, Italy

2.1.1 History and Description

The sculptural group representing the *Visitation* is the earliest surviving freestanding statuary work in glazed terracotta by Luca della Robbia (figs. 1, 3). It consists of two large figures, each made in two sections, modeled for the altar of the Confraternity of Saint Elizabeth toward the end of 1445. The Virgin, represented as a simple and very beautiful girl, reaches out toward the elderly Elizabeth with care and affection while their gazes mutually transmit an intense humanity.

The sculpture is entirely glazed, even on its nonvisible side, though the details there are defined to a lesser extent (fig. 4). With this work of art we can affirm that a new chapter in art history is starting—the chapter of glazed sculpture.

Fig. 3. *Visitation* after the restoration, front side (Courtesy of Opificio delle Pietre Dure)

The group was fired in two sequential steps: the bisque firing, which transforms the clay into a ceramic body, and then a second firing, after the application of the glaze, at a temperature near 900°C (fig. 5).

The sculptures are hollow and were created in sections in order to allow firing in furnaces with limited dimensions, but also for easier handling and transportation. The four sections interlock perfectly thanks to connecting joints between the parts, which are concealed under the folds of the draperies. The arms of the two figures are incorporated within the body of the other figure (figs. 6, 7). The gap between the two figures is concealed by a slight widening of the outer folds of the draperies. In this way, the edges of one figure are incorporated within the contours of the other figure.

Despite being hollow, it was always possible that the sculpture could crack in the first phase of firing. The wood-fired kilns did not distribute heat evenly. The *Visitation* is the first large-scale sculptural work of the della Robbia workshop. Thus, there are technological mistakes, such as firing cracks, that would become gradually less frequent in their subsequent artworks until they disappear altogether. In this specific case,

Fig. 4. *Visitation* after the restoration, back side (Courtesy of Opificio delle Pietre Dure)

there were numerous microfractures and some major fractures, especially in the lower parts of the two figures, that went on to cause further breakages.

2.1.2 Previous Repairs and Interventions

Due to early technological problems in firing such large-scale works, microfractures and large-scale breaks have necessitated that the work be restored several times over the last centuries. The largest fractures were filled by Luca himself: the stannic lead enamel used for the glaze was used as an "adhesive" to repair the fractures caused by the first firing, and some small terracotta wedges were also inserted inside the fractures to fill the losses. It is a kind of "proto-restoration." At a temperature of about 880°C, during the vitrification process of the surface, the glaze created a rigid adhesive in all of those breakages and fractures (fig. 8).

Fig. 5. *Visitation* after it arrived at the Laboratory of the Opificio (Courtesy of Opificio delle Pietre Dure)

Inside the artwork there is, however, another purplish glaze. Analysis revealed that this glaze contains manganese and traces of an organic material. It is thought that during the second firing, other fissures opened. Thus, a manganese glaze—being much tougher, more resistant, and more hard-wearing than a tin glaze—was applied along with organic components used to further reinforce the enamel. Then, the sculpture was fired a third time, again inserting the same kind of terracotta wedges inside the fractures.

In addition to these original "restorations," a thick layer of colored gypsum plaster reinforced with straw was found inside the sculptures, whose function was to keep all of the fragments joined together. Over this first layer of gypsum plaster, there is a second, more recent coating, which does not contain any straw. This second coat of plaster was colored red and ochre to imitate the terracotta.

This sculptural group underwent a very quick restoration before being displayed in the exhibition *Una scuola per Piero* (A School for Piero), held at the Uffizi Gallery beginning in September 1992, on the occasion of the celebrations for the fifth centenary of the death of Piero della Francesca. The intervention was realized at the Opificio by Beatrice Angeli, who wrote a conservation report: basically, the glazed surface was cleaned with a neutral nonionic surfactant, a solution of acetone and alcohol and poultices of ammonium carbonate. After reducing and resurfacing the old altered fills with Polyfilla Fine Surface, a stucco made of cellulose fibers, plaster, and acrylic gouache colors was added to match the original glaze. The artwork was, in fact, very soiled, with evident glue lines along the fractures. The lines had been filled but had also discolored noticeably and, in the lower part of the figure of Saint Elizabeth, many alterations of the old fills were present (fig. 9).

Fig. 6. *Visitation*: The upper section of Mary during the restoration (Courtesy of Opificio delle Pietre Dure)

Fig. 7. *Visitation*: Detail of the bust of Saint Elizabeth (Courtesy of Opificio delle Pietre Dure)

In preparation for celebratory events related to Pistoia being named capital of culture in 2017, a new restoration of the artwork was begun, assisted in large part by funding received from the Museum of Fine Arts, Boston (fig. 10). In this new intervention, the Opificio revisited the restoration of 1992, which had altered considerably, and realized new procedures aiming to improve the artwork's stability and its aesthetic appearance. Our intervention foresaw new fills that are less visible and certainly more long-lasting thanks to the use of watercolors instead of gouache and a 3D consolidation system.

Fig. 8. *Visitation*: Small terracotta wedges inserted inside the firing fractures (Courtesy of Opificio delle Pietre Dure)

Fig. 9. *Visitation*: The lower section of Saint Elizabeth before the 1992 restoration (Courtesy of Opificio delle Pietre Dure)

2.1.3 Examination and Condition

The sculpture comes from the church of San Giovanni Fuorcivitas in Pistoia, where it is housed inside a niche and protected by a thick glass (see fig. 1). The microclimatic conditions, lack of air recirculation, and water condensation caused the formation of superficial molds, deposited on the layer of dust on the white glaze. The sculpture has shifted several times over the centuries and has undergone disassembly interventions that, coupled with tensions due to the original fractures, have compromised its integrity, causing further fractures and microfractures. Probably due to incorrect handling, the back of the legs of Saint Elizabeth broke and fragments were lost. The robe that falls to the floor near her feet has been modeled *ex novo* in a recent restoration. Even other unaffected small portions of the Virgin Mary were remodeled. Under ultraviolet radiation, all of these old material additions are clearly visible as well as widespread cracking that is most prominent in areas of higher tension, that is, between the legs and the busts, especially on the back of Elizabeth. Here, a "spider web" of fractures radiates vertically and

Fig. 10. Dismantled *Visitation* at the OPD Laboratory with the Boston colleagues (Courtesy of Opificio delle Pietre Dure)

horizontally (fig. 11). Due to the presence of reinforcing gypsum, the cohesion between the parts is still effective except for a weakness along the upper edges of the two large pieces of the legs.

2.1.4 Restoration

The restoration work was organized into different stages: cleaning, consolidation, filling, retouching, and static adjustment.

The first cleaning phase included the microsuction of overall dirt and dusting with soft brushes. The glazed surface was cleaned with a mixture of ethyl alcohol and water, using natural sponges and cotton wool.

After the cleaning, the old integrations were removed, but the red-painted gypsum plaster fills inside the sculptures were almost completely maintained for structural purposes and cleaned with water. However, enough of the upper part of the red-painted gypsum plaster near the edge was partially removed to allow for the injection of consolidating resins in the open faulty fractures. The glaze and the craquelure were consolidated with a fluoroelastomer resin (Fluoline CP[1]) applied with a brush. The fractures that seriously compromised the solidity of the sculptures were consolidated by injecting a two-component epoxy resin at 50% in ethyl alcohol (Uhu-Plus). The gypsum plaster inside the sculptures was also consolidated, using an acrylic resin (Acril 33)[2] at 10% in water. Plasticine and a latex film were used to avoid resin leakage, thus preventing irreversible marks on the terracotta surface. All gaps and losses were filled and shaped

Fig. 11. *Visitation*: Comparison under visible light and UV radiation (Courtesy of Opificio delle Pietre Dure)

with a white acrylic filler, which guarantees a safe and easy reversibility and resists humidity, and then smoothed with sandpaper, taking great care not to touch the surrounding glazed areas (figs. 12, 13). The firing defects were not filled, as is the normal practice of the methodology adopted at the Opificio (see figs. 3, 4).

The retouching on the integrations was carried out with small color dots, using the pointillism technique in watercolor (fig. 14).

2.1.5 Laser Scanning and 3D Printing for Documentation and Assembly Solutions

Three-dimensional digital technologies played an important role in the restoration process of the *Visitation* sculpture of Luca della Robbia: first, as a means of documenting the work and second, for the creation of a 3D-printed cushion used to protect the parts of the sculpture from damage when reassembled.

The terracotta sculpture was scanned with a 3D scanner belonging to the Opificio delle Pietre Dure. A full survey of both outer and inner surfaces was obtained in order to create a complete set of documentation that would complement the photographic records. The della Robbia sculpture was scanned with a Structured Light handheld 3D scanner; the texture was also acquired. The acquisition has a maximum precision of 0.5 mm. The data are collected as OBJ and STL files, useful for studying and planning the restoration intervention, and serve as complete documentation of the conservation conditions before the restoration. The 3D files allowed for the measurement of the various parts and the evaluation of the new assembly system.

Originally, the *Visitation* was assembled with a layer of plaster between the upper and lower sections (busts and legs). Over the centuries, this thick layer was gradually removed and not replaced. By the time of our restoration, the pieces of terracotta were in direct contact along only limited areas, increasing the risk of damaging the fired clay and glaze due to impact and friction. There was another important risk

Fig. 12. *Visitation*: Mary's foot, before and after the restoration (Courtesy of Opificio delle Pietre Dure)

Fig. 13. *Visitation*: Detail of the arms, before and after the restoration (Courtesy of Opificio delle Pietre Dure)

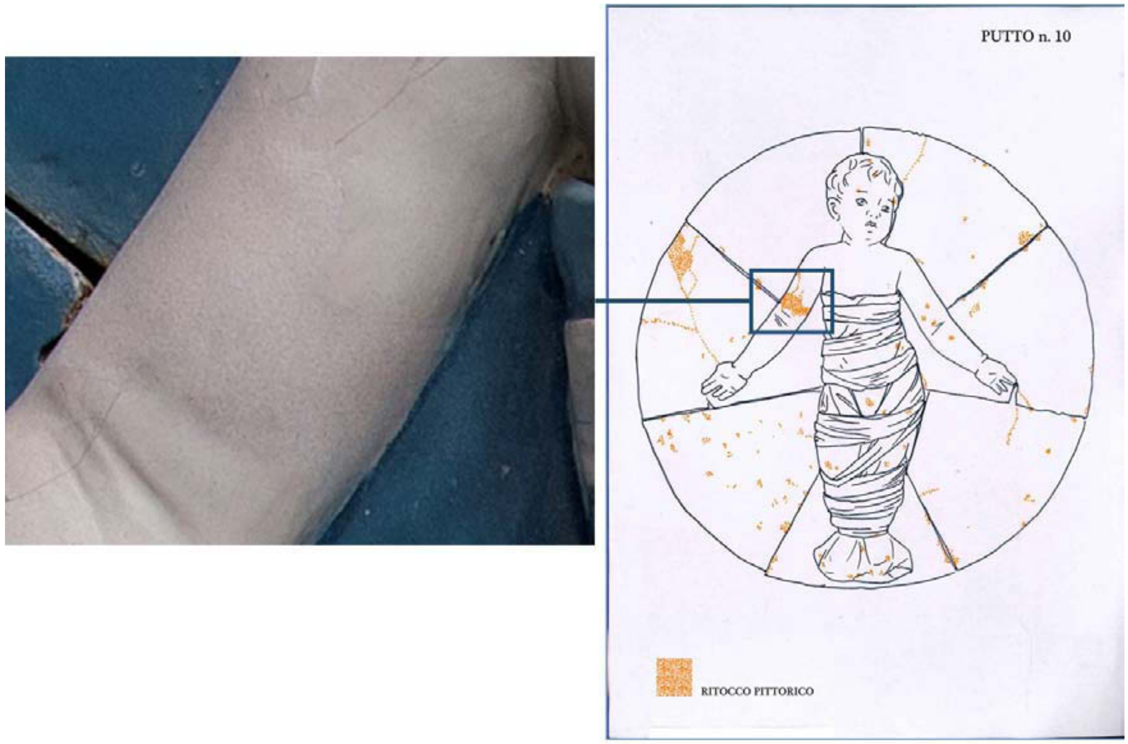

Fig. 14. *Putto* number 10's pictorial retouching (Courtesy of Opificio delle Pietre Dure)

factor to consider in the sculpture's preservation: the contact points between the border sections were few and of a smaller size than those required for stable conditions—only a half dozen points in the statue of Saint Elizabeth and even fewer in the figure of the Virgin Mary. The weight of the busts (more than 45 lbs./20 kg each) creates an excess of pressure above these reduced contact points on the lower parts of the sculpture. Furthermore, the fragility is increased by the breakages and fractures in the legs: the busts' weight is a real factor of risk for the structural integrity of the statue as a whole.

In order to ensure the correct weight distribution of the busts, we created a resin gasket that bridges all of the gaps between the contact surfaces. Possible available solutions were either a protective silicone layer or a printed "cushion" made of resin. The first option is commonly used by the Opificio but requires rapid moving and handling of the sculpture's parts, as silicone curing times are relatively quick. The second option is based on an important currently available resource, 3D printing technology, which allows multiple solutions in the field of restoration. We therefore decided to create an inner gasket with this second method, a solution that allowed for reduced handling of the original pieces compared with the creation of a protective silicone layer.

The procedure of arriving at the new assembly method was carried out in various steps. The first step started with scanning each separate section: the interior of the two sections of the Virgin Mary and the two of Saint Elizabeth were also scanned to obtain an adequate survey of the matching contact profiles (fig. 15). The second step consisted of scanning the surface of the exteriors of both assembled figures. The scanned area was limited to the surface surrounding the joins. Thanks to these scans, we obtained a precise 3D file that stores the correct position and orientation of the upper pieces above the lower ones.

The next step was the modeling of a new protective inner gasket (or "cushion") with 3D editing software. The scans were edited and virtually oriented: a minimum distance of 0.08 in./2 mm was created between

Fig. 15. The real-time 3D scanning of *Visitation* (Courtesy of Opificio delle Pietre Dure)

the contact areas. The empty space between the lower edge of the busts and the upper edge of the legs was filled virtually with a new volumetric shape—a fill perfectly matching the contours of the join.

The final step was to make this new fill real. By means of a stereolithographic 3D printer, we prototyped the cushion. The printer cures a photosensitive resin (a mixture of methacrylated monomers and oligomers plus photoinitiators) and converts the virtual 3D mesh into a real, solid and durable resin piece.

A brief explanation of the stereolithography process that we used can help to better understand the technique. A liquid resin is placed into a Plexiglas tank with a transparent bottom; then, a building plane is mounted on a vertical motorized axis and starts its path from inside the tank and slides slowly out of it. Meanwhile, a system of mirrors orients and moves a UV spotlight generated by a laser (405 nm). The resin is cured sequentially layer after layer and comes out of the tank, attached to the build plate. The printing software generates supports and structures automatically to build the pieces correctly. These supports can be easily removed by the users at the end of the printing process. The uncured liquid resin is removed from the sheath by means of baths of isopropyl alcohol and is then post-cured under UV light in order to increase its full structural properties.

The chosen resin has the following values, suitable for our purposes: tensile strength 9380 psi/65 MPa, Young's modulus 402 ksi/2.8 GPa, flexural modulus 320 ksi/2.2 GPa, notched IZOD impact strength 0.46 ft.–lbf/in./25 J/m. These values ensure that the 3D print has the properties necessary to perform the necessary functions: to hold and distribute the weight of the busts and to protect the terracotta from impacts and self-collisions (fig. 16).

Fig. 16. *Visitation*: The 3D-printed cushion placed above the lower section of Saint Elizabeth (Courtesy of Opificio delle Pietre Dure)

The resin gasket fills the gaps along the entire join so that there are no longer just a few contact points, but rather all the weight is continuously and evenly distributed. Its custom shape keeps the pieces in place and avoids unwanted movements or rotations of the busts. The resin's hardness is less than that of the terracotta; thus, if an accident should happen, this layer is sacrificial, saving the sculpture's border without stressing the glazed surface.

We used a white resin, as it has a suitable visual impact within the white color of the *Visitation*'s glazing. Once put in place between the parts, the cushion is barely visible.

Another advantage of this solution over that of the molded silicone layer is that if the printed cushion should ever be damaged, it will be possible to reprint it. Stereolithographic machines are becoming ubiquitous around the world at all levels of accessibility. In the event that a new cushion needs to be created, it will not need to be printed in a specific place or country: this will drastically reduce working times and simplify logistics.

2.2 The 10 *Putti* by Andrea della Robbia from the Facade of the Hospital of the Innocents in Florence

2.2.1 History and Condition

Andrea della Robbia's cycle of glazed polychrome terracotta bas reliefs depicting "putti in swaddling clothes" was commissioned by Francesco Tesori, Prior of the Hospital dedicated to Saint Mary of the Innocents, to decorate the outer loggia of the Hospital facing onto the Piazza SS. Annunziata, built according to a project by Filippo Brunelleschi. The reliefs were placed in the façade in 1487, documented on the 21st of August of that year in a transaction in which Antonio di Marco della Robbia (Andrea's brother) was paid "*per sua fatica d'aver aiutato mettere i bambini di terra ne' tondi sopra la loggia di fuori*"—for his efforts in helping to put the children from the ground into the tondos above the outer loggia—surrounded by a frame in pietra serena.[4]

The glazed medallions, each one unique, are executed partly in relief with the paleness of the flesh tones contrasting with an intense cobalt blue background. For almost 600 years, the *Putti* have stood as the symbols of the historical Florentine Institute that takes care of abandoned children. In 1845, when the loggia was extended on the two sides, four copies of the della Robbia medallions were added, realized in porcelain by the Ginori Manufactory. The four Ginori tondos were not treated as part of our restoration.

Each ceramic medallion was supported by thin metal brackets, some of which were not stable, fixed in the masonry inside the stone frames. Mortar and plaster fills in the joins between the component sections and the retaining bracket had various gaps and a weak grip on the tondos. The precarious mounting system was very different from the usual technique implemented for the glazed reliefs of the della Robbia sculptors; it seemed to be the result of a subsequent restoration, probably carried out in the post-war period. The artworks showed visible signs of degradation in both the body and the glaze.

The causes of the degradation can largely be ascribed to outdoor exposure and accidental factors over the years but also to faults related to the original manufacture of the works. Exposure to atmospheric agents induced physical degradation that increased the aperture of the cracks and exacerbated the loss of the glaze.

After the restoration, the 10 *Putti* were exhibited in the Innocenti Museum from June to December 2016 (fig. 17).

2.2.2 Restoration Intervention

In May 2016, the 10 *Putti* were removed from the hospital's facade and transported to the Restoration Workshops of the Opificio. This required the consolidation of the reliefs prior to taking them down, removing the mortar around the edges of the sections, removing both of the metal pins used to anchor the *Putti* to the wall, and disassembling the central part of the relief with the putto's body. After disassembling all of the various sections, the reliefs were packed and taken to the Opificio.

Fig. 17. *Putti* on exhibition at degli Innocenti Museum after the restoration (Courtesy of Opificio delle Pietre Dure)

The restoration work was articulated in several phases. The most complex phase dealt with the creation of a carbon fiber support that was made under vacuum pressure with seven layers of carbon tissue and epoxy resin.

Each putto was inspected under the microscope and the top layer of surface dirt was removed. The old stucco infill was removed using an ultrasonic dental scaler, the old oxidized metal pins were taken out, and the ceramic body consolidated.

The cleaning started with the use of specifically formulated gels and delicate cotton wool swabs, removing the special coating applied to protect the glazing when taking the reliefs off the façade. The back of the relief was cleaned with a pneumatic microchisel to reduce the mortar bed and any inappropriate stucco infill.

The broken fragments were glued with an epoxy resin and the gaps filled with an acrylic stucco with features suitable for outdoor exposure. We inpainted these fills using watercolor paint in a dotted, almost "pointillist" style.

In our work, we decided to use reversible materials for both consolidation and surface treatment. The fill, pigments, protective film, and varnish were subjected to accelerated aging tests in a climate chamber, reproducing solar radiation and temperature and humidity fluctuations in an outdoor environment. These tests confirmed excellent characteristics: absence of yellowing, inalterability of colors, and overall resistance.

3. A MATTER OF ETHICS AND AESTHETICS

The terracotta polychrome sculptures, just like similar ones in wood, are a particular type of artwork in which two meanings, the three-dimensional meaning and the pictorial one, coexist and help to establish an instant communication with the observer. Not by chance, these artifacts often have a religious or highly symbolic value. For this reason, for centuries, attempts have been made to maintain original polychromy on these works, contrary to what has happened to marble sculpture, whose colors and therefore meanings were often changed completely for reasons of style or moral rigor. The modern interpretation of conservation arises from the consciousness of this complementarity between volume and color. In this sense, the gap assumes a new value, which we call "double gap": material gap and pictorial loss.

In the theory of Italian restoration, starting from the 1972 "Italian Restoration Charter"—the first ministerial document attempting to regulate restoration practices from a methodological and ethical point of view—restoration theorists wanted to "allow" or "ban" certain restoration practices, placing the main focus on what was morally but also aesthetically right about a restoration intervention. The answer, which has seen its application through different styles and proposals, has always been to denounce the restorer's intervention and make it visible to the viewer.

Retouching made distinguishable from the original surface is now widely accepted in the Italian restoration of pictorial artworks. *Selective retouching*, made with thin little vertical lines of color, allows one to minimize the visually disfiguring effects of a loss and at the same time ensure that it is easily recognizable on close inspection. To achieve coherence in the method of restoring various materials, we tried to apply selective retouching to the restoration of 3D works. Sometimes this did not yield very satisfactory aesthetic results, because linear retouching tends to flatten volumes and make the loss too visible even from a distance.

In the field of ancient Greek and Roman ceramic vessels, a philological and archaeological criterion has for a long time prevailed that discourages pictorial reconstructions. Beginning in the early 1990s, the restorer Giovanna Bandini proposed and applied the *pointillist* method for the retouching of fills on archaeological artifacts (Bandini 1992). Subsequently, the Opificio adopted this method, which was then extended to the restoration of terracotta statuary, using watercolor paints to achieve the original color tones. Viewing at a certain distance returns a whole and unified image and hence its best reading, while a close inspection makes it easy to understand which parts have been added during restoration.

Various gap-filling materials have been tested at the Opificio for their ability to return the brilliance, especially to glazed surfaces. These include alkyd resins, acrylic colors, and varnish colors. In light of these experiments, watercolor is preferred today for its durability over time compared with resins and varnish colors.

In a glazed ceramics restoration, the glossy surface sheen of the glaze is suggested by the materials used to protect the watercolor retouching. Initially, an epoxy resin used in glass restoration, Hxtal NYL-1, was tested for its very liquid consistency, which can be applied by brush or spraying. In the recent restoration of Andrea della Robbia's *Putti*, we produced many mockups of various materials, which then underwent accelerated aging. It was seen that the epoxy resin used in glass restoration has the serious drawback of being sensitive to UV radiation. Such a disadvantage in the restoration of glass windows can be avoided by the use of protective glass that shields the UV rays, but we decided to avoid its use for terracotta-glazed statuary that would be located outdoors. Following these tests and research, we opted for watercolor retouching with the application of Regalrez 1126,[3] a glossy, protective, anti-UV coating, in white spirits.

For the integration of cobalt blue, the pictorial retouching was made with cerulean blue, ultramarine blue, yellow, brown, and ochre dots. For the integration of white glaze, the retouching was made with carminium, primary yellow, cerulean blue, brown, cobalt blue, and burnt siena. At a certain distance, the many dots blend together and are visually well connected with the white of the della Robbia glaze, while a closer look will reveal areas of retouching.

In the restoration of polychrome wooden sculpture, the coexistence between *selezione cromatica* (chromatic selection) and pointillist retouching has been researched to overcome the risk of an ambiguity in the reading of the artifact: with the traditional chromatic selection, the viewer can recognize a loss of paint layers, while the dotted retouching indicates a loss of both volume and paint layers. In the field of restoration of glazed terracotta, in which the polychrome surface is not painted but rather fired with clay, we think it is fair to interpret the lack of glaze as a double loss. Therefore, we opted for a dotted retouching, harmonizing the retouching with the original surface and applying a finishing glossy varnish that also has the characteristic of protecting the watercolor paints from UV rays and aging.

This debate is still open, and the department continues to experiment with materials and methods, orienting its research toward natural and mineral materials that will be the subject of future publications.

ACKNOWLEDGMENTS

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Visitation Restoration Credits:

OPD Superintendent: Marco Ciatti
Director and Coordinator of the Restoration—Ceramic and Plastic Materials Department
Conservation: Laura Speranza
Restorers: Shirin Afra, Mattia Mercante, Filippo Tattini
Diagnostic Investigations: Monica Galeotti
Photography Campaign: Marco Brancatelli and the Restorers

Ospedale degli Innocenti – *Putti* Restoration Credits

OPD Superintendent: Marco Ciatti
Director and Coordinator of the Restoration—Ceramic and Plastic Materials Department
Conservation: Laura Speranza
Technical Direction: Rosanna Moradei, Stefania Agnoletti
Restorers: Shirin Afra, Daniele Angellotto, Maria Grazia Cordua, Chiara Gabbriellini, Chiara Fornari, Francesca Rossi, Filippo Tattini
Diagnostics, OPD Scientific Laboratories, Chemical Analyses: Monica Galeotti
Photography Campaign: Antonio Quattrone and the Restorers
Digital 3D Scanning: Mattia Mercante

APPENDIX 1: The Opificio delle Pietre Dure: A Brief History and Current Conservation Activities

The Opificio delle Pietre Dure is an autonomous institute of the Ministry of Cultural Heritage and Activities and Tourism, specializing in conservation, research, and education concerning cultural heritage. It began as a national agency in 1975 when two Florentine institutions active in the fields of artistic production and conservation of works of art were merged. These were the historic and renowned Opificio delle Pietre Dure, founded in 1588 as a grand-ducal workshop and transformed into a restoration center toward the end of the 19th century, and the Laboratori di Restauro (restoration laboratories), created in 1932 as part of the Florentine Soprintendenza and greatly expanded after the 1966 flood.

THE MODERN OPIFICIO

The reinvigorated Opificio had authority throughout Italy and, since 2007, it has been recognized as an essentially autonomous institute of the Ministry, under the General Secretariat.

Today, the Opificio extends its research and conservation across many fields, divided into 11 departments: Bronzes and Ancient Weapons, Ceramic and Plastic Materials, Stone Materials, Mosaics and Semi-Precious Stone Artifacts, Goldsmithery, Canvas and Panel Paintings, Paper and Parchment, Polychrome Wooden Sculpture, Mural Paintings, Tapestries, Textiles, and Laboratories and Archaeological Artefact Services. It also has a scientific research laboratory subdivided into competence fields: chemistry, physics, biology, geology, climatology, and preventive conservation, in addition to other offices and general services.

The Opificio employs 89 individuals, among these: art historians, conservator-restorers, conservation scientists, laboratory technicians, and administrative and auxiliary personnel. Its activities take place in three different sites in Florence as well as beyond Italian borders, both contributing directly to conservation projects and consulting for technical and scientific problems. The OPD also has a School of Higher Education and Research that offers a five-year education program leading to the equivalent of a master's degree as well as 13 international professional development and 15 internship courses. The overall aim is to provide knowledge and competencies concerning all aspects of conservation for the different cultural heritage materials and their related artistic techniques. The Opificio carries out research collaborations on cultural heritage, especially in the fields of technical art history and the study of conservation materials. Institutional partners include national and international public entities, universities, and research institutes. In some instances, these collaborations have resulted in the stipulation of conventions establishing common lines of research.

For more than 20 years, the Opificio has published its annual journal, *OPD Restauro*, dealing with technical, scientific, analytical, theoretical, and historical aspects of conservation, availing itself of contributions by specialists and external institutions. Additionally, complex, high-profile conservation treatments are often presented in monographs, such as those in the series entitled *Problemi di conservazione e restauro*.

CONSERVATION SCIENCE: ANALYSIS AND RESEARCH

Conservation science and, in general, the application of scientific disciplines to the conservation of cultural heritage represent an important and well-established part of the Opificio. The scientific laboratories provide assistance to the conservators while at the same time carrying out research in the fields of technical art history and conservation science for cultural heritage. They also are responsible for science education and training in the Scuola di Alta Formazione (Higher Education School). These laboratories have been active for many years, and they constitute an important authority in conservation science for conservator-restorers, scientists, art historians, architects, and archaeologists at both national and European levels.

The two departments working in diagnostics, analysis, and research are the Laboratorio Scientifico (Conservation Science Department) and Climatologia e Conservazione Preventiva (Environmental Management and Preventive Conservation Department).

SCHOOL OF HIGHER EDUCATION AND RESEARCH: THE OPIFICIO'S ACADEMIC PROGRAM

The school at the Opificio began teaching conservation in 1978, becoming a School of Higher Education and Research in 1992. Acceptance to the school is contingent on a rigorous and competitive entrance examination, also open to international candidates, publicized each year by the Ministry of Culture. The five-year program offers five specialized curricula for professional formation. Courses include theoretical lessons taught by both internal staff and other specialists involved in research, preservation, and conservation of works of art. Nonetheless, the emphasis is on practical and applied conservation problems, with hands-on experience offered both within the Opificio's laboratories and on external worksites. As of 2006, the diploma issued by the Opificio is equivalent to a master's degree (a five-year university degree).

NOTES

1. Fluoline CP is a ready-to-use consolidant/protective product based on fluoroelastomers and acrylic polymers in acetone, which is reversible and resistant to UV rays. It can be used for the consolidation and protection of architectural elements without changing their chromatism.

   Physical and chemical properties

   - Appearance: Colorless, transparent liquid
   - Drying time: Approximately 10 hours (at 23°C)
   - Specific gravity: 0.86 ± 0.03 kg/l (ASTM D 792)

2. A 100% pure acrylic resin in aqueous dispersion characterized by excellent resistance to atmospheric agents and chemical stability. Thanks to its high alkali resistance, Acril 33 is particularly suited for applications with hydraulic binders (hydrate-hydraulic limes, cement, plaster). It is a resin used in the restoration field as an additive for injection and filling mortars, a binder for pigments, glazes, and whitewashes, an adhesive, and a consolidant and fixative of paint layers.

   Properties and characteristics

   - Excellent freeze-thaw stability
   - Good pH stability
   - Excellent binding power
   - High resistance to yellowing

Physical and chemical properties

- Appearance: White, milky liquid
- Solids content: 46 ± 1%
- Viscosity: 3750 mPas at 20°C
- pH: 9.5

3. Regalrez 1126 is an aliphatic resin of low molecular weight, characterized by high resistance to aging and optical properties that are comparable to those of natural resins. It is ideally used as a bland consolidant for wood artifacts. A solution with low viscosity and high penetration can be obtained by dissolving in solvent amounts ranging from 10% to 20% of resin by weight. Regalrez 1126 is soluble in medium- and low-polarity solvents (white spirit, petroleum essential oil, butyl acetate); it is insoluble in water and polar solvents.

   Physical and chemical properties

   - Appearance: Colorless flakes
   - Density at 21°C: 0.97 kg/l
   - Glass transition temperature (Tg): 65°C
   - Softening point: 122°C–130°C

4. Pietra serena is a gray sandstone used extensively in Renaissance Florence for architectural details. The material obtained at Fiesole is considered the best and it is also quarried at Arezzo, Cortona, and Volterra. Examples of its use in Florence include the interior pilasters, entablatures, and other decorative elements of Brunelleschi's Pazzi Chapel and Michelangelo's Medici Chapel.

REFERENCE

Bandini, G. 1992. "Forma e immagine, ossia considerazioni sul problema delle lacune nelle ceramiche." In *Faenza*, vol. LXXVIII, n.3-4. 223–230.

FURTHER READING

Bandini, G. 2002. "Forma e immagine, ossia ulteriori considerazioni sul problema delle lacune nelle ceramiche." In *OPD Restauro,* vol. 14.108–120.

Speranza, Laura, Shirin Afra, M. Mercante, and F. Tattini. 2017. "Luca della Robbia's Visitation and its restoration." In *La Visitazione, Luca della Robbia*, ed. Giorgio Tesi Editore, Pistoia. 77–101.

Speranza, Laura. 2016. I dieci *Putti in fasce* di Andrea della Robbia nel loggiato dell'Ospedale degli Innocenti a Firenze. Anticipazioni sul restauro. In *OPD Restauro*, 28. Ed. Centro Di, Firenze. 15–40.

Vaccari, M. G. 1998. "Tecniche e metodi di lavorazione." In *I della Robbia e l'arte nuova della scultura invetriata, a cura di G. gentilini,* ed. Giunti, Firenze. 97–116.

SOURCES OF MATERIALS

Fluoline CP, Acril 33, and Regalrez 1126
CTS Srl (https://www.ctseurope.com/en/index.php)

Uhu-Plus
UHU BOSTIK SpA

LAURA SPERANZA graduated in Art History with Roberto Salvini at the University of Florence, where she also obtained a specialization in Medieval and Modern Art History. Winner of the public competition at the Ministry of Cultural Heritage, she held the role of Art Historian Inspector to the Superintendence of Arezzo where, for 10 years, she curated exhibitions, museum installations, and publications and directed two State Museums: Casa Vasari in Arezzo and Palazzo Taglieschi in Anghiari. She has collaborated in the restoration of wall paintings with the Legend of the True Cross by Piero della Francesca, the Cross painted by Cimabue in the Church of San Domenico, and the stained-glass windows by Guillaume de Marcillat in Arezzo. She moved in 2000 to the Opificio delle Pietre Dure in Florence and currently directs the Restoration Department of Ceramic, Plastic and Glass Materials and the Restoration Department of Bronze and Ancient Weapons. She co-directs the Magazine of the Opificio delle Pietre Dure and Restoration Laboratories of Florence, and she is a member of the editorial board of the same magazine. She is involved in publications and conferences, especially on the theme of conservation. Other important work she has performed on glazed terracotta pieces are the 10 *Putti* in swaddling clothes by Andrea della Robbia in the Ospedale degli Innocenti of Florence and the *Visitation* by Luca della Robbia in the San Giovanni Fuorcivitas church in Pistoia.

SHIRIN AFRA is a restorer of ceramics and terracotta sculptures, objects, glass, and stained glass. She graduated from the School of Higher Education and Research of the Opificio Delle Pietre Dure in Florence, the National Institute of the Italian Ministry of Cultural Heritage, responsible for conservation, research and education concerning cultural properties. She is currently working toward a permanent position as Senior Restorer-Conservator of the Ceramics, Objects and Glass Conservation Department of the Opificio delle Pietre Dure and is also involved in teaching OPD School of Higher Education and Research students. The most significant recent professional work she has performed on glazed terracotta pieces includes the restoration of the 10 *Putti* in swaddling clothes by Andrea della Robbia in the Ospedale degli Innocenti of Florence and the restoration of the *Visitation* by Luca della Robbia in the San Giovanni Fuorcivitas church in Pistoia.

THE TREATMENT OF TWO TERRACOTTA ARCHITECTURAL RELIEFS BY ANDREA DELLA ROBBIA AT THE METROPOLITAN MUSEUM OF ART

CAROLYN RICCARDELLI AND WENDY WALKER

The Metropolitan Museum of Art has among its extensive collection of Renaissance-period glazed terracotta sculpture two masterpieces by Andrea della Robbia that have recently undergone major conservation treatment. The *Saint Michael the Archangel* lunette, which sustained extensive damage after a tragic fall in 2008, returned to The Met's galleries in 2015 after years of meticulous reconstruction, filling, and inpainting of losses. While daunting, the treatment of the damaged lunette was relatively straightforward, and culminated in the creation of an elegant mounting system designed to secure each of the sculpture's original 12 interlocking sections independently. More recently, a large tondo with a central representation of the cardinal virtue Prudence was treated in preparation for the exhibition *Della Robbia: Sculpting with Color in Renaissance Florence*, returning the piece to public view after being kept in storage for more than a generation. The massive *Prudence*, made of 15 molded and modeled sections comprising a central tondo surrounded by a colorful garland, was found to be structurally unstable in its 150-year-old mount as well as having many aesthetic issues due to previous restoration campaigns. Conservators disassembled the sections with the goal of remounting this large work in preparation for travel. Following disassembly, surfaces were cleaned, revealing a previously unknown numbering system. This discovery led to a dramatically different arrangement of the tondo's garland. To prepare *Prudence* for travel, an innovative mounting system was created using an aluminum honeycomb backing panel combined with carbon fiber clips.

KEYWORDS: Terracotta, Glaze, della Robbia, Conservation, Cleaning, Terracotta repair, Carbon fiber, Mounts, Tool marks, Gilding, Ceramics

1. INTRODUCTION

Luca della Robbia (1399/1400–1482), a Florentine sculptor working in bronze, marble, and clay, invented the technique of glazing terracotta sculpture, giving rise to an entirely new and widely valued art form. Luca trained his nephew Andrea della Robbia (1435–1523) in the secrets of the trade. Andrea, a brilliant artist and sculptor in his own right, advanced the family business to include the production of glazed terracotta sculpture for architectural use on a grand scale. In time, the business was passed to Andrea's sons, of which Giovanni and Girolamo were most notably active. The family business continued successfully until these descendants passed away, Giovanni in 1530 and Girolamo in 1566. Soon thereafter, the della Robbias' carefully guarded technological secrets were lost (Cambareri 2016).

The Metropolitan Museum of Art began acquiring its collection of della Robbia glazed terracotta sculptures in the early 20th century. Among the many magnificent pieces at The Met, *Saint Michael the Archangel* and *Prudence*, both created by Andrea della Robbia in 1475, are among some of his finest works. This paper will cover the treatment of these two sculptural reliefs, which arose for very different reasons: one following a tragic accident and the other on the occasion of an exhibition focused on della Robbia sculpture. Prior to their treatments, these two masterpieces drew little attention from the general museum visitor. The Saint Michael lunette was installed above a doorway in a gallery that many visitors consider a conduit to other areas of the museum. *Prudence* was in deep storage and had not been exhibited in more than 25 years. Whatever the story that led to their treatment, these two works have rightly regained their position as some of the finest expressions of Renaissance-period sculpture at The Metropolitan Museum of Art.

2. OVERVIEW OF DELLA ROBBIA MANUFACTURING TECHNIQUES

Saint Michael the Archangel and *Prudence* were made by Andrea della Robbia when he was 50 years old and only in the middle of his long career. Andrea was working in his uncle Luca's workshop, which was located on *Via del Guelfa* in Florence, about a 10-minute walk from the Duomo. Luca had been living and working there approximately 30 years and was already famous for his novel use of glazes to decorate terracotta sculpture (Raggio 1961). Our lunette and tondo are large, both around 155 cm (5 ft.) in diameter, and weigh 100 and 350 kg (220 and 775 lb.), respectively. They were created as architectural elements to be installed above doors or mortared into exterior walls. One of the most extraordinary features of della Robbia's glazed terracotta is its durability, even in outdoor environments; many of the della Robbia pieces found throughout Florence have been in place for over 500 years.

In order to produce large glazed sculptures such as these, many steps are required to transform raw clay into a strong ceramic body covered in fields of shiny, colored glazes so characteristic of the della Robbia workshop. In 2013, one of the authors of this paper, Wendy Walker, had the opportunity to visit a factory outside Florence that reproduces della Robbia works in the traditional manner. Daria Dolfi, Director of N. D. Dolfi, in Scandicci, Italy, gave Walker an extensive behind-the-scenes exploration of her factory. At N. D. Dolfi, as the della Robbia workshop did 500 years ago, clay is pressed by hand into plaster molds and left to dry for several hours. Then the piece is unmolded, the seam lines removed, details refined, and additional sculpting is done. The completed piece is left to dry slowly over a period of weeks. Once bone dry, the sculpture is fired in a kiln to about 1,000°C for the first of two firings. The bisqued piece is then ready to be decorated; blue and white glazes are applied by brush as separate color fields. After glazing, the piece is fired again, the second and final time (Dolfi, pers. comm.). When this technique was first developed in the 15th century, the resulting stunning blue and white glazed terracotta with a slightly uneven gloss—dimpled and satiny—made the della Robbia workshop famous, establishing a family practice that would be active for over 100 years.

3. *SAINT MICHAEL THE ARCHANGEL* LUNETTE

Saint Michael the Archangel is the leader of all angels and of God's army against evil; one of his responsibilities is to help the faithful on Judgment Day. His qualities are courage, strength, and mercy. He is depicted in our lunette with wings outstretched, a sword in his right hand. In his left hand, he holds a set of scales to weigh the virtue of souls. The *Saint Michael the Archangel* lunette is composed of 12 interlocking sections, made to be installed over the main entrance on the exterior of the church of *San Michele Arcangelo* in Faenza. The church was deconsecrated in 1798; a few decades later, the lunette passed into private collections. It was first owned by Count Pasolini dell'Onda, a nobleman from Florence. Eventually, in 1875, the lunette was acquired by German collector Heinrich Vieweg of Braunschweig. In 1930, the lunette was purchased by Myron C. Taylor of New York and, in 1960, acquired by The Met at auction (Marquand 1922; Raggio 1961).

The lunette was mounted on a heavy plywood panel with a gilded frame (fig. 1) and was installed on a ledge above a doorway in The Met's Quattrocento Gallery for 12 years. In the early hours of July 1, 2008, it fell and crashed to the floor. Through some miracle of gravity, the piece landed on its back, still contained within the wooden mount. The lunette's sections were secured by T-shaped nails, preventing them from bouncing off the mount on impact. Even so, the lunette suffered terrible damage and fragments were strewn everywhere (fig. 2). A systematic recording and retrieval system was employed; the

Fig. 1. The lunette set into a modern gilded frame, shortly after it was acquired by The Met in 1960. Andrea della Robbia (Italian, 1435–1525), *Saint Michael the Archangel*, ca. 1475, glazed terracotta, 79.1 × 157.2 cm, The Metropolitan Museum of Art, Purchase, Harris Brisbane Dick Fund, 60.127.2. (©The Metropolitan Museum of Art)

Fig. 2. The lunette as it was found in the gallery on the morning of July 1, 2008 (Courtesy of D. Stone, ©The Metropolitan Museum of Art)

area was mapped and hundreds of fragments were bagged and labeled according to where they were found. This extra precaution proved to be extremely helpful in locating where the fragments belonged once it was delivered to the conservation lab.

The old mount included heavy layers of plaster located between the plywood panel and the lunette, functioning as a sort of shim to level out the ceramic sections. While it undoubtedly helped to soften the impact, the plaster layer was completely smashed and mixed with the ceramic fragments, which ranged in size from tiny glaze flakes to large pieces, many of which were riddled with cracks. Fortunately, major elements such as the head, hands, and even the little souls remained remarkably intact.

3.1 Treatment

The conservation treatment was lengthy but relatively straightforward. The first step was to sort through the fractured plaster to find the ceramic fragments and glaze flakes. The fragments were covered in plaster dust that had infiltrated even the smallest cracks in the ceramic body. Thorough and careful vacuuming, dusting, and then surface cleaning with ethanol and deionized water were carried out before consolidating hairline cracks and sealing break edges with 10% Paraloid B-72 in acetone.

Bonding fragments was accomplished section by section using a 3:1 blend of B-72 and B-48N.[1] This adhesive mixture was researched, tested, and used successfully on Tullio Lombardo's marble sculpture *Adam*, making it an excellent choice for repairing an object the size and weight of *Saint Michael the Archangel* (Riccardelli et al. 2014). The adhesive was wonderful to apply, and the conservators were able to achieve extremely close joins between the fragments—often a challenge with terracotta. Fragments were held in position with low-tack tape or small clamps and left undisturbed for 2 weeks for the adhesive to set completely (figs. 3a, 3b). Once the sections were assembled, the multitude of glaze flakes could be placed and bonded.

The missing areas were filled with Modostuc (a proprietary filling material composed of calcium carbonate and barium sulfate in a polyvinyl acetate copolymer binder). Completed fills were inpainted with Golden Acrylics followed by layers of Primal WS24 (a water-based acrylic colloidal dispersion) applied by brush to replicate the gloss of the glaze. On one of the larger fills, the surface of the somewhat uneven, dimpled glaze was recreated by applying a thin layer of HXTAL NYL-1 on the already inpainted fill, then laying on a thin layer of Zhermack Elite Double 8 silicon rubber that had been previously cast from an adjacent undamaged glazed area. The silicon rubber sheet imparted the texture of the dimpled glaze to the HXTAL NYL-1, making the fill seamlessly blend into the surrounding glazed ceramic surfaces. The blue glaze color proved to be challenging to replicate due to the metameric nature of many modern blue pigments. However, we found that mixtures of Golden Acrylic's ultramarine blue, Naples yellow, raw umber, and occasionally titanium white had less of a metameric shift than others, and remained successfully color matched even under gallery lighting.

3.2 Mount

In 1475, the sections of the lunette were created using a combination of plaster molds and hand modeling, and were carefully designed to fit tightly together in one specific sequence. Della Robbia clearly meant to hide the gaps between sections because, once assembled, the joins are barely noticeable (fig. 4). To maintain this illusion, the new mount had to be low profile and unobtrusive while holding securely each section of the lunette.

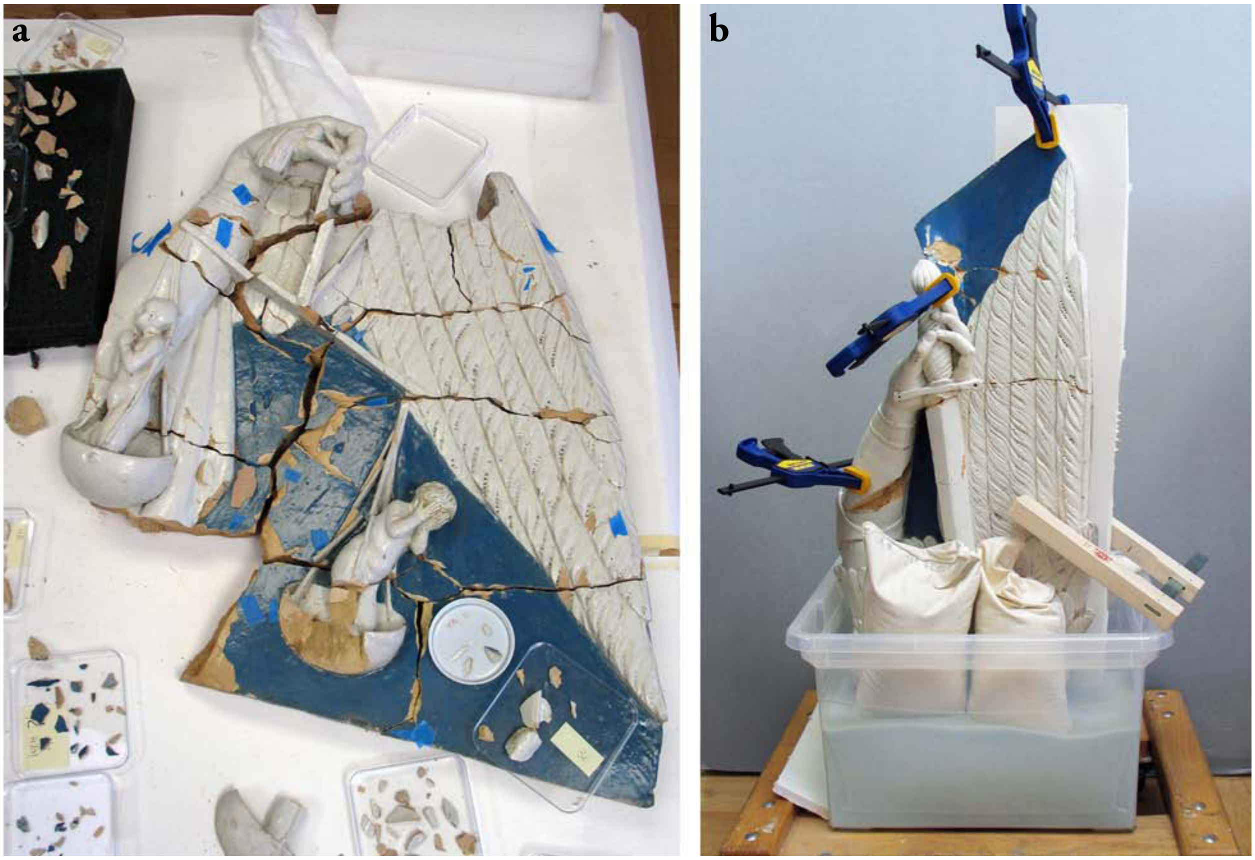

Fig. 3. (a) Sorting and locating fragments of *Saint Michael the Archangel* lunette. (b) Bonding and clamping. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

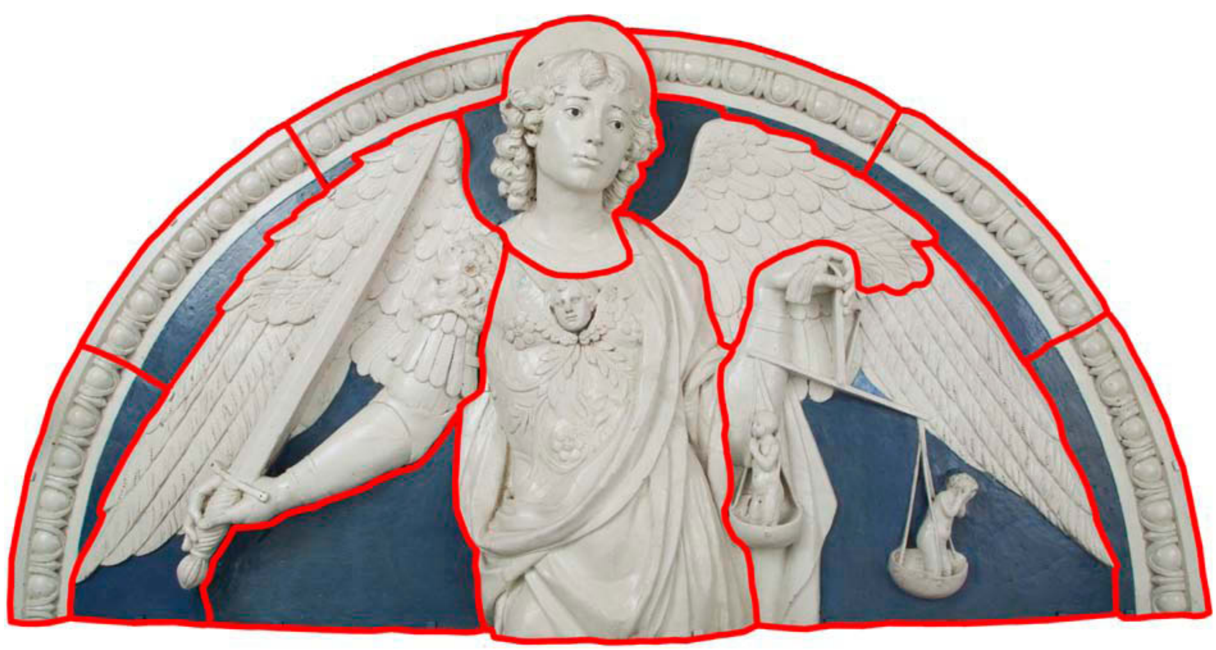

Fig. 4. Diagram highlighting the 12 sections of the lunette (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

A custom mounting system was designed and fabricated by Fred Sager, supervising conservation preparator at The Met. Approximately 30 brass clips, each one uniquely designed to accommodate the varying heights and curving sides of the lunette sections, were placed in strategic and discreet points. The location of each clip, some of them simultaneously supporting three sections, was first planned on a plywood backing board. Then, the clip locations were transferred to a solid ½-in.-thick aluminum backing panel. Each brass clip, lined with acrylic felt to protect the object, was attached to the backing panel using countersunk machine screws that fed into holes tapped into the aluminum. Finally, the visible portions of the clips were inpainted with acrylics to match the surrounding glaze color. When fully assembled, the lunette and its backing plate were secured to a reinforced wall with an interlocking cleat. *Saint Michael the Archangel* has now returned to the same gallery in which it was displayed before the accident, but with a more prominent placement, closer to eye level.

3.3 Discoveries Made During Treatment

3.3.1 Clay Body and Glaze

The fragmentary nature of the lunette allowed us to view the interior clay structure, providing us with a rare glimpse into the working methods and expertise of the della Robbia workshop. One of the most striking features was on the right arm, where the presence of large air pockets and folds suggests that the wet clay was pressed into the mold or sculpted with seemingly little care (fig. 5a). Distinct color variations and lumps observed in other fragments indicate that the clay was not thoroughly wedged before use (fig. 5b). As any student of ceramics would know, properly wedged clay produces a compressed matrix with a smooth consistency and even color. Wedging is done to reduce risk of firing flaws that can be caused by the rapid and destructive expansion of water vapor contained inside air pockets. It was surprising to discover that the della Robbia workshop, known for producing large-scale sculptures, was not meticulous in the handling of their clay. This ostensibly cavalier workmanship reveals that they had an intimate understanding of their clay and of how far the boundaries could be pushed while still producing a good result.

The clay that the della Robbia family used has been studied extensively. Legend persists of a secret clay source at a property that they had along the Arno River. This chalky clay, also referred to as "marly clay," fires to a pale buff color (as opposed to the usual terracotta red) and has the effect of making the overlying glazes appear especially luminous. It also fires well at a wide range of temperatures and is a good "fit" for

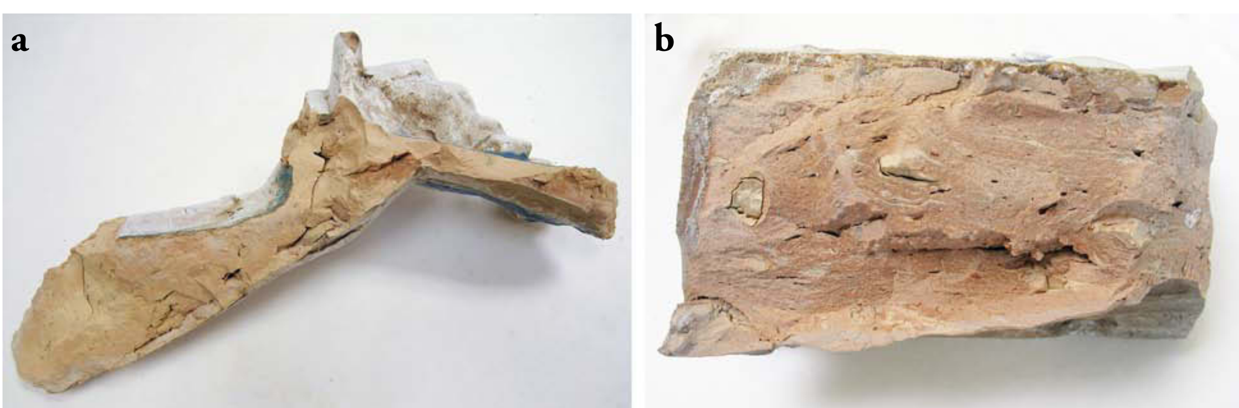

Fig. 5. (a) Air pockets revealed in the clay body under the right hand. (b) Lumps and color variations in the clay visible in a cross section of a large fragment. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

the della Robbia glazes in that the clay and glaze expand and contract at the same rate throughout the firing. The della Robbia family carefully guarded the secrets of their clay preparation as well as their glaze recipes, much to the chagrin of contemporary sculptors attempting to produce similarly glazed works (Hykin 2016).

SEM-EDS analysis of the Saint Michael lunette and the Prudence tondo found the clay bodies to consist of a high-lime, or calcareous, clay with relatively small amounts of sodium, magnesium, and potassium. On both objects, the white glaze is a tin-opacified glaze; the blue is the same white glaze with cobalt, iron, copper, and nickel added (Wypysky 2013, Basso et al. 2015).

3.3.2 Tool Marks and Other Impressions

During a visit to La Torre Ceramica d'Arte, another ceramic factory producing della Robbia reproductions in Scandicci, Italy, a man demonstrating the process of pressing clay into a mold explained, "Pressing the clay into the mold, I can feel the resistance of the plaster below and can therefore make the walls even." This modern-day account had a direct connection to our observations of the Saint Michael lunette. In sections like the torso, which are in high relief, a great deal of care was taken to press the clay into the mold evenly (figs. 6a, 6b). In contrast, the head was sculpted by hand as a solid form, then hollowed out to achieve even wall thickness and to reduce its mass. Generally speaking, consistent wall thickness is critical to avoid cracking and warping as an object is dried and fired. Throughout the lunette, each section that had areas of high relief had been hollowed out from the back for this reason.

Fig. 6. (a) The torso section. (b) The torso from behind showing even wall thickness. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

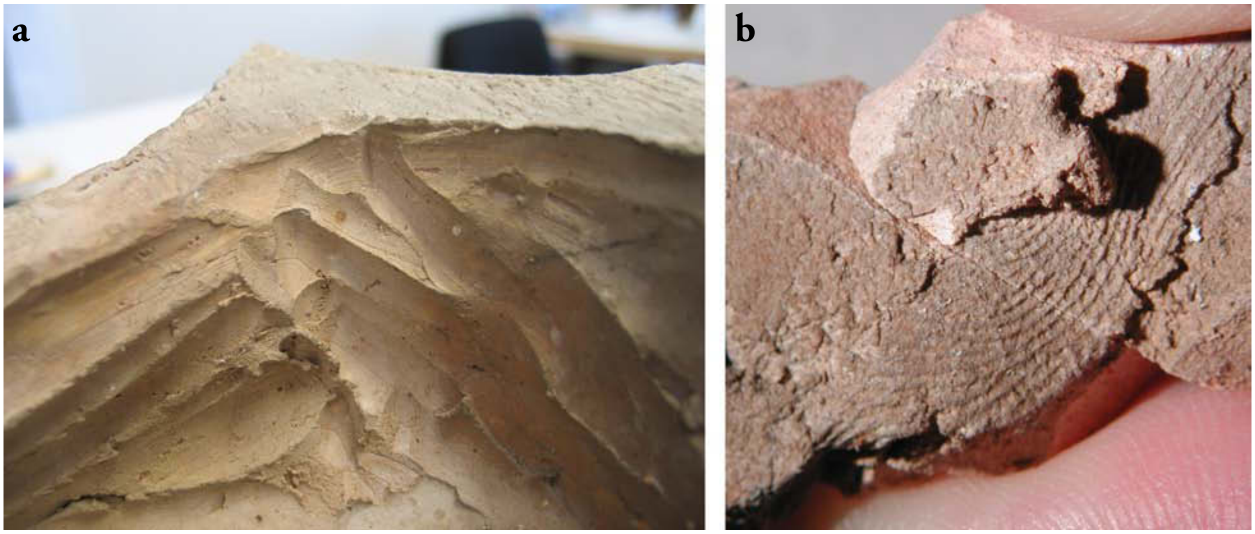

Fig. 7. (a) Finger marks from pressing soft clay into the mold. (b) Fingerprints found on the back of the Saint Michael lunette. (Photographs by W. Walker ©The Metropolitan Museum of Art)

Figure 7a illustrates how the process of pressing clay into the mold left numerous fingermarks. There is some discussion among scholars as to whether the clay was pressed into the mold or the mold filled completely and then scooped out. Examples supporting both strategies have been observed, but it is clear from these marks that the clay was quite wet when introduced into the mold. Occasionally, clear impressions of fingerprints are preserved on unglazed surfaces (fig. 7b). A variety of tool marks are present along the sides of the lunette's sections, including incised graffiti, paddling marks, and impressions of wood planks pressed against the clay (figs. 8a, 8b). These marks give one a sense of the physical labor involved in forming, handling, and maneuvering large terracotta sculpture.

3.3.3 Glaze Repairs

One interesting discovery made during the treatment concerns a large firing flaw in the torso section. When the lunette fell from the wall, a large section of the drapery broke away, exposing a large area of the

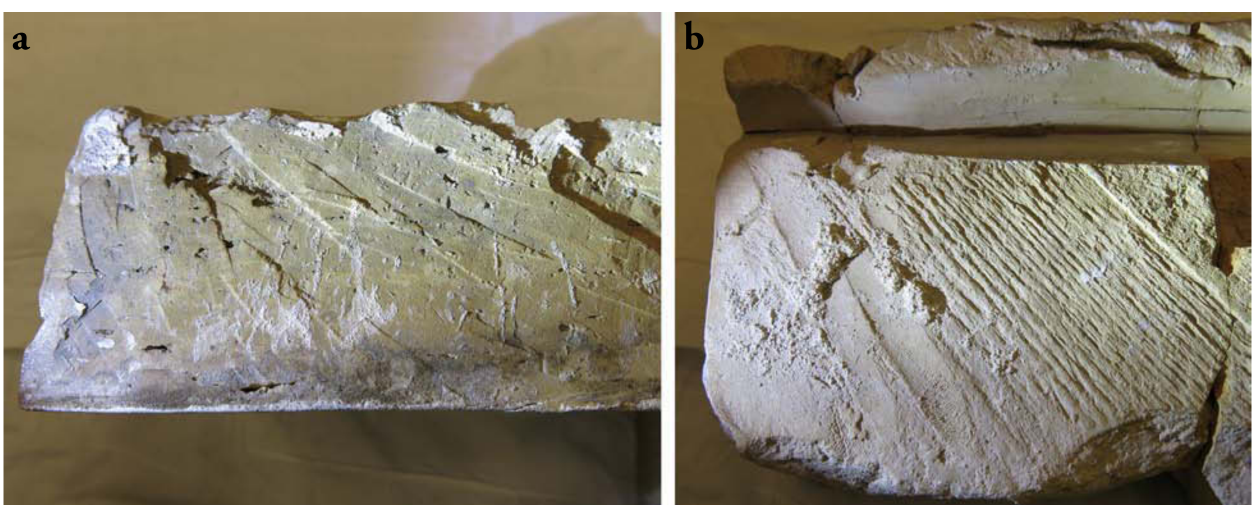

Fig. 8. (a) Tool marks along the side of a section. (b) Wood impressions in the clay. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

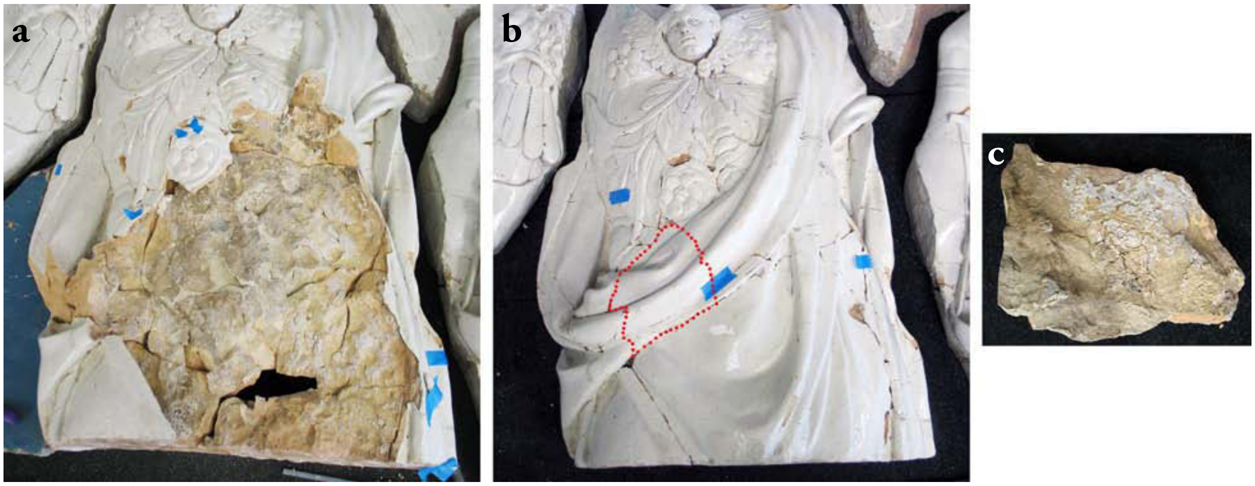

Fig. 9. (a) "Abdomen" area exposed after drapery fragment detached. (b) Torso section with drapery fragments in place; dotted red line indicates location of fragment seen in next figure. (c) White glaze on the underside of a portion of drapery fragment, revealed after the accident. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

clay body (fig. 9a). Upon close examination, we found that the matching surfaces of the exposed "abdomen" and the detached fragment were not fractured; they were, in fact, smooth, and it was clear that they had never been whole. This revelation suggests that the torso came out of the mold in a basic form and was then further sculpted by adding slabs of clay to create the drapery (fig. 9b). Probably in this case, the clay was too dry to adhere well; as a result, it split away during the first firing.

To salvage the piece, della Robbia applied white glaze to the area exposed after firing and then put the drapery fragment back in place; some of this glaze is visible in figure 9c. A thicker paste of glaze and fired clay was used to fill gaps around the edges.[2] Finally, the whole section was glazed in white and blue in the usual manner and fired a second time, during which the "glaze glue" melted and bonded the separated fragments together. In this example we see how the workshop's proficiency with clay enabled them to perform successfully this potentially risky repair. The glaze repair secured the fragment in place for over 540 years until the impact of the recent fall caused it to detach. There is evidence that the della Robbia workshop often did glaze repairs, but to see it as we did on Saint Michael's torso is rare.

3.3.4 Other Observations

Another detail that became apparent while the lunette was dismantled was that the sides of each section slant inward, creating V-shaped voids. This alteration was done after the sections were removed from their molds when the clay was still somewhat pliable. The voids provided extra space for mortar, thus more effectively securing the object to the wall while minimizing the visible gaps between sections once installed.

4. *PRUDENCE* TONDO

The second della Robbia work covered in this paper depicts the cardinal virtue, Prudence. *Prudence*, like *Saint Michael the Archangel*, was made in sections: seven sections for the inner tondo and eight vibrant garland sections framing the piece. In a field of blue, a three-quarters-length young woman is portrayed floating among clouds or water; she is looking to the right. She holds a mirror in her right hand and, coiling vertically along her torso, a snake is gripped by her left hand. The surrounding garland is a colorful and realistic depiction of citrons, oranges, grapes, quince, cucumbers, and pine cones accompanied by their associated foliage, all grouped and separated by blue ribbons.

The figure of Prudence represents the mother of all virtues. She is entirely good—the measure of justice, temperance, and fortitude. The snake represents wisdom and careful thought, and the mirror refers to the Delphic inscription "Know thyself." One of *Prudence*'s most striking attributes is her second face—that of an old man—implying wisdom of the past. Prudence herself looks into the future (Wardropper 2011).

Apart from knowing the tondo's date of manufacture in 1475 by Andrea della Robbia, there are only vague records of where it resided in Italy. There is an 1888 photograph showing the tondo prominently displayed at the Georgian country house, Badger Hall, in Shropshire, England, were it remained until it was sold in 1905 (Knox 2007). The tondo was then owned privately by various collectors, ending up in Paris before being purchased at auction by The Met in 1921 (Raggio 1961; Wardropper 2011). Following its acquisition, the tondo was installed in The Met's galleries for many years. It eventually was placed in storage, where it stayed out of sight for a generation until a request came from Marietta Cambareri at the Museum of Fine Arts, Boston to borrow the tondo for her groundbreaking exhibition *Della Robbia: Sculpting with Color in Renaissance Florence.* We had a year to prepare the tondo for this exhibition with venues in both Boston and Washington, DC.

4.1 Treatment

When *Prudence* first arrived in the Department of Objects Conservation, the tondo was relatively unchanged from when it first came into the collection in 1921 but for the addition of significant quantities of grime. On the front surface were old discolored restorations and extensive plaster fills (fig. 10a). The 15 sections of the tondo were mortared into a heavy iron ring surrounding the piece; on the back were the remains of a brick wall from a previous installation (fig. 10b). These remnants were

Fig. 10. (a) Front of *Prudence* before treatment. (b) Back of tondo showing remains of brick wall. *Prudence*, Andrea della Robbia, glazed terracotta, ca. 1475, 164.5 cm dia., The Metropolitan Museum of Art, Purchase, Joseph Pulitzer Bequest, 1921, 21.116. (Courtesy of S. Levin, ©The Metropolitan Museum of Art)

attached to the tondo with hard, red-tinted concrete (some of which contained slabs of slate, bits of tile, and marble chips) and a substantial amount of plaster, among other materials. The components of the tondo were held in compression by the iron ring, but some sections were so loose that it was possible for light to pass through.

The assembled tondo was too unstable to travel on loan; thus, we decided it would be prudent to completely dismantle the piece and create a new mount. Conservator Michael Morris joined us on this project. We began by taking the piece apart, first removing the inner tondo and then working our way around the garland. Sections were released from the mortar by carefully chiseling between them with tiny improvised chisels, like mini-screwdrivers. Occasionally, the mortar was perforated by making a series of drill holes with small-gauge bits. The garland sections were removed one at a time, always securing the adjacent areas with ratchet straps to prevent any accidents as we worked (fig. 11). Dismantling the tondo was a slow and deliberate process that took place over several months.

With the sections separated, we turned to cleaning away centuries of accumulated dirt. The grime was quite intractable and had created a brittle film covering much of the surface. In addition, there were large areas of oil-based overpaint. This old paint not only covered areas filled with plaster but also covered significant areas of perfectly preserved glaze. By repeating a sequence of steam, solvent, and mechanical cleaning, the layers eventually gave way, revealing a beautifully preserved surface. A mixture of 25% Triton XL 80N, 50% mineral spirits, and 25% deionized water, applied in a gentle scrubbing motion with natural bristle stencil brushes, proved useful in removing surface grime. The brittle film was removed after repeated campaigns of steam cleaning, followed by careful mechanical action with a scalpel blade.

Fig. 11. Michael Morris and Carolyn Riccardelli dismantling the tondo (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

4.1.1 Mount

One of the most time-consuming aspects of this project was the development and fabrication of a mounting system. The basic concept of the mount was taken from the one made for the Saint Michael lunette: support each individual section of the tondo independently using a system of conforming clips connected to a backing panel. However, because the weight of each garland section exceeded 36 kg (80 lb.), brass clips were not sufficient to support the components. Carbon fiber fabric proved to be a versatile material that allowed us to create thin, tightly conforming, and strong supports that would have been impossible to make out of brass or steel. Because we had used this material on the Tullio Lombardo *Adam* sculpture project, the solution provided some efficiency as we could fabricate the clips ourselves in the conservation studio (Riccardelli et al. 2014).

The foundation of the mount is a custom honeycomb backing panel designed to support the pieces as well as to be a means for lifting the entire object during installation. Removable carbon fiber straps, at least three per section, were made for each piece.[3] Specialized flanged and threaded metal components called "weld nuts" embedded into the base of each strap served as the method by which they were attached to the backing panel. The threaded component of the weld nuts protruded anywhere from ¼ to ½ in. from each strap, and seated into holes drilled through the aluminum honeycomb. Once each section was properly positioned on the panel, they were held in place mechanically using bolts fed through from the back of the panel (fig. 12).

At strategic moments during the mounting process, the panel and any attached sections were raised to a vertical position to test the efficacy of the straps against the forces of gravity. There were areas where the straps flexed slightly, causing some sections to drift out of place. In those locations that needed extra support, we made small Magic-Sculpt epoxy "bumpers" that were also attached through the panel using weld nuts (figs. 13a, 13b). After all the sections were secured, the black carbon fiber clips were painted to disguise them. The combination of the clips' low profile and the expert painting by Met

Fig. 12. Cross sectional diagram of *Prudence* clip system for a garland section; a weld nut (rendered in red) was embedded into the bottom of each carbon fiber clip. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

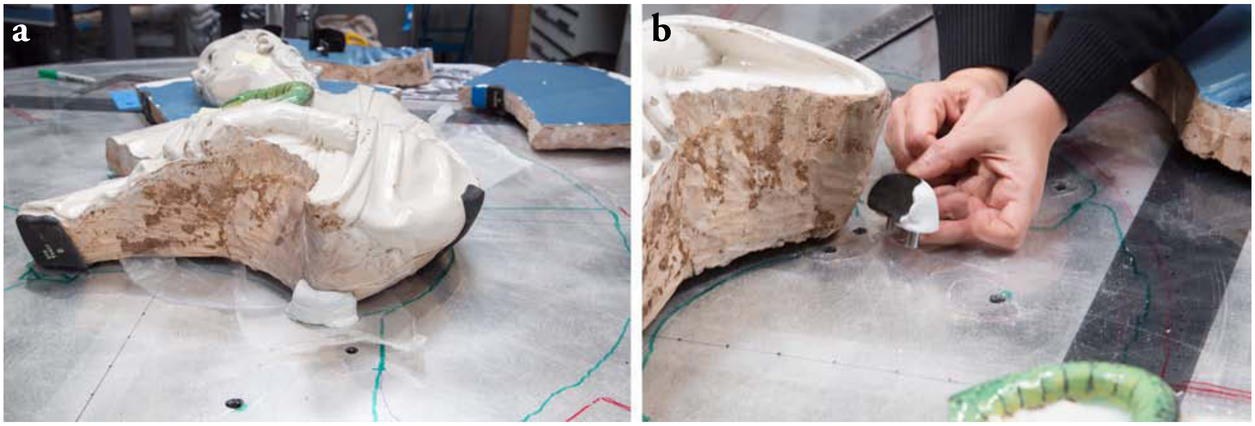

Fig. 13. (a) The bottom of *Prudence*'s torso, where an additional support made of Magic-Sculpt epoxy was placed. (b) An epoxy "bumper" showing weld nut attachment points protruding from the bottom. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

Preparator Matthew Cumbie created a mounting system that was virtually invisible from both the front and side views of the tondo. Because we consider both the lunette and tondo to be architectural fragments that are displayed outside of their original contexts, we opted to leave the gaps between the sections unfilled.

4.1.2 Fills and Inpainting

As the sections were cleaned, we began the work of making fills. Large areas of loss were executed in plaster after applying a barrier coating (15% Paraloid B-72 in acetone) to the fractured terracotta surface. Smaller losses were filled using Modostuc. Completed fills were sealed using dilute shellac. As with the Saint Michael lunette, we used Golden Acrylics for the inpainting, followed by layers of Primal WS24 to replicate the gloss of the glaze. Most of the inpainting was accomplished after the tondo was fully mounted on its backing board (fig. 14).

When inpainting with acrylics, many conservators in the Department of Objects Conservation use Sta-Wet palettes. The palette surface is a piece of specialized paper that sits on top of a wet cellulose sponge sheet. These components are housed in a plastic box that, when properly closed, can keep the paints alive for several days. One of the drawbacks of the Sta-Wet pallet is that colors can flow together over time (fig. 15a). If the inpainting project will take place over a long period, the palette will need to be refilled occasionally. To help make this process more efficient, snapshot photos were taken of the fresh palette and the jars of colors used (fig. 15b). These photos served as a quick visual reminder when it was time to make a new palette. Figure 15 gives an idea of the range of colors that were used to inpaint *Prudence*'s vibrant glazes. To match the blue field of the inner tondo, we used a combination of ultramarine blue, Naples yellow, and a bit of raw umber. Sometimes, titanium white was needed as well. The star of the show turned out to be the Golden Acrylic color "light turquoise," which we found to be the solution to almost any color-matching problem we encountered while inpainting the many shades of green of the garland's leaves. Mixing Primal WS24 into the colors on the palette was helpful in replicating the flowing multicolored glaze of the foliage. The extra medium extends the paint and allows for more accurate layering and blending of glaze color.

Fig. 14. Carolyn Riccardelli, Janis Mandrus, and Wendy Walker inpainting *Prudence* after it was mounted on its backing board (Courtesy of D. Sastre, ©The Metropolitan Museum of Art)

4.2 Discoveries Made During Treatment

4.2.1 Garland Numbering Sequence

A fascinating feature of the tondo was uncovered as we cleaned the white molding that frames the inner tondo, located on the inward-facing sides of the garland sections. As the layers of overpaint and grime were removed, we noticed numbers carved into the clay, underneath the glaze layer (figs. 16a, 16b). As we continued to clean off the obscuring layers, we found that each section was similarly numbered. It was then we realized that these numbers were related to the arrangement of the garland. Figure 17a shows the garland as it originally came to The Met; we believe it was mounted in this configuration during the late 19th century. The primary feature of this arrangement is that it groups similar elements together: a pair of pine cones at the top, the grapes below, and the yellow fruits grouped at the sides.

We found that each garland section was furnished with a consecutive pair of numbers, one at each edge of the white molding. The numbering system was not consecutive overall, but rather relied on an interesting method of matching like numbers at the edge of the sections. The first section was marked “1” and “2.” The adjacent section was marked “2” and “3,” the next “3” and “4,” and so on. The final section was marked “8” and “1.” Because of the large scale of the tondo (which was, at this time, in mid-treatment), we dashed to our computers to rearrange the garland digitally. We found that, rather than grouping the similar sections together, the rediscovered sequencing system *alternated* them. The result was a much livelier arrangement.

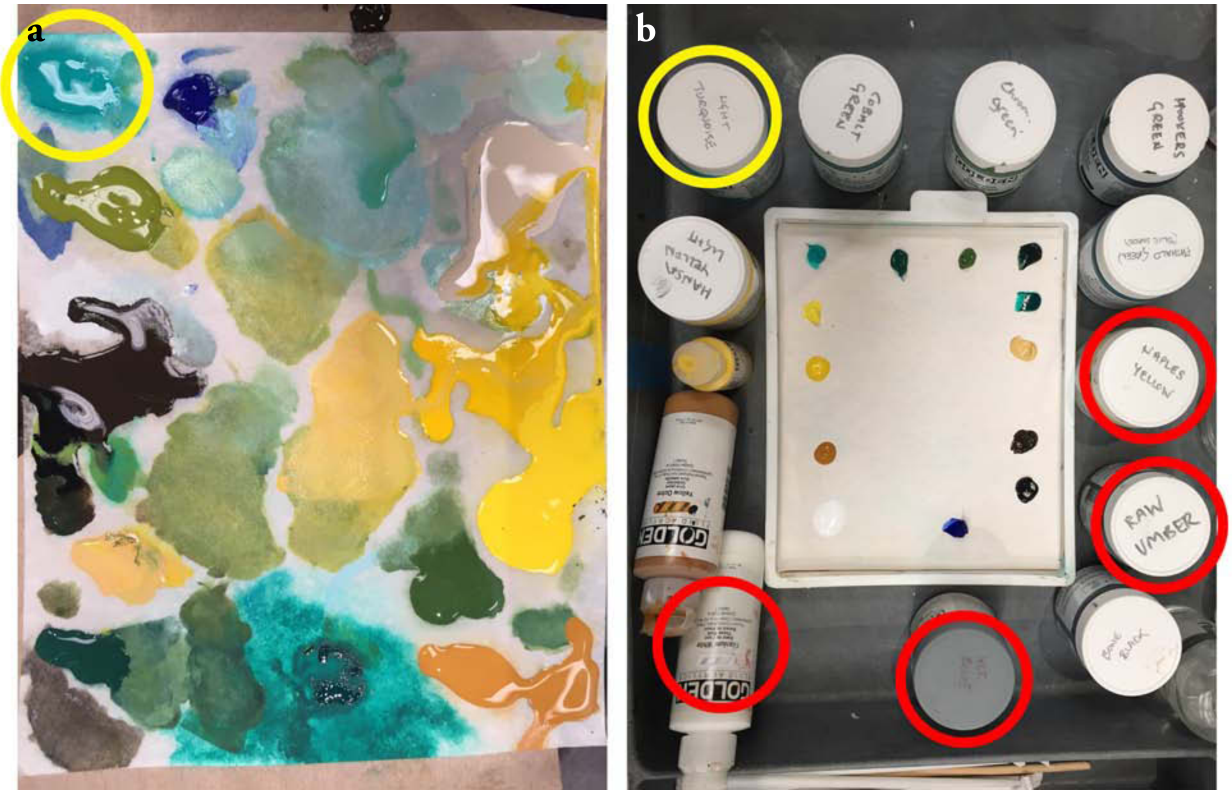

Fig. 15. (a) Sta-Wet palette showing colors; light turquoise is circled in yellow. (b) Snapshot of fresh palette and jars of paint (red circles indicate colors used to make della Robbia blue). (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

Uncovering the numbering sequence was quite an exciting moment in this project, and led to fruitful discussions between conservators and curators, particularly about what join to place in the top position. Could we simply assume that "1" started at the top? We reached out to colleagues in Florence for help. Laura Speranza, Director of the Department of Conservation of Terracotta and Wooden Sculpture at the *Opificio delle Pietre Dure*, and Conservator Daniele Angellotto, both in Florence, Italy, had experience dismantling in situ della Robbia works with similar numbering systems. They confirmed that they consistently found a 1 to 1 or equivalent join oriented at the top. Our colleagues also reported that they

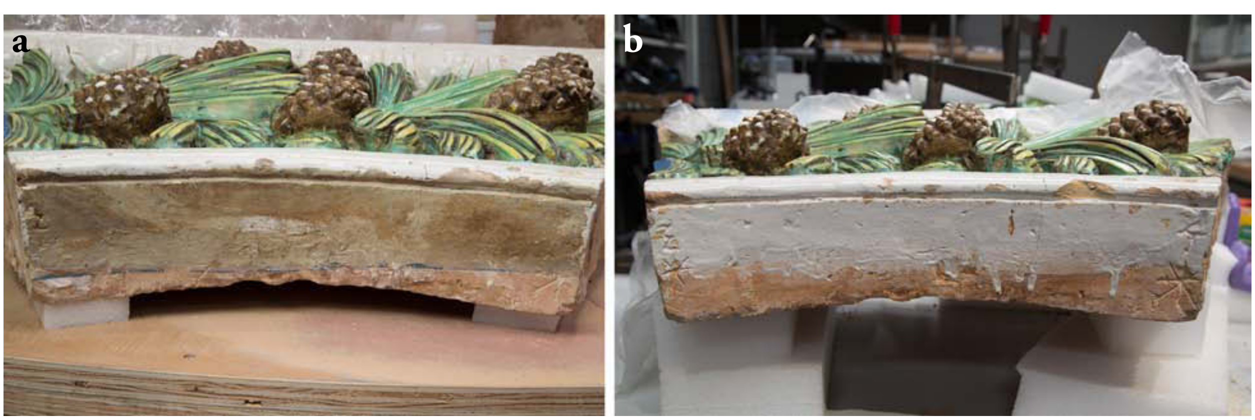

Fig. 16. (a) Pine cone section of garland during cleaning. (b) Same section after cleaning revealed sequencing numbers 3 and 4 (Photographs by C. Riccardelli, ©The Metropolitan Museum of Art)

Fig. 17. (a) *Prudence* garland as arranged before treatment. The blue lines indicate the divisions between the sections, along with tracings of the numbering system found on each piece. (b) Garland arranged according to rediscovered numbering system (Diagrams by C. Riccardelli ©The Metropolitan Museum of Art)

have often encountered Roman numeral sequencing systems. Thus, based on our discussions at The Met and with our colleagues in Florence, we decided to go with the 1 to 1 join at the top (fig. 17b).

4.2.2 Tool Marks and Impressions

While many interesting impressions and tool marks came to light during the treatment of the Prudence tondo, the most unexpected ones were found around the outside of the garland. These only became clear to us once the tondo was fully mounted and we could view the continuous unglazed outer surface created by all of the sections. At the intersection of each pair of garland sections are markings that matched up and are unique to each join. Where the quince and pine cone sections meet, there is a clear impression of three fingers dragged across the join between two pieces (fig. 18a). At the connection between the pine cone and the orange, there are two round impressions that were clearly made by the same tool (fig. 18b). The marks are undoubtedly deliberate, and suggest that there were two phases of organizing the garland sections. The marks on the outer surfaces were executed in the wet clay, probably as a way to keep the sections in order as they were being made, and the numbering system on the inner sides were meant to direct the orientation of the garland during installation in its architectural setting.

4.2.3 Gilding

In the blue field of the inner tondo, we observed the faint remains of bands radiating out from Prudence. Della Robbia terracottas were often gilded, but the nature of the embellishment is impermanent, leaving us today with a ghost of where the gilding once was. With that in mind, we suspected that the radiating bands were the remains of mordant from gilding. During our examination of the piece, we located a tiny spot of what appears to be gold tucked underneath Prudence's right hand where it connects to the blue field, adding further support to our theory. Unfortunately, the location of the gold was in a deep recess and did not allow access for an analytical instrument. FTIR analysis of the rays showed that the residual material is primarily calcium oxalate (whewellite). Research Scientist Adrianna Rizzo (2015) reported

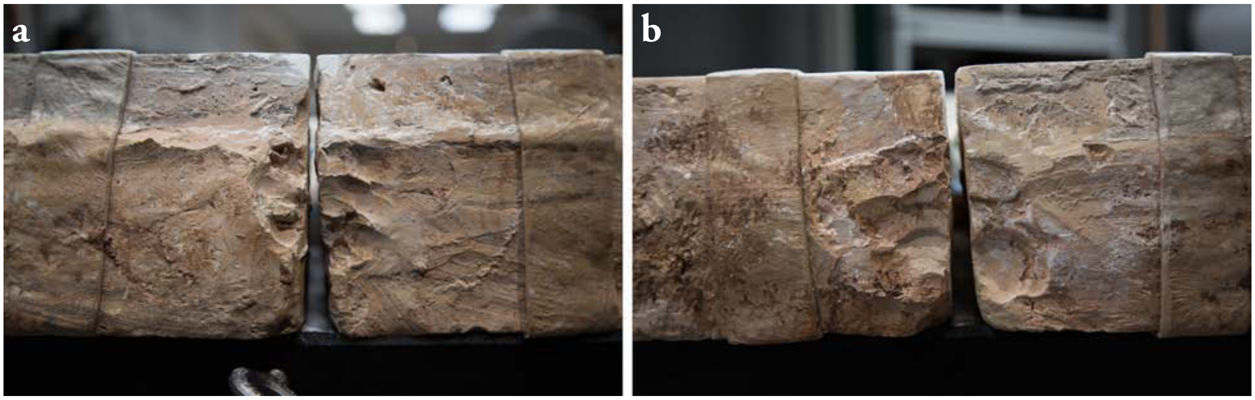

Fig. 18. (a) Finger markings on the outer surfaces of the garland might have helped keep sections in order during fabrication. (b) Impressions of a round tool made in the wet clay. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

that this compound could be derived from an oil or proteinaceous layer, which is consistent with the theory that the bands are mordant from gilding. At this stage, it is not possible to speculate on when the gilding might have been applied.

To provide an impression of what Prudence may have looked like with gilding, we turned to Photoshop to create a digital reconstruction. Inverting the blue color of the inner tondo helped to visualize the remnants of the gilded rays; translucent lines of color were then added over the blue field (figs. 19a, 19b). After some experimentation with the length of the rays, we settled on a varying pattern based on contemporary comparisons for this aesthetic. Met Curator Denise Allen suggested works by Botticelli from the 1480s, *Madonna del Magnificat* and *Madonna del Melagrana*, both in the Uffizi Gallery, to provide inspiration for reconstructing the golden aureole. The beautiful final result made quite an impression on conservators and curators alike.

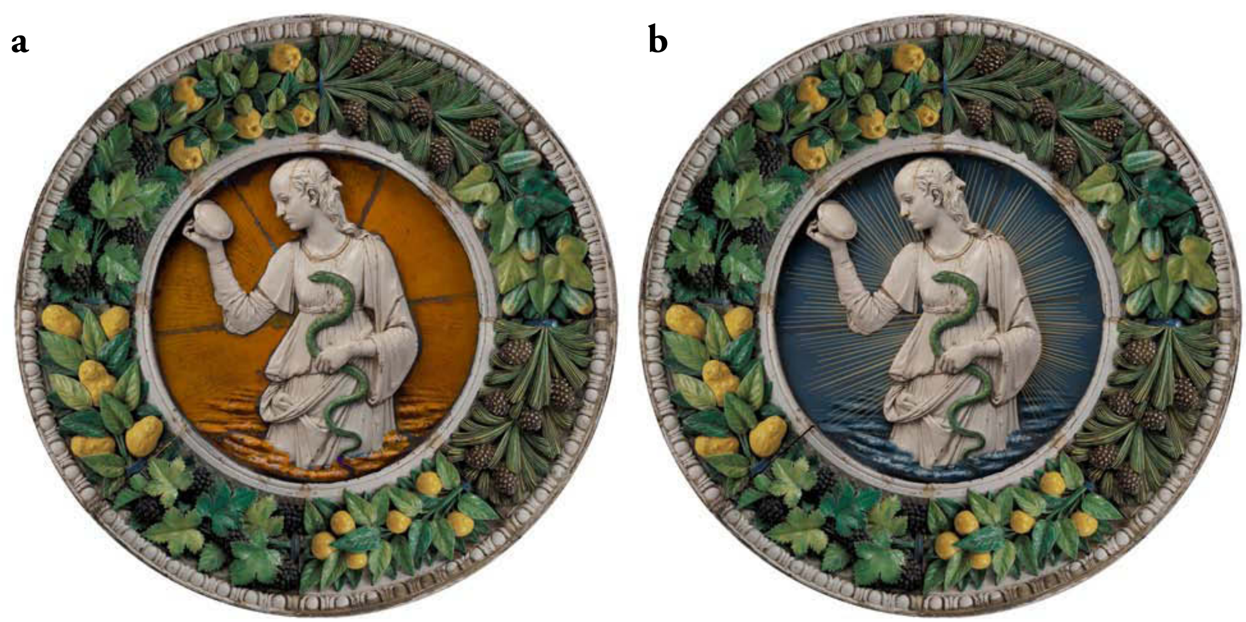

Fig. 19. (a) Prudence tondo with color of blue field inverted to highlight the presence of mordant lines. (b) Digital reconstruction proposing how gilded rays might have appeared. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

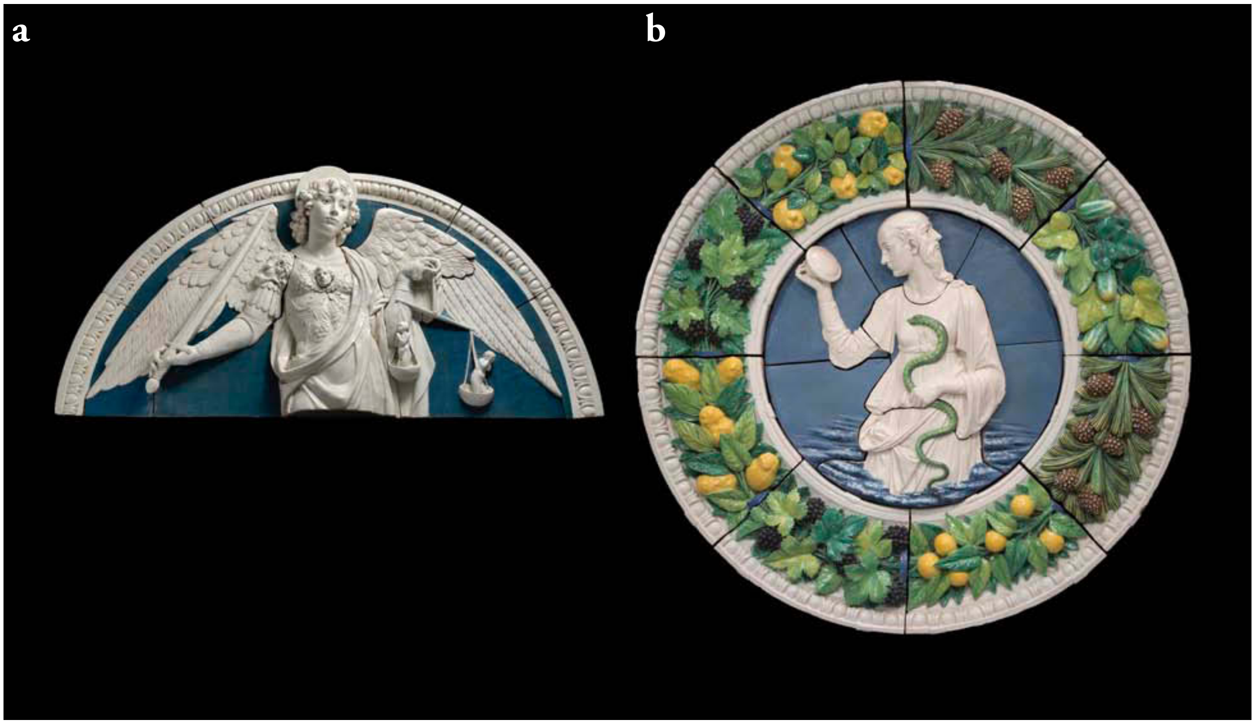

Fig. 20. (a) *Saint Michael the Archangel* after treatment, and before mounting. (b) *Prudence* after treatment, secured on the new mounting system, [Photograph in (a) by Joseph Coscia, Jr.; photograph in (b) courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

5. CONCLUSION

Working on *Saint Michael the Archangel* and *Prudence* was a wonderful opportunity to explore and become quite intimate with these great works. It led to study trips in Florence and further afield, and to marvelous collaboration with our own curators and colleagues at The Met, the Museum of Fine Arts, Boston, and in Italy. Yes, the technology of these pieces is interesting, and the conservation process absorbing, but the wonderful thing that results from this sort of in-depth work is that you cannot help but develop a sincere interest in and connection to the pieces, to the artist, and to a time so completely unlike our own. It is these things that make the field of art conservation so endlessly interesting and fulfilling. Andrea della Robbia was certainly skilled in working the material, but the expression of emotion that he achieved through the medium of clay is remarkable. We look at Saint Michael and see compassion in his face and a sense of burden as well. Prudence is serene, with a quiet confidence. The longer we spent time with these pieces, the more enchanting they became (figs. 20a, 20b).

ACKNOWLEDGMENTS

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Both authors are grateful to conservators Janis Mandrus and Michael Morris for their help with *Prudence*: Janis for the hours of filling and inpainting, which helped us to meet a tight deadline both with *Saint Michael the Archangel* and *Prudence*, and Michael for his expertise in dismantling and mounting *Prudence*. Thanks also go to preparators Fred Sager and Matthew Cumbie for their impressive work throughout both projects. Many interns contributed to this project: Sara Levin, Ashley Jehle, and Camille Beziers carried out the initial research, documentation, examination, and cleaning tests on *Prudence*—to them we extend a special note of gratitude. We thank our curators Denise Allen, Peter Bell, James Draper, and Luke Syson for their enthusiasm and support throughout the project. We thank Collections Manager Denny Stone for her fortitude following the accident. Finally, we are indebted to Marietta Cambareri for bringing the art of della Robbia into our lives.

NOTES

1. The "Tullio Blend" is a 40% solution mixed by weight, and is created as follows: make one batch of each adhesive (40 g Paraloid B-72, 54 g acetone, 6 g ethanol; and 40 g B-48N, 54 g acetone, 6 g ethanol) and then combine by volume 3 parts B-72 and 1 part B-48N.

2. These materials—a combination of white glaze and fired clay used to fill in gaps around the torso fragment—were confirmed by recent analysis by Mark Wypyski in The Met's Department of Scientific Research.

3. The process of making the carbon fiber straps is covered in detail in "Carbon Fiber and its Potential for Use in Objects Conservation," also in this volume (Riccardelli 2019).

REFERENCES

Basso, E., F. Carò, and M. Wypyski. 2015. "Examination and analysis report for 60.127.2." Unpublished report, Department of Objects Conservation, The Metropolitan Museum of Art, New York.

Cambareri, Marietta. 2016. *Della Robbia: Sculpting with color in Renaissance Florence*. Boston: MFA Publications.

Hykin, Abigail. 2016. "Materials and Techniques." In *Della Robbia: Sculpting with Color in Renaissance Florence*, edited by M. Cambareri, Boston: MFA Publications.

Knox, Tim. 2007. "Edward Cheney of Badger Hall: A Forgotten Collector of Italian Sculpture." *Sculpture Journal* 16 (1): 5–20.

Raggio, Olga. 1961. "Andrea della Robbia's Saint Michael Lunette." *The Metropolitan Museum of Art Bulletin* 20 (4): 135–44.

Riccardelli, Carolyn, Jack Soultanian, Michael Morris, Lawrence Becker, George Wheeler, and Ronald Street. 2014. "The Treatment of Tullio Lombardo's *Adam*: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49: 48–114.

Riccardelli, Carolyn. 2019. "Carbon Fiber and its Potential for Use in Objects Conservation." *Objects Specialty Group Postprints, Volume 24, 2017.* Washington, DC: American Institute for Conservation (AIC). In press.

Rizzo, A. 2015. "Examination and Analysis Report for 60.127.2." Unpublished report, Department of Objects Conservation, The Metropolitan Museum of Art, New York.

Wardropper, Ian. 2011. *European Sculpture, 1400–1900, in The Metropolitan Museum of Art*. New York: The Metropolitan Museum of Art.

Wypyski, Mark. 2013. "Examination and Analysis Report for 60.127.2." Unpublished report, Department of Objects Conservation, The Metropolitan Museum of Art, New York.

FURTHER READING

Domestici, F. 1992. *Della Robbia: A Family of Artists*. Milan: SCALA.
Marquand, A. 1922. *Andrea della Robbia*. Princeton, NJ: Princeton University Press.
Pope-Hennessy, J. 1980. *Luca della Robbia*. Oxford: Phaidon.

SOURCES OF MATERIALS

Carbon fiber fabric
FibreGlast
385 Carr Dr.
Brookville, OH 45309
http://www.fibreglast.com/

Composite panels for *Prudence* mount
Composite Panel Solutions (No longer in business)
7167 Rte. #353
Cattaraugus, NY 14719

Golden Acrylics, Sta-Wet Palette, Paper, and Sponge
Dick Blick Art Materials
P.O. Box 1267
Galesburg, IL 61402
https://www.dickblick.com/

HXTAL NYL-1, Primal WS24 (also sold as Rhoplex WS24), Paraloid B-72, and Paraloid B-48N
Conservation Resources International
5532 Port Royal Rd.
Springfield, VA 22151
http://www.conservationresources.com/

Magic-Sculpt epoxy putty
The Compleat Sculptor
90 Vandam St.
New York, NY 10013
http://www.sculpt.com/

Modostuc
Talas
330 Morgan Ave.
Brooklyn, NY 11211
http://www.talasonline.com

Weld nuts
McMaster Carr
P.O. Box 5370
Princeton, NJ 08543
https://www.mcmaster.com/

Zhermack Elite Double 8
Chase Dental & Medical Supply
40480 Grand River Ave. G
Novi, MI 48375
http://chasedentalsupply.com/

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STRUCTURAL REPAIR OF PLASTER SCULPTURE USING POLYVINYL BUTYRAL RESIN

L. H. (HUGH) SHOCKEY JR.

This article will focus on the design and use of an adhesive system for the structural repair of plaster sculpture. The parameters influencing adhesive system design and the choice of polyvinyl butyral resins as a consolidant will be explored, including methods for dealing with prior adhesive repairs, the issue of plaster's structural strength, controlled reversibility, and planned stress relief. These topics will be illustrated through the presentation of a case study of the treatment and retreatment of a painted plaster sculpture over the course of 10 years. The information presented will be applicable to the treatments of conservators working with plaster in a variety of formats, including hollow cast, solid cast, modeled, and architectural applications.

KEYWORDS: Plaster, Calcium sulfate dihydrate, Sculpture, Adhesive, Polyvinyl butyral resin, Butvar, B-76, B-98

Calcium sulfate dihydrate, gypsum, plaster of Paris, or just plaster, all are names to describe a widely used material for the creation of art throughout history. Whether used as part of the modeling process for a sculpture rendered in a different final material or the primary constituent of a finished sculpture, it is a material frequently used by artists. My own experience with plaster—from "coloring" on a classmate's cast in grade school to any number of cast, carved, dripped, and molded "experiments" in a college studio class—gave me an understanding of its versatility and low cost, perfect for an artist's needs. As a conservator, I've learned much more about plaster as a material from its seeming solid durability to its incredible fragility and susceptibility to both surface and structural damage. Plaster also presents a number of treatment problems that haven't always had satisfying solutions. My own search for a better solution for structural repair began when confronted with the evidence of several previous repair campaigns to Ferdinand Pettrich's *Washington Resigning His Commission* of 1841, a faux-bronzed plaster in the collection of the Smithsonian American Art Museum (fig. 1).

My treatment of Pettrich's sculpture included mending the broken right hand with outstretched scroll. This was not the first time that the area had been damaged or treated—far from it, as evidence from the sculpture's conservation record would illustrate. The history of damage and repair dated far into the past, with numerous episodes of damage followed by repair. One of the better documented interventions from the late 1960s is described and illustrated as an extensive treatment, necessitated by damage done to the sculpture while on display, that included the remodeling of two fingers on the hand in addition to rejoining the scroll and finger portion with the upper hand at the palm (fig. 2). The file also contained documentation of additional repairs, always to the same break across the palm, with different adhesives over the course of 50 years. The record and the evidence in the break line indicated that, in addition to more reversible natural and synthetic adhesives, less easily reversible polyvinyl acetate emulsion and epoxy had been tried. Looking closely at the break faces, it was possible for me to see a variety of surface conditions related to the prior interventions (fig. 3). The conditions I observed included: areas where a prior adhesive remained adhered to one of the break faces that had a thin layer of plaster over the surface apparently pulled from the opposite face; areas where a mass of adhesive with a smooth glossy surface was well adhered to only one face, suggesting no actual contact with both break faces; and areas of gloss with filled-in surface topography that suggest the application of a resin and solvent mixture that may have been used to mend, consolidate, or seal the surface. In all, the surfaces before me could be described as heterogeneous in nature, no longer just plaster, but soft porous plaster with a menagerie of other materials scattered over its surface.

While contemplating the treatment of the sculpture, I had the good fortune of being invited to a workshop on adhesives jointly taught by Peter Sparks and Richard Wolbers (fig. 4) at the Winterthur

Fig. 1. Ferdinand Pettrich, *Washington Resigning His Commission*, ca. 1841, painted plaster, 86 × 48 1/2 × 36 3/8 in. (218.3 × 123.2 × 92.3 cm), Smithsonian American Art Museum, Gift of the Artist, XX35 (Courtesy of the Smithsonian American Art Museum)

Museum, Garden and Library in January 2006. It was during this workshop that I began to think of alternative paths to mend the damage to the Pettrich sculpture. The workshop provided a review and distillation of adhesive science, coupled with benchtop testing methods, and a decision-making framework to assist practicing conservators in thinking more strategically when making adhesive selections for what are often less than ideal adherend and adhesive variables.

Fig. 2. Images from the conservation file for *Washington Resigning His Commission* showing the stages of treatment in 1968 (Courtesy of the Smithsonian American Art Museum)

Fig. 3. The break face of the scroll and finger fragment from *Washington Resigning His Commission* with a variety of adhesive residues and previous repairs

In addition to providing a review of adhesives used in conservation, the workshop helped me think more about what I am actually doing when I choose an adhesive—beyond being reversible, solvent compatible, and strong enough for the repair. I began to think more about the surface properties of the adherend, how it can be modified, and how its interface with the adhesive can be manipulated. How does this relate to the treatment of Pettrich's sculpture? The previously described menagerie of surface materials on the break faces presents a challenge to a single adhesive system because it requires the selected adhesive to match the surface energies of each material on the surface. Should the selected adhesive match the surface energies (attracted to versus repelled by) of a heterogeneous adherend (the face of a break with mixed

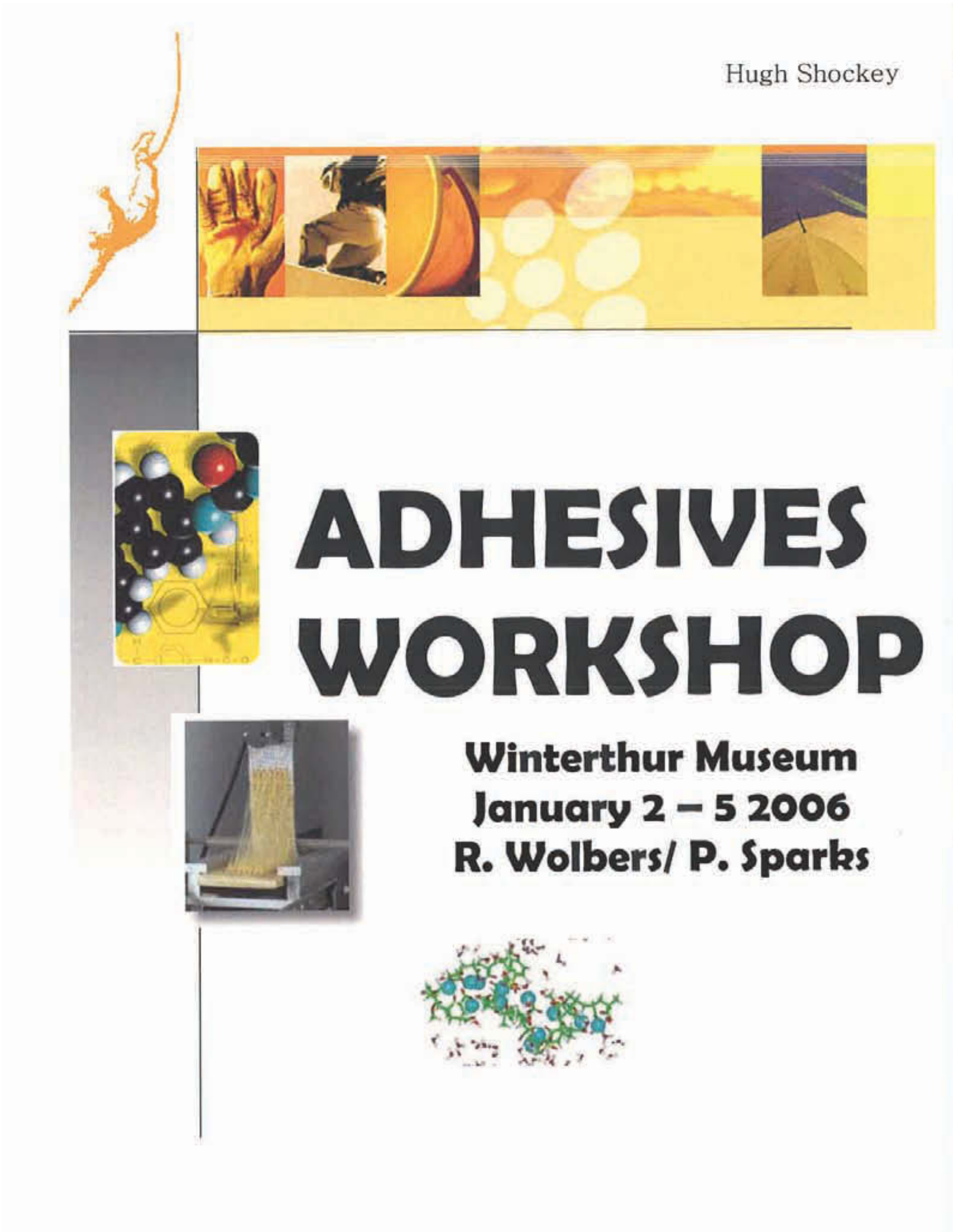

Fig. 4. Adhesive workshop notebook cover; the contents included articles and references on adhesive properties established through testing, adhesive science and theory, case studies on adhesive use, and evaluation methodology for use in treatment.

surface types), the bond energies between each of the materials of the surface are certain to be different (e.g., adhesive A will have a different affinity for surfaces 1, 2, and 3 if all surfaces are different materials chemically), resulting in areas of high and low bond strength. In the workshop, I learned that choosing a broadly compatible secondary coating for application to a heterogeneous surface can have the effect of creating a homogeneous adherend surface for the application of the mending adhesive, effectively establishing a new unified surface for mending. If theory holds, application of the mending adhesive to the newly established homogeneous surface will tend to bond with equal force across the break. It was with this advantage in mind that I began to think more seriously about designing a multi-adhesive system rather than choosing a single-adhesive solution to solve the problem of the mend surface being a mixture of historic plaster and previously applied and absorbed adhesives.

Pursuant to the idea of a multi-adhesive system, I began to look at the properties of the Butvar series of polyvinyl butyrals (PVBs) that, as a family of resins, offers a broad range of variability in formulation and considerable control of their physical properties in solution. I was introduced to the adhesive potential of PVB resins, the Butvar line specifically, during the workshop. It was interesting for me to learn that PVBs have been considered for use in archaeological conservation since the 1960s (Kostrov and Sheinina 1961). While many other common conservation adhesives were discussed, PVBs stuck in my mind as an intriguing possibility for the repair of plaster sculpture due to its mechanical properties and solvent-influenced viscosity.

Of the Butvar formulations available, both B-98 and B-76 drew my attention as possibilities for designing an adhesive system for repair of the Pettrich sculpture. At first glance, both resins have a wide range of solvent solubility, which suggests that they have the ability to wet onto and bond with a variety of materials. As I began to consider the problem further and compare the technical specifications of the two resins, a potential solution to the problems of the Pettrich sculpture took shape. Taking into consideration the sculpture's long history of damage and repair cycles, I shifted my thinking from how to make the strongest repair possible to how to create a repair that will fail under excess stress in a controlled way. My thought was that, by designing an adhesive system that would fail under excess stress, it would help prevent additional damage to the plaster body by relieving the stress at the bond line rather than deeper in the plaster body. The challenge with plaster is that it has very little tensile or shear strength, well below the adhesive strength of most resins. In thinking back on the idea of establishing a homogeneous adherend surface, I wondered whether it was not possible to pick a resin that could penetrate the surface and create a cohesively strengthened break face—a break face that is strong and tough enough that a weaker resin's adhesive strength would fail before its cohesive strength would. To add to the challenge, I also wanted the system to be retreatable and solvent reversible according to best practices.

Butvar B-98's use in conservation for the consolidation of porous archaeological materials with limited structural strength has been documented in the literature several times and has included evaluation of its aging characteristics and reversibility (Spirydowicz et al. 2001; Simpson 2003). As a penetrative consolidant, Butvar B-98 offers the advantage of a strong resin that has very low viscosity depending on the solvent selected for a solution. It is these properties that make it a good resin to consider for strengthening the porous crystalline matrix of plaster. Anecdotal evidence from benchtop testing suggests that the introduction of Butvar B-98 into the plaster matrix alters its physical characteristics, making it a tougher, more resilient material. The perceived result in treatment applications is that a plaster substrate infused with Butvar B-98 becomes more durable when handled with less powdering and loss on the soft, friable surfaces associated with a break, including improved handling of small fragments.

Butvar B-76 has been mentioned sparingly in the conservation literature when compared with Butvar B-98 (Davidson 2004). As a higher molecular weight sibling of B-98, B-76 has interesting properties for consideration as an adhesive paired with B-98. While B-98 and B-76 are both PVBs, the distribution of their alcohol, acetate, and butyral species occurs in different proportions along the polymer chain (Eastman Chemical Company 2017). Review of the manufacturer's properties data indicates that B-76's molecular weight is nearly twice that of B-98, which is likely related to the increased butyral content. This higher percentage of the bulky butyral structure also has an effect on the rheology of solutions made from the polymer. Looking again at the data, B-76 has more than twice the viscosity of B-98 at the same concentration in the same solvent (Eastman Chemical Company 2017). What I found most interesting in my review of the properties was the comparison of tensile strength between B-76 and B-98. The test results clearly indicate that B-76 has a much lower yield and break strength than B-98. Even more interesting is that the upper threshold of B-76's results just meet or slightly overlap with the lowest threshold of B-98's performance (Eastman Chemical Company 2017).

In addition to the way the physical testing results align, the results of solvent solubility testing show that, depending on the solvent chosen, it is possible to dissolve or at least partially solubilize B-76 while only swelling or having no effect on B-98 (Eastman Chemical Company 2017). When I examined these properties together, B-76 began to look very good as the mending resin for the adhesive system I was hoping to formulate. In review, B-76 is adhesively compatible with B-98. Thus, it should bond to the surface with uniform strength; it can be formulated to have a high, but spreadable, viscosity so that it will stay at the bond line rather than migrate into voids or the pores of the plaster; it has a lower tensile strength than B-98 such that, in theory, when excess stress is applied it should fail cohesively along the bond line when B-98 is just beginning to be stressed; and, finally, B-76's bond can be undermined more readily than B-98's in select solvents commonly used in conservation should it become necessary to reverse or reactivate the adhesive bond in the future.

Following my investigation and identification of the potential resins I hoped to use for mending Pettrich's sculpture, I began benchtop testing. During the tests I was keen to understand how B-98 and B-76 would perform together and to arrive at optimal concentrations for the repair to carry it out successfully. Mock-ups were made using USG Hydro-Stone (a type of gypsum cement made by United States Gypsum) and Plaster of Paris found in the Smithsonian American Art Museum lab's stock. Each material was mixed in water to a creamy consistency and cast into aluminum sample trays, giving finished cast discs approximately 1.75 in. (4.45 mm) in diameter and 0.375 in. (9.53 mm) thick. I then broke the samples in half across their diameter with a chisel and hammer. Fragments of unsuccessfully split samples were used to evaluate the application and absorption of B-98 into the plaster surfaces.

Knowing that I wanted a very-low-viscosity solution with as high a solids content as possible, I chose methanol, despite its toxicity, as the carrier solvent for B-98. The penetrative consolidation treatments in the literature most often describe the use of toluene and ethanol mixtures or ethanol alone. However, review of the manufacturer's data clearly shows that at the same percent solids, B-98's viscosity is significantly lower in methanol than in mixtures of ethanol and toluene or ethanol alone (Eastman Chemical Company 2017). I tested a number of concentrations on the plaster fragments and evaluated the surface for visible change and the presence of a film. Concentrations (all w/v) from 1% to 5% showed no perceptible change on the matte plaster surface, even on the very-low-porosity Hydro-Stone samples. Concentrations from 5% to 10% would begin to show film formation on the surface depending on the porosity of the sample, and concentrations above 10% formed a surface film quickly.

Having established some idea of how to deliver the penetrative consolidant and at what concentration, I moved to consider B-76 for the mending adhesive. In thinking about formulating the B-76 solution, I settled on ethanol as the solvent since the data indicated that it would create a workable viscosity for controlled application. I conducted simple benchtop testing on the strength of the B-76 bonded samples by clamping one-half of the broken sample to the work bench, with the break line parallel to the bench's edge, and then applied force with my hands and upper body to the other side. Two things became quickly apparent: concentrations (w/v) of B-76 below 10% are not suitable for structural repair of large plaster sculpture, and the improvement in bond performance between the samples with B-98 applied and those without was glaringly apparent. While B-76 would bond to the untreated plaster surface and could hold the two halves of a sample together, it did not perform in a way that I would consider serviceable, as it took very little applied force to cause failure of the join. Further testing found that concentrations between 20% and 25% offered the best balance of strength and handling. Samples mended with concentrations of B-76 within that range, when applied to surfaces pretreated with B-98, were sturdy enough to handle with normal care but would yield and fail under excess force without significant damage along the bond line. Concentrations above 25% became very viscous and were bulky in the bond line.

When I considered the results of the testing anecdotally, it was clear that for my needs a multipart adhesive system performed better than a single adhesive alone. Given the substrate and the solvent used, a number of factors could be contributing to the results. Since the depth of penetration for the B-98 was not measured, it is difficult to claim to what extent the resin provides reinforcement of the plaster matrix. However, it is clear that pretreating the surface of the break face helped improve bonding with the mending adhesive. Having observed minimal damage to the break faces of the samples after causing failure of the adhesive bond suggests, to me, some degree of penetration and cohesive distribution in the pores of the plaster must occur. If not, I would otherwise expect to see large areas where the dried resin had pulled away from plaster completely or cleaved a thin layer of adjacent plaster from the surface.

In considering the performance of the B-76 resin as an adhesive, I was pleased to see that it behaved very much as predicted. The B-76 solution was compatible with the B-98 treated surfaces, helping the system achieve uniform bond strength. Its higher viscosity helped it remain on the surface of the break face, and its sufficient but not excessive strength demonstrated good yielding properties before causing damage to the surrounding area. Its poor performance bonding to untreated plaster surfaces may be due to the bulkier molecules' tendency to stay on the surface as well as the porous plaster substrate's ability to wick away solvent, starving the join and reducing the resin's ability to bond with the surface.

While benchtop testing confirmed the hypothesized performance, there are a number of alterations that I would incorporate into future sample preparation and evaluation. These include greater aeration of the sample mixture to reflect historical plaster densities and the addition of a visible light or UV visible marker to the solution to better gauge distribution across and into the substrate.

In practice, using the B-98 and B-76 adhesive system is no different than adhesive mending of the many other types of materials that an object conservator might encounter in a museum collection. It is critical to consider sequence and timing for the application of the resin solutions. As the penetrative solution, B-98 is applied to the surface of break faces first and allowed to set for 12 to 24 hours. Application of the solution is easily accomplished by flowing from a brush or hypodermic syringe fitted with a 20- to 28-gauge needle. The B-76 solution should be applied liberally to all pretreated break edges just prior to assembly and clamping since ethanol's evaporation rate from the film gives it a short open time. Delay in joining may cause an increase in viscosity of the solution, which can result in an overly thick bond line. Once assembled, the mends should stay clamped and unstressed for a minimum of 24 hours; longer is advisable. Removing clamps from a mend prior to complete setting of the B-76 resin will likely result in join opening or failure, as the resin does not reach full mechanical strength until set. Application of the B-76 solution is best done with a moderately stiff bristle brush and the surface should be liberally covered on all break faces such that some excess adhesive will ooze from the break line. The oozed excess can be removed using mechanical or solvent methods depending on the finished surface of the plaster.

For the treatment of Pettrich's sculpture, I undertook a more tailored approach, with intermediary steps. In an effort to get deep penetration into the already compromised plaster body of the sculpture, I saturated the plaster with methanol just prior to wicking a 5% (w/v) concentration of B-98 in methanol onto the surface of the exposed plaster and around all areas of previous repair. After allowing the adhesive and solvent-saturated surface to dry, I followed by wicking and brushing a 10% (w/v) solution onto the surface to more strongly reinforce the plaster matrix at the break edge. This was followed by a brush application of 20% B-98 (w/v) overall, including over old repairs and a menagerie of adhesive deposits to establish a homogeneous break face. After the B-98 set, I applied a 10% (w/v) solution of B-76 in ethanol to the area of the break faces overall to ensure that the B-76 mending resin would bond well with the B-98 during assembly and clamping. Once the coating set and the parts were ready for assembly, I used a 25% (w/v) solution of B-76 in ethanol applied liberally by brush to the break faces to complete the mend. Excess adhesive was removed from the surrounding surfaces with mechanical and solvent methods as necessary. I clamped the mend with self-adhering silicone tape (fig. 5) and allowed it to set for two days, checking in frequently during the first few hours to ensure that there was no drift in alignment after clamping and to clean up any additional residues surrounding the break line. After the setting period, the clamping tape was removed to reveal a stable mend. The remainder of the overall treatment included compensation for loss of the plaster body and surface coating.

At this point, I believe that most articles on treatment come to a conclusion, but mine does not end just yet. Recalling my previous thoughts on designing a mend that would fail controllably if too much force was applied, there remains the question of how the theory holds up in practice. Well, no thanks to my own head's accidental collision with the outstretched scroll, I can report that the system performs beautifully! The force of the collision at the end of the scroll was enough to pop open the break line across the palm. It disrupted the soft fill material and acrylic emulsion paint film on the surface, but there was no visible loss or fragmentation of plaster along the break faces. This unfortunate good fortune also gave me the opportunity to assess the retreatability of the repair, which I found to be easily undertaken by removal of loose fill material and a new application of a B-76 solution to the break faces clamped as before. Losses along the break line were again filled and inpainted to match the surrounding area. The story of failure and retreatability does not stop at this incident. The sculpture was "damaged" at least

Fig. 5. The joint clamped for curing

twice more by inappropriate visitor interaction over the course of 10 years and each time successfully retreated.

Having now worked with Butvar B-98 and B-76 regularly over the last 10 years, I can offer a few tips for the new user. When using either B-98 or B-76 with fast-evaporating solvents such as methanol and ethanol, it is wise to have a neat solvent at hand to clean your chosen applicator regularly, as not doing so will likely result in the gumming up of your tool. If you are attempting to consolidate very friable or porous material with a low-resin concentration, a syringe often offers more control and continuous feed as an applicator without the problem of evaporative concentration change. Cleanup of thickly applied B-76 that oozes out of the break line is actually easier to remove in bulk if it is allowed to dry to the consistency of a thick-bodied caulk. Cleanup of oozed B-76 is also aided by a light application of chalk or talc to the areas around the break line if the surface is compatible, allowing for the removal of fine particulate from the surface. High concentration solutions of Butvar that appear thick when applied, generally dry down to thin, compact films—that thick bond line will shrink tight as the resin sets. As an adhesive and consolidant, Butvar does not reach full strength until its carrier solvent has completely evaporated from the film. When in doubt, wait to test the strength of the mend or remove the clamps. Both B-98 and B-76 are strongly reactive to water, and not in a beneficial way: contact with excess moisture can cause the resin to drop out of solution in opaque, ropey strands. If you experience problems with surface "whitening" of methanol solutions, confirm that your solvent has not absorbed atmospheric moisture.

In conclusion, I hope that I have provided an option for structurally mending plaster sculpture that the practicing conservator can use and a window into the method I followed for evaluating the manufacture's data to predict performance. I chose to highlight treatment of the sculpture that challenged me to think a little more broadly, but it is by no means the only plaster sculpture that I have used the adhesive system described in this article to mend. The combination of Butvar B-98 as a penetrative consolidant and B-76 as a mending adhesive has, in my opinion, proven successful for the structural repair of plaster. In my experience, it has proven to be adaptable in scale and provides serviceable strength. The anecdotal evidence in the treatment history of Ferdinand Pettrich's *Washington Resigning His Commission* suggests that the system may also offer support for alternative perspectives on how mends should perform. I think that confirming our understanding of the forces at work in the system by analytical means is worthwhile and lacks only the interested researcher with the necessary resources available. The data would be particularly useful if paired with statistical research into the characterization of plaster densities correlated to location and historical period. For the practicing conservator considering or attempting to use the system as described, I encourage you to conduct your own benchtop tests since—in the parlance of our time—your mileage may vary.

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Richard Wolbers

REFERENCES

Eastman Chemical Company. 2017. *Butvar Polyvinyl Resins: Properties and Use.* Kingsport, TN: Eastman Chemical Company.

Davidson, Amy. 2004. "Preparation of a Fossil Dinosaur." *Objects Specialty Group Postprints, Volume Ten, 2003.* Washington, DC: American Institute for Conservation of Historic and Artistic Works (AIC). 49–61.

Kostrov, P. I., and E. G. Sheinina. 1961. "Restoration of Monumental Painting on Loess Plaster Using Synthetic Resins." *Studies In Conservation* 6 (2-3): 90–106.

Simpson, Elizabeth. 2003. "The Conservation of the Wooden Objects from Gordion, Turkey: Methods for the Treatment of Dry Archaeological Wood." In *Art, Biology, and Conservation: Biodeterioration of Works of Art*, edited by Robert J. Koestler. New York: Metropolitan Museum of Art. 358–369.

Spirydowicz, Krysia E., Elizabeth Simpson, Robert A. Blanchette, Arno P. Schniewind, Mauray K. Toutloff, and Alison Murray. 2001. "Alvar and Butvar: The Use of Polyvinyl Acetal Resins for the Treatment of the Wooden Artifacts from Gordion, Turkey." *Journal of the American Institute for Conservation* 40 (1): 43–57.

FURTHER READING

Pizzi, A., and K. L. Mittal. 2003. *Handbook of Adhesive Technology*. Boca Raton, FL: CRC Press.

Skeist, Irving, ed. 1990. *Handbook of Adhesives*. New York: Springer.

SOURCES OF MATERIALS

Butvar B-76 and B-98
Talas
330 Morgan Ave.
Brooklyn, NY 11211

High-Temperature Self-Adhering Electrical Tape
McMaster-Carr
200 New Canton Way
Robbinsville, NJ 08691-2343

USG Hydro-Stone Gypsum Cement
United States Gypsum Company
Industrial Products Division
550 West Adams St.
Chicago, IL 60661

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CARBON FIBER FABRIC AND ITS POTENTIAL FOR USE IN OBJECTS CONSERVATION

CAROLYN RICCARDELLI

Carbon fiber fabric is a high-performance woven cloth made from carbon filament. It is widely known for its applications in the aerospace, auto, marine, and sporting equipment industries. While high-strength carbon fibers became commercially available in the 1960s and more broadly obtainable for consumer use in the 1990s, we have yet to see this versatile material reach its full potential within the field of objects conservation. Carbon fiber fabric is designed to be used in concert with a resin system to create rigid parts that have a modulus of elasticity comparable to steel. These polymer-reinforced carbon composites are fabricated from layers of carbon fiber cloth laminated together with epoxy. One notable benefit to the conservator is that, while laying up the fabric and resin, the material can be made to conform to almost any shape. The cured composite can be quite thin and is as strong as steel but a fraction of the weight. Carbon fiber composites are ideally suited to applications in which strength, stiffness, lower weight, and outstanding fatigue characteristics are critical requirements, making them particularly well suited for fabricating object supports and mounts. This paper will introduce carbon fiber fabric as a strong, lightweight material that has the potential to replace steel or brass in many conservation mounting applications and will explore ways that carbon fiber fabric has been used in the Department of Objects Conservation at The Metropolitan Museum of Art. Also included is an overview of the material's history and manufacture. Details on how to choose materials and methods for working with carbon fiber fabric are featured.

KEYWORDS: Carbon fiber, Carbon fiber composite, Conservation, Mounts, Aluminum honeycomb

1. INTRODUCTION

Carbon fiber (CF) fabric, once a specialized material reserved for the aeronautics and aerospace industries, is now regularly encountered in daily life. Commercially, it is valued for its lustrous good looks and has been embraced by architects as well as designers of furniture and decorative arts. Carbon fiber composites (CFCs) are becoming more common in sporting equipment and have been adopted by the sailing industry, in which carbon fiber is used in the fabrication of hulls, booms, masts, and even the sails themselves. One of the advantages of carbon fiber composites is that they can be fabricated in virtually any shape or size.

Though widely considered a space-age product, the first carbon fibers were created by Thomas Edison, who patented the material in 1880 for use as a filament in his incandescent lightbulb (Harholdt 2003). Edison's technique involved burning cotton threads in a vacuum until they were fully carbonized, resulting in a material that could make an ideal lightbulb filament due to its heat tolerance and inherent ability to conduct electricity. Edison's carbon fibers, however, had little tensile strength, one of the many ways they differed from modern carbon fibers.

Carbon fiber fabric is a woven cloth made up of thousands of filaments; each filament is composed of primarily carbon atoms that are more or less aligned along the axis of the fiber. It is important to note here that the terms "graphite fiber" and "carbon fiber" are often used interchangeably, but this is a misuse of the terms. "Graphite" refers to a material with a specific molecular structure in which sheets of aromatic carbon atoms are regularly stacked so that they overlap with a carbon atom at the center of each ring. The most commonly available carbon fibers are rarely produced with a graphitic structural alignment. True graphite fibers, which are produced for highly specialized purposes, universally have mechanical characteristics that far exceed those of standard carbon fiber, hence the importance of using the correct terminology when discussing these materials (Lavin 2001).

2. MANUFACTURING PROCESS

Just as Edison used a cotton thread to create his carbon fiber filament, modern carbon fibers are also manufactured from precursors. Historically, rayon was the first precursor used to create high-tensile-strength carbon fibers. Today's CFs are created in a highly controlled manufacturing process and are derived primarily from one of two precursor materials: petroleum pitch (originating from coal tar and petroleum products) or polyacrylonitrile (PAN). The most recently developed feedstock is hydrocarbon gas, which is used to make vapor-grown fibers (Bahl et al. 1998). PAN-based fibers, however, dominate the world carbon fiber market. The first viable production method with this precursor was developed in Japan in the early 1960s and further refined in the United States by Union Carbide as well as the Royal Aircraft Establishment, or RAE, in the United Kingdom (Langley 1971; Bahl et al. 1998).

The first step in manufacturing carbon fibers from PAN is to spin fibers from vats of the precursor, which can be accomplished in a variety of ways—one method is high-speed extrusion of the polymer into a solvent bath (Morgan 2005). The resulting PAN fiber typically goes through a steam heating and stretching process. The fiber then undergoes an oxidation step, which changes the color of the fiber from white to gold, then copper, and eventually to black (fig. 1). This heating process drives off PAN's pendant nitrile groups, ultimately converting the material to a cyclic molecular structure. This is a highly exothermic reaction, which provides an opportunity to recover energy that can be recycled in other parts of the processing (Lavin 2001).

Next, the fibers pass through multiple oxidation stages, adding oxygen atoms to the carbon rings. This step ultimately reaches 200°C and raises the melting point of the fibers. Then, they pass through two furnaces (heated to 1,000°C, and then to 1,500°C) that carbonize the fibers, driving off volatile noncarbon atoms. At this stage, large randomly oriented, aromatic sheets of carbon start to form. The fibers then go through a surface treatment process that roughens the exterior texture to make it compatible with resins, ensuring excellent adhesion during the fabrication of composites. Finally, the fibers are sized with a proprietary polymer, making them easier to process into spools, and then are woven into fabric (Lavin 2001; Oak Ridge National Laboratory 2011).

Fig. 1. Polyacrylonitrile (PAN) fibers going through the oxidation process; as PAN fibers oxidize, they change from white to copper, then finally to black (Courtesy of StellaViegas.com.br)

3. MATERIAL CHARACTERISTICS OF CARBON FIBER

The result of the thermal conversion process described earlier is a carbon filament ranging from 5 to 10 μm in diameter—a fraction of the thickness of a human hair (fig. 2). This tiny fiber has extraordinary characteristics. While the mechanical properties of CF can vary based on manufacturer, precursor, and specific manufacturing techniques, carbon fiber can be described generally as having a stiffness-to-weight ratio that makes it twice as stiff and five times stronger than steel (Gross 2003; Quinn 2010).

Such strength comparisons are commonly reported, but describing carbon fibers in general terms in relation to steel may be misleading. The typical material characteristics used to describe the strength of carbon fiber are tensile strength, a measure of the pulling force a fiber can withstand before it fails, and Young's (or elastic) modulus, which measures the stiffness of a material, or its ability to resist elongation under load. Carbon fibers can be manufactured with a range of tensile strength and moduli. For example, it is possible to create a fiber with high tensile strength and low modulus. A low modulus would be necessary when flexibility is needed, while high modulus would be sought when bending or deflection is not desired (Morgan 2005). For these reasons, it is inaccurate to make broad characterizations stating that CF is "n" orders of magnitude stronger than steel. It is more accurate to say that most CFs match or beat the strength and stiffness of steel.

Strength aside, one of the most desirable features of carbon fiber is its high strength-to-weight ratio. Carbon fibers are universally significantly lighter than steel, making them appropriate for a wide variety of applications for which low weight is required (Gross 2003). Carbon fiber is also chemically resistant and does not corrode the way metals do. It has high temperature tolerance and a low coefficient of thermal expansion, making CF ideal for the construction of spacecraft. Carbon fibers are not subject to creep or fatigue failure, as metals are. Finally, CF is electrically conductive, as Edison discovered nearly 140 years ago.

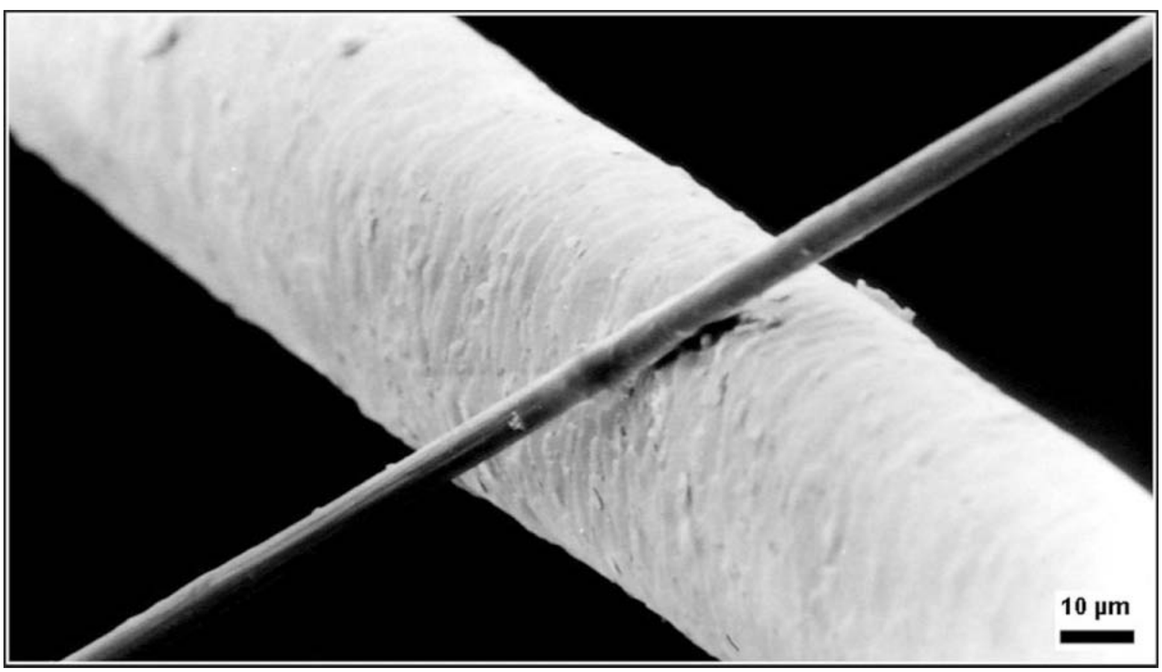

Fig. 2. Carbon fiber filament (top) compared to a human hair (bottom) (Courtesy of Wikimedia Commons)

4. CHOOSING MATERIALS

The material characteristics of carbon fiber are fully realized only when they are carried in a matrix, creating a laminated composite of fiber and resin, or CFC. There is a plethora of fabric weights and weaves on the market, but being aware of common industry terms will help the user to select appropriate materials (fig. 3). A “filament” is a single strand of carbon fiber; thousands of filaments make a “fiber,” or “yarn.” “Tow” is the material used to weave carbon fiber fabrics as well as a standalone product made available on spools. Fibers are described by the number of filaments present: for example, “3K tow” indicates that there are 3,000 filaments in the fiber. With regard to describing weaves, the CF industry refers to the fibers running in the warp direction as “ends” and those running in the weft, or “fill” direction, as “picks.” Ends and picks are measured per linear inch. Thus, a 12 × 12 fabric has 12 fibers in the end direction and 12 fibers in the picks direction. The addition of “3K” in front of 12 × 12 would mean that each of those fibers has 3,000 filaments each (see fig. 3).

4.1 Fabric

FibreGlast is one of many companies selling carbon fiber fabric; they maintain a helpful website with a “learning center” section that includes white papers and videos to inform their customers. As this article was being written, FibreGlast had no fewer than 15 different fabrics available for purchase. Most conservators will find that FibreGlast’s 6K 5HS satin weave cloth and carbon fiber tape will likely suit the needs of most relevant projects. The 6K 5HS satin weave is a versatile fabric available in wide rolls. This fabric is more easily draped over complex shapes than plain weave fabric, and it builds up quickly to create structural parts with virtually no flexibility. Carbon fiber tape is not adhesive backed but is called “tape” because it is woven to width with a selvage to prevent unraveling, one of the inconveniences of slippery carbon fibers. The tape format is convenient if a project requires many narrow strips of fabric. When layering with a laminating epoxy, the plain weave tape wets out quickly and handles easily. Only three layers are typically necessary to produce useful nonstructural pieces, and it is particularly convenient for joining prefabricated parts together.

Prefabricated components are a convenient option for building structures that have regular geometries, as they are available in a wide variety of shapes, such as right angles, C channel, I beam, round or square tubes, and rods. These structural components can be cut with a band saw and then assembled using carbon fiber tape and epoxy. Many online companies offer these components, including CarbonFiberTubeShop.com, McMaster-Carr, Dragon Plate, GraphiteStore.com, and Rock West Composites.

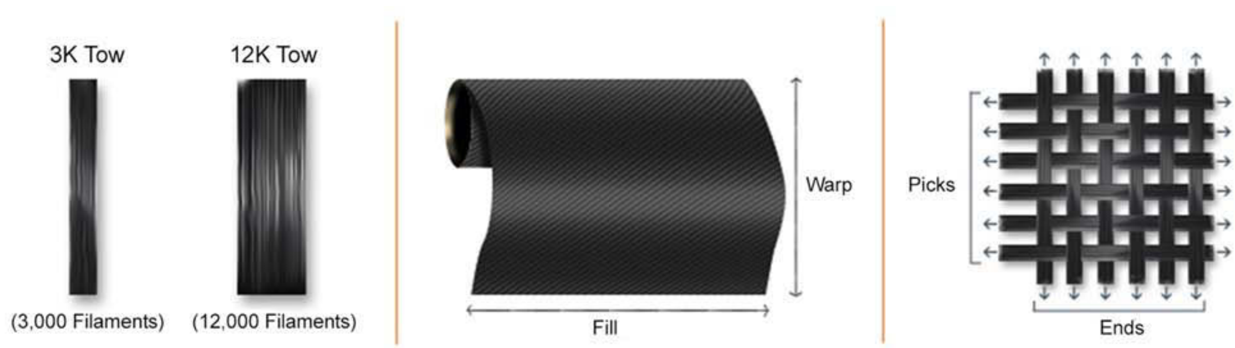

Fig. 3. Terminology of carbon fiber fabric (Courtesy of FibreGlast.com)

4.2 Resins

The three most commonly available laminating resins are polyester, vinyl ester, and epoxy. Polyester is widely used in the composite industry because it is less expensive and more forgiving than epoxy; it is typically paired with fiberglass fabric. Vinyl esters are low-viscosity resins and are well suited for vacuum infusion of composites. Despite the conveniences of other resins, epoxy is the best option for conservation projects because it outperforms polyester and vinyl ester resins in strength and dimensional stability. Epoxy is the most expensive resin of the three options. For the best results, conservators should always use the laminating resin recommended by their CF vendor. For example, when using FibreGlast's fabrics, best results will be achieved when using their FibreGlast 2000 epoxy system specifically designed for laminating CF fabric.

WEST System 105 epoxy is commonly used to make composite parts; however, the reader should be aware that it was not developed for the production of carbon fiber laminates. WEST System was designed to serve the boat-building industry and was specifically made for laminating fiberglass to wood. This brand of epoxy has a lower heat deflection temperature than FibreGlast's resin, which means that CFCs made with WEST System epoxy could potentially soften and sag with direct and extended exposure to sunlight.

5. EXAMPLES OF CARBON FIBER FABRIC IN OBJECTS CONSERVATION

The following examples illustrate some of the ways that carbon fiber fabric has been used in the Department of Objects Conservation at The Metropolitan Museum of Art. This broad overview will help to provide some understanding of CF's versatility and will potentially spark the imagination of conservators to find new and innovative ways to use this material.

5.1 Tullio Armature

Tullio Lombardo's *Adam* is a Renaissance marble sculpture that broke into hundreds of pieces when the pedestal beneath it collapsed in 2002. The conservation project that followed lasted over 10 years and was a time of fruitful research and innovation (Riccardelli et al. 2014). In the early phases of the project, conservators needed a way to hold the individual fragments of the sculpture in an external treatment armature designed to aid in the assembly of the sculpture. After trying various materials, CF proved strong enough to support the marble fragments and sufficiently versatile to allow fabrication in the conservation lab without the need for special equipment (fig. 4).

5.1.1 Torso Corset

The largest piece of the damaged sculpture was the torso, weighing approximately 172 kg (380 lb.). A carbon fiber "corset" was conceived, equipped with a wide flange that would allow the torso to be suspended from an overhead bridge crane. A full-scale model of the torso (the result of three-dimensional laser scanning and computer numerical controlled [CNC] milling) was used as the form on which the corset was fabricated. To account for the thickness of a cushioned lining inside the strap, the torso model was first prepared with a layer of Volara followed by tight layers of protective stretch wrap plastic (fig. 5a). Strips of 6K 5HS satin weave fabric were cut to fit around the torso. Then, the fabric was laid down on the form, layer by layer, each time applying a coating of FibreGlast System 2000 laminating epoxy (the same epoxy was used for all of the examples in this paper). Finally, the whole was wrapped with more stretch wrap plastic, ensuring that the carbon fiber and epoxy would cure perfectly conformed to the shape of the torso (fig. 5b).

Fig. 4. Fragments of Tullio Lombardo's *Adam* supported by an external armature; the black straps around torso and legs are carbon fiber supports (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

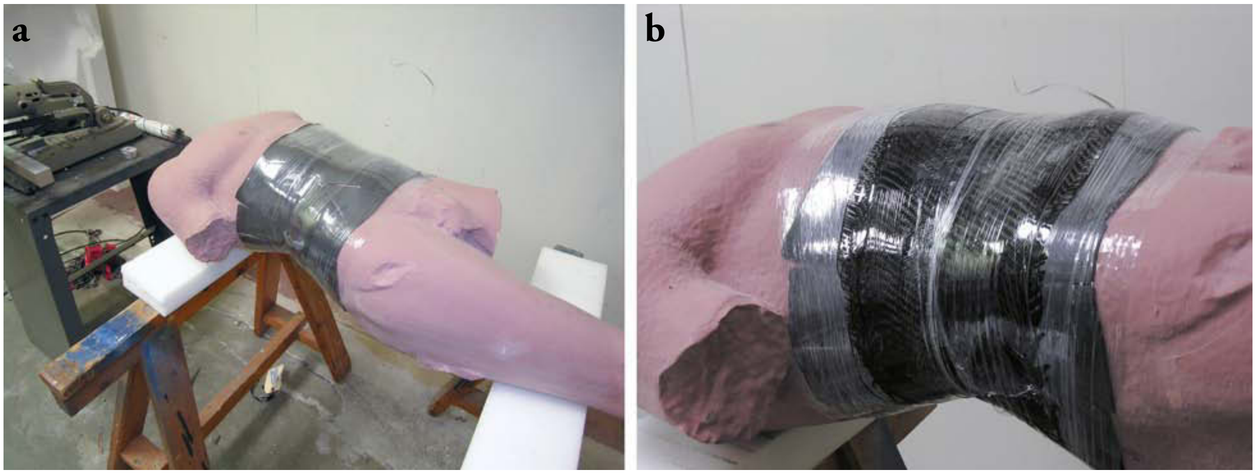

Fig. 5. (a) Computer numerical controlled (CNC)–milled torso form prepared with Volara and stretch wrap plastic. (b) Four layers of 6K 5HS satin weave fabric laminated with epoxy, then compressed with stretch wrap (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

Next, as a separate part, a flange that extends horizontally from the corset was created by simply laying down on a flat surface protected with silicone Mylar several layers of fabric in a ring form. The flange was bisected and then attached to the right and left sides of the cured corset while still attached to the torso model using strips of CF tape and epoxy (fig. 6). Once the flange was well attached, a thin hacksaw blade was used to make cuts at the front and back of the whole assembly, releasing it from the torso form. The corset at this point was rough, far from being finished. The cured form was then shaped on a belt sander. Laminating carbon fiber fabric is messy, and it is common for epoxy to drip and pool around the edges of the fabric, inevitably resulting in dangerously sharp protrusions of fibers embedded in epoxy. It is essential to use personal protective equipment (PPE)—including eye protection, dust mask, and gloves—when cutting or sanding carbon fiber fabric.

After the flange was attached, additional vertical “buttresses” were secured to the corset to provide more structural support. These parts consist of separately made sheets of laminated carbon fiber, cut to fit on a band saw, and then attached with a few layers of carbon fiber tape and epoxy. Several layers of fabric were added to the corset overall to increase the stiffness of the form. The completed torso corset, shaped and sanded to be free of sharp edges, was tightened in place by means of two knob-and-bolt assemblies that passed through the front and rear buttresses. The entire assembly was suspended from an overhead bridge crane by means of threaded rods (fig. 7).

5.1.2 Leg Straps

Carbon fiber was also used to make the straps that held *Adam*’s leg fragments in place. As with the torso, full-scale models of the major fragments served as the forms on which the straps were made. The leg straps were built up with carbon fiber similarly to the corset but without the need for flanges or structural reinforcement. Another difference from the torso corset was that hardware connectors and closures were built into the leg straps. By incorporating flange nuts into the layers of carbon fiber, the straps could be connected to a rigid external framework by means of ball joints, adding some articulation to the setup. The straps were tightened around the fragments by means of hose clamps embedded into the layers of carbon fiber fabric (fig. 8). The resulting straps were rigid enough to support the stone fragments but still had enough flexibility to be removed at the end of use without the need to cut them off the sculpture.

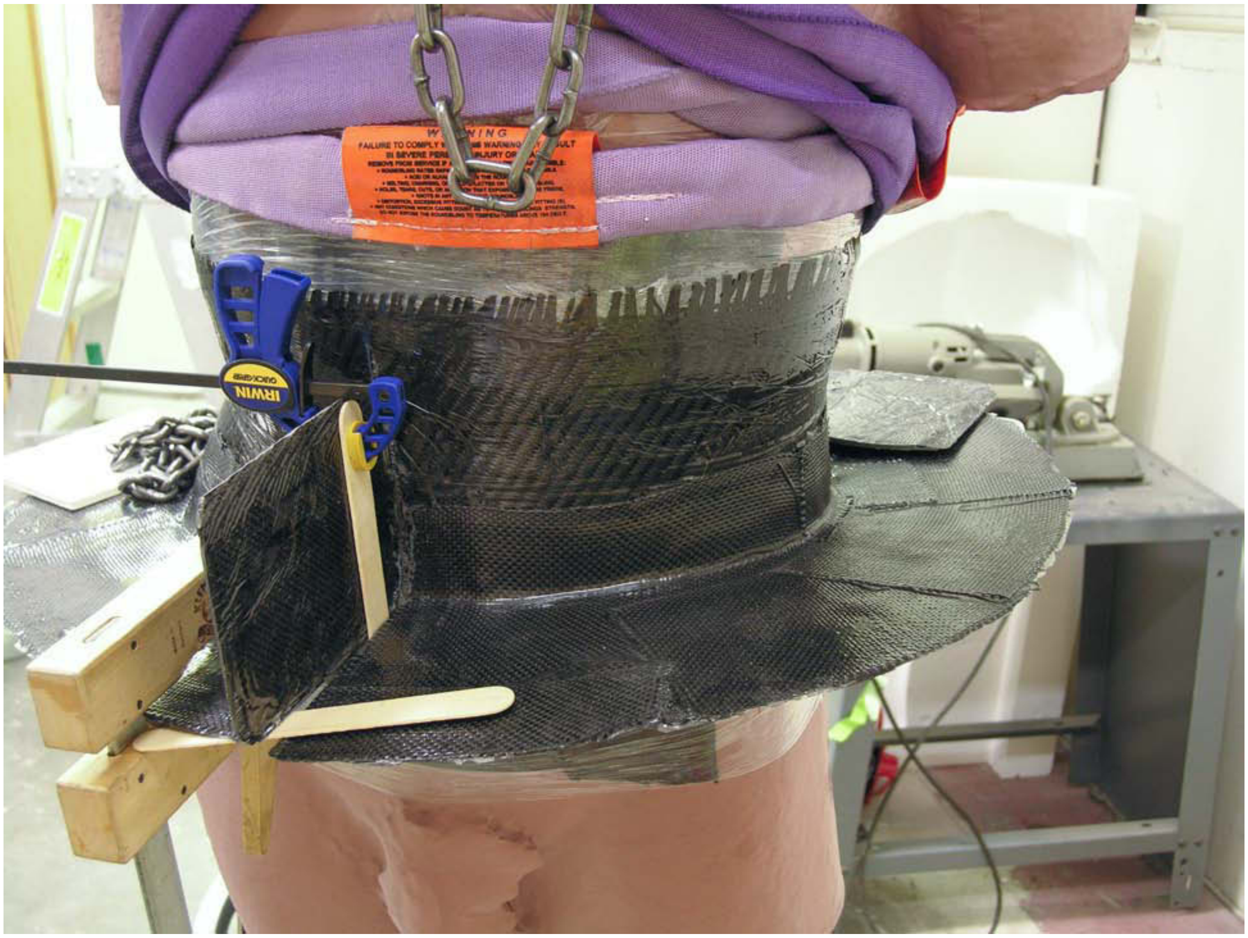

Fig. 6. Attaching a previously fabricated flange to the inner corset using additional layers of plain weave carbon fiber fabric (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

The corset and leg straps were critical components of the external armature used throughout *Adam*'s reconstruction, serving as a support system that allowed assembly and reassembly of the fragments as needed, and was capable of holding the fragments in precise positions for long periods while the chosen acrylic resin adhesive reached full strength. The sculpture was fully assembled in its armature each time adhesive was applied to a join, providing the opportunity to closely monitor the alignment of the fragments. Riccardelli et al. (2014) provide a detailed account of how the external Tullio armature was developed and used.

5.2 *Prudence* Tondo Mounting System

Prudence is a glazed terracotta architectural relief made by Andrea della Robbia in 1475. Fifteen sections comprise the tondo—eight in the colorful garland and seven making up the inner tondo relief. This impressive piece is 164.5 cm (5-1/2 ft.) in diameter and weighs 350 kg (775 lb.). In 2016, the tondo was removed from a deteriorating iron and cement support and remounted in preparation for travel to two exhibition venues (Riccardelli and Walker 2019). One of the main tasks of the project was to create a mounting system that would support each of the tondo's sections individually without the use of adhesives or mortar. The weight of many of the sections surpassed 36 kg (80 lb.) and were deemed too

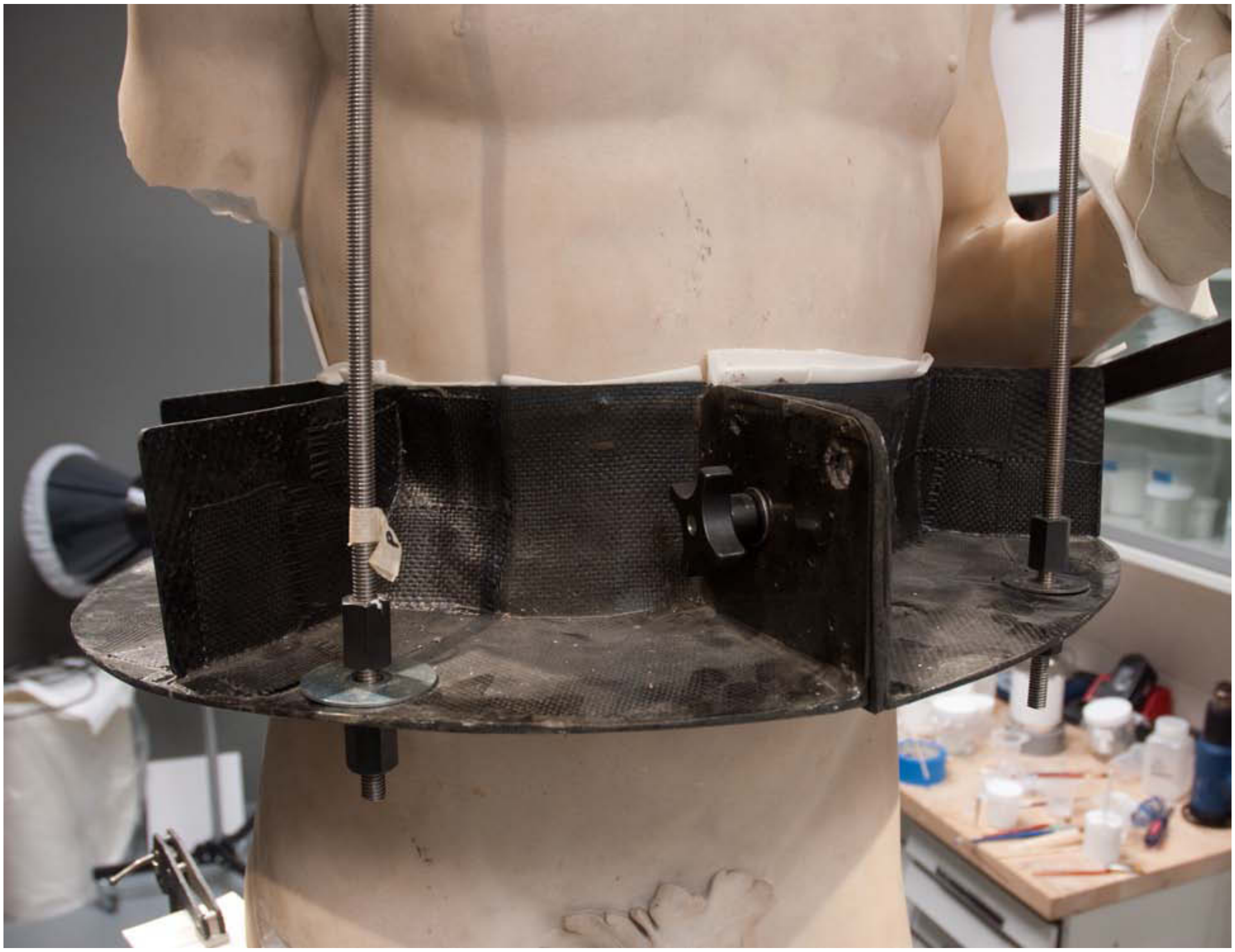

Fig. 7. Completed torso corset with additional buttresses and hanging hardware. Bolts and knobs were used to pressure fit the corset around the torso. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

heavy for brass strap mounts normally made by the Department of Objects Conservation's preparators. The use of steel mounts was ruled out, as the logistics of fabrication by The Met's metal shop would have proven too complicated and time-consuming. Furthermore, heavy steel mounts would not have been aesthetically acceptable. Carbon fiber once again proved to be a versatile, lightweight solution to our needs and was used to create customized mounting clips that fit into a specialized backing panel (figs. 9a, 9b).

The foundation of *Prudence*'s mount is an aluminum honeycomb backing panel custom-fabricated for the project, designed with a diameter slightly smaller than the assembled tondo so that it would not be visible when installed on the gallery wall. Each section of the tondo is held individually by three carbon fiber clips that are mechanically attached to this backing panel. Into the base of each clip, a metal weld nut (a threaded cylinder with a flange at one end) was embedded, allowing it to seat into holes drilled into the panel. The clips are held in place with bolts, fed through from the back of the panel into the nuts (fig. 10). The addition of fender washers under each hex head prevents localized crushing of the honeycomb panel as the bolts are tightened.

Fig. 8. Detail of *Adam*'s left knee in the external armature. Hose clamps embedded into the carbon fiber layers allowed the strap to be tightened around the fragment or loosened to remove the strap at the end of the treatment; flange nuts in the strap allowed attachment of ball joints that connected to a rigid external framework. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

5.2.1 Creating the Prudence *Clips*

Carbon fiber can conform to almost any shape, but it must be molded under some pressure to ensure the best conformation between the fabric and the substrate. Commercially, this is achieved with vacuum bagging, but such equipment and expertise was not available for the *Prudence* project. Furthermore, due to the vacuum pressure required and potential difficulty in controlling the flow of resin, this technique might not be appropriate for use on many art objects. On the armature straps for *Adam*, stretch wrap plastic was used to compress the layers of carbon fiber fabric and epoxy while it cured. For *Prudence*, the object's contours were much more complicated, necessitating the use of a two-part molding system to compress the carbon fiber and epoxy as it cured. The inner part of the mold was created with a quick-set silicone dental putty (Delikit VPS putty) rolled out into a thick slab and pressed around the section to cure (fig. 11a&b). Then, an exterior "mother mold" was made from hard Ethafoam 900 (fig. 11c). The

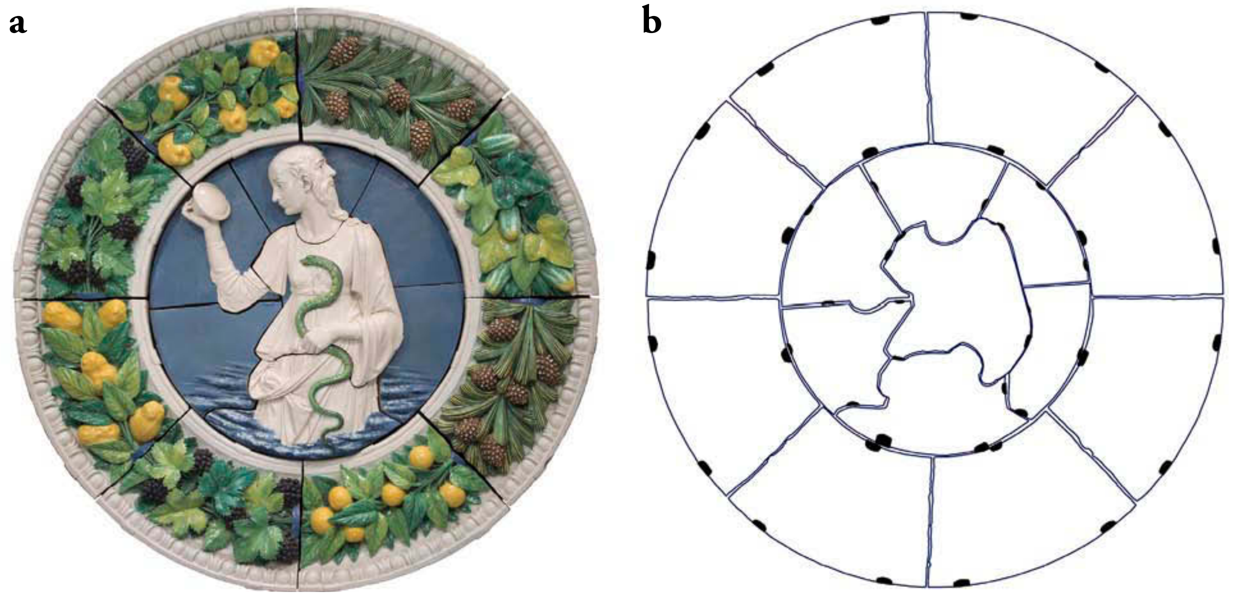

Fig. 9. (a) The tondo after treatment and mounting. *Prudence*, Andrea della Robbia, ca. 1475, glazed terracotta, 164.5 cm diameter, 21.116. Purchase, Joseph Pulitzer Bequest, 1921. (b) Diagram of carbon fiber clips used to hold the tondo's sections. (Courtesy C. Riccardelli, ©The Metropolitan Museum of Art)

inner mold ensured excellent conformation of the CF to the surface, while the outer Ethafoam provided a firm support against the inner mold to distribute pressure from clamps.

As with most multistep processes, thorough preparation made the job of laminating much more efficient. Precutting all of the required CF before getting started was an essential step (fig. 12). Because carbon

Fig. 10. Cross-sectional view of a garland section on the *Prudence* mounting system (Courtesy C. Riccardelli, ©The Metropolitan Museum of Art)

Fig. 11. (a&b) Creating internal mold of a garland section using silicone dental putty. (c) Ethafoam "mother mold" in place around a section of the inner tondo (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

Fig. 12. Precutting the carbon fiber fabric into strips in preparation for layering with epoxy (Courtesy of D. Hausdorf, ©The Metropolitan Museum of Art)

fiber fabric is slick and the weave unravels easily, a rotary cutter, commonly sold in fabric stores, was effective for cutting the material. While the fabric appears soft to the touch, it is highly recommended for those handling the cloth to use PPE, as tiny, loose filaments generated while cutting can work their way into the skin and nose and are extremely irritating. For each round of lamination, we found it useful to prepare the workspace with a sheet of plastic wrap (taped down on all edges), which provided a convenient work surface that was quick to clean up. Prior to mixing the epoxy, we went over a mental checklist of prepared supplies and rehearsed all of the steps in the process.

With the mold forms of the tondo sections complete, fabric cut, and the workspace prepared, we could begin laminating the cloth and epoxy. A small batch of epoxy was mixed (enough for two clips). Then, the strips of fabric were laid down, one layer at a time, each time brushing on epoxy and tamping it through the fabric with a brush to saturate all of the fibers with resin (fig. 13a). Inexpensive "chip brushes" with natural bristles were ideal for this purpose. As the layers were built up, we found it helpful to lay down a temporary layer of plastic wrap, and to firmly squeegee the fabric and epoxy with a scraper of some kind. A stiff plastic ceramic rib worked well for this task (fig. 13b). Taking time to do this extra step mid-way through the process helped to ensure the cloth was thoroughly wetted with epoxy.

Next, we incorporated a weld nut into the carbon fiber layers. It was necessary to create a hole in the fabric using a sharpened pencil prior to pushing the nut through (fig. 14a). To prevent epoxy from flowing into the threads of the weld nut, a temporary nylon set screw was inserted into the nut along with some Orvus paste as a release agent. Additional layers of fabric were added on top of the flange in order to securely integrate it into the clip (figs. 14b, 14c). In all, seven layers of 6K 5HS satin weave fabric were used for each of the *Prudence* mounting clips.

After all layers were assembled, the plastic wrap that had been functioning as the work surface was carefully folded around the material, making a protective package to assist in moving the slippery, sticky material. This package was then laid into the silicone component of the mold (fig. 15a). With the surface of the object protected with layers of plastic wrap, the prepared carbon fiber and silicone mold were carefully put in the predetermined location, the Ethafoam "mother mold" was added, and then was clamped tightly (figs. 15b, 15c).

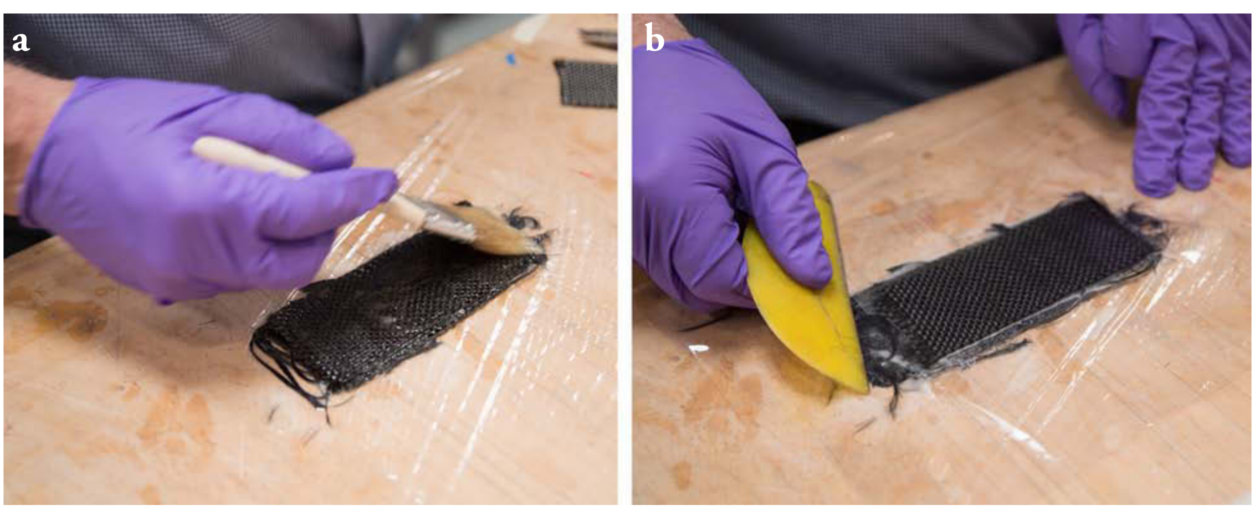

Fig. 13. (a) Brushing epoxy onto carbon fiber fabric. (b) Squeegeeing the layers to ensure saturation of the fibers (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

Fig. 14. (a) Insertion of weld nut hardware into the cloth; a nylon set screw prevented epoxy from flowing into the threads. (b) Flange of weld nut on top of carbon fiber layers. (c) Additional carbon fiber layers added on top of weld nut's flange. (Courtesy of W. Walker, ©The Metropolitan Museum of Art)

Fig. 15. (a) Layers of carbon fiber fabric and epoxy enclosed in plastic wrap package, laid into silicone inner mold. (b) Clamping while epoxy cures. (c) Detail showing clamping pressure on molds and carbon fiber. (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

After the epoxy had cured a minimum of 12 hours, the molds could be removed from the object, revealing a strip of hardened carbon fiber fabric perfectly conformed to the shape of the object (fig. 16a). The clips were strong and stiff, but still flexible enough to remove from the object using a bit of leverage applied from the bottom of the clip. The clips were then shaped on a belt sander to remove excess material and rough edges. Thin acrylic felt padding was applied to the inner surfaces of the clips before they were returned to the object (fig. 16b). A finishing step was to paint the clips to match the surrounding terracotta or glaze. While labor intensive, using carbon fiber fabric on this project produced strong, lightweight, low-profile supports that were barely visible either from the front or side of the object (figs. 9a, 16c).

5.3 Turtle Shell Mask Support

Carbon fiber fabric can be built up to create strong and lightweight supports for heavy objects, but it can also be used on more delicate objects. In 2007, Amy Jones Abbe (now of Jones Abbe Art Conservation, LLC) treated a turtle shell mask in preparation for the reinstallation of The Met's Oceanic galleries. The piece, which originates from an island in the Torres Strait, separating Australia from New Guinea, is made of more than a dozen large sheets of turtle shell that have been bent, pierced, and lashed together with vegetable-fiber cord. This combination forms a mask representing a human face superimposed on a frigate bird. The turtle shell sheet that formed the bird's right wing had broken, a problem that had been only partially addressed in the past by the use of an external mount to hold it in place. After Amy realigned and joined the break, she proceeded to reinforce the cantilevered wing with a thin, slightly flexible integral support. Carbon fiber fabric was an ideal material for this purpose.

Fig. 16. (a) Rough carbon fiber clip after removing molds. (b) Clips on one of the garland sections, after shaping but before painting. (c) Tondo viewed from the side, showing painted clips (Courtesy of C. Riccardelli, ©The Metropolitan Museum of Art)

To make the supports conform to the shape of the object, a silicone cast was made of the underside of the wing. From that, a two-part plaster mold was created. Because one surface of the support would be in direct contact with the turtle shell, Amy chose EPO-TEK 301-2 as the laminating epoxy for the first layer of fabric, presuming that it might provide a more archival surface on that face of the support. Furthermore, because the weight to be supported by this CF part was minimal and contained within a museum environment, the use of an alternative resin did not raise concern. The first layer of 6K 5HS satin weave CF fabric and epoxy (along with plastic wrap barrier layers) was placed into the prepared plaster mold and then clamped shut. After curing, the mold was opened, and two more layers of CF fabric were added using the FibreGlast 2000 system. The completed strips, about 1.5 cm wide, were shaped and sanded smooth, and then attached across the break using Paraloid B-72 (figs. 18a, 18b). The supports were positioned so that they overlapped primarily in the dark-brown mottling of the turtle shell, with the intention that they would only minimally interfere with the transparency of the material. When the mask is viewed at eye level, the support is barely noticeable even with light transmitting through the wing. The ability to create a lightweight, thin, yet stiff support was the advantage to using CF in this treatment.

Fig. 17. (a) Turtle shell mask before treatment; the bird's right wing was broken and unsupported; mask (Buk, Krar, or Kara); Torres Strait Islands; mid- to late 19th century; turtle shell, wood, cassowary feathers, fiber, resin, shell, paint; 54.6 × 63.5 × 57.8 cm. 1978.412.1510. The Michael C. Rockefeller Memorial Collection, Purchase, Nelson A. Rockefeller Gift, 1967. (b) Detail of broken wing before treatment. ((a) ©The Metropolitan Museum of Art; (b) Courtesy of A. J. Abbe ©The Metropolitan Museum of Art)

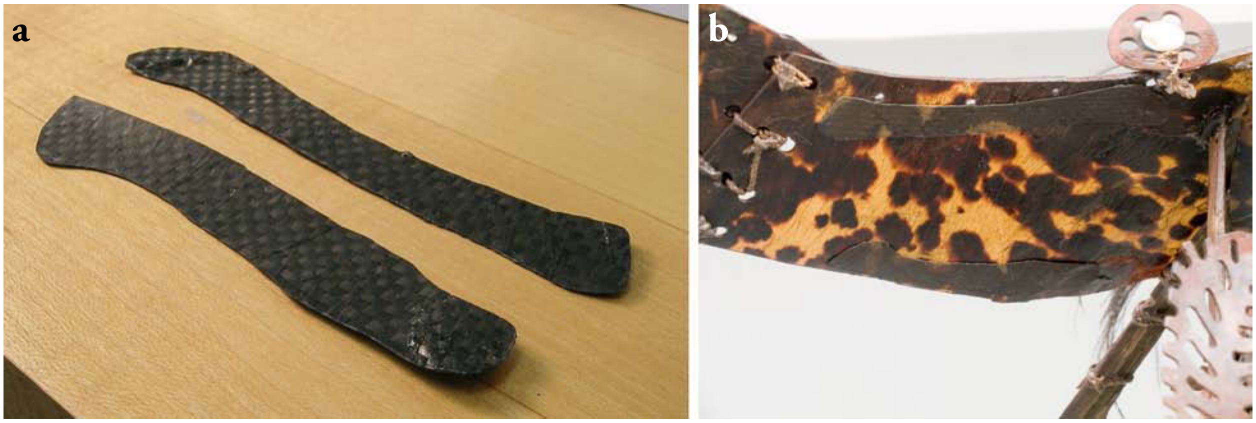

Fig. 18. (a) Carbon fiber supports after molding and shaping. (b) Supports attached to underside of the wing. (Courtesy of A. J. Abbe, ©The Metropolitan Museum of Art)

5.4 Upholstery Supports

The Met's upholstery conservator, Nancy Britton, has been using CF fabric for more than 15 years, and has devised clever techniques to use the material to make rigid frameworks for upholstery. A good, basic example of her technique can be found in a Klismos chair, made in Philadelphia around 1815 (figs. 19a, 19b). For this half over-the-rail chair, Nancy made a cap system that slips over the rails without the need to insert metal fasteners into the wood. Traditional upholstery techniques cause irreparable damage to wooden furniture elements from repeated use of metal fasteners such as tacks or staples, leaving tacking rabbets riddled with holes. Conversely, upholstery conservation methods aim to be noninvasive and employ techniques that avoid insertion of fasteners as much as possible. Nancy's cap

Fig. 19. (a) Chair with new show cover removed. (b) Show cover in place with decorative nail heads. Side Chair, Philadelphia, 1815–1830, ash and pine, 58.7 × 46.4 × 54 cm. 63.143. Anonymous Gift, 1963 (Courtesy of N. Britton, ©The Metropolitan Museum of Art)

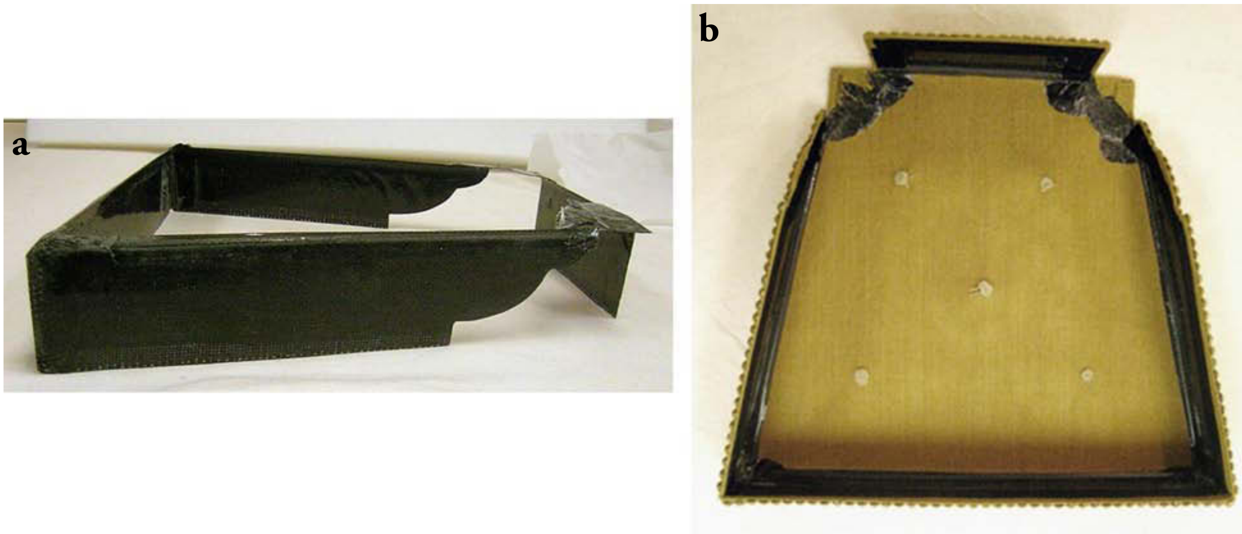

Fig. 20. (a) Upholstery cap frame created from prefabricated right-angle carbon fiber components. (b) Cap with reproduction fabric attached using PVA adhesive. (Courtesy of N. Britton, ©The Metropolitan Museum of Art)

system is completely reversible and easy to remove to provide access to examine the structure of the chair or if the textile needs to be replaced.

On the seat of the Klismos chair, a carbon fiber shell with an open top was made using a combination of prefabricated right-angle components and carbon fiber fabric (fig. 20a). In this case, Nancy left the seat open to allow for the tufting process, which required access to both sides of the fabric. The wool reproduction fabric and padding adhered over the edges of the frame using PVA adhesive, which bonded well with the sanded surface of the CF shell (fig. 20b). Then, tufting was completed using loop Velcro discs that functioned as the stops for silk tufts on the top of the show cover. The final step was to attach reproduction nail heads around the edge of the show cover—these were cast in tinted epoxy and then painted with mica pigments (see fig. 19b). The thin and stiff properties of CF were advantages in this treatment.

6. CONCLUSIONS: MAKING THE CHOICE TO USE CARBON FIBER FABRIC

While high-strength carbon fibers became commercially available in the 1960s and more broadly obtainable for consumer use in the 1990s, we have yet to see this versatile material reach its full potential within the field of objects conservation. With knowledge of the projects shared earlier and the understanding of how to fabricate composites, carbon fiber fabric will undoubtedly inspire conservators to find new and clever ways to incorporate the material into their practice. However, there are many factors to take into consideration before deciding whether CF fabric is the correct material for a project.

Consider your budget. Carbon fiber is expensive. The mid-weight fabric purchased for the *Prudence* mounting project was $220 for a 2.75-m (3-yd.) roll in 2016. A 45.72-m (50-yd.) roll of 5-cm (2-in.) wide carbon fiber tape cost $260 in 2016. Depending on how many layers of lamination are required for a project, the yardage is consumed quickly, and expenses can soar.

Consider whether your project requires the stiffness of carbon fiber fabric. If creating a conforming backing support for a relatively small object, an alternative material, fiberglass fabric, might be sufficient for the project. Fiberglass is laminated in a similar fashion to CF, but is significantly cheaper. On the other hand, there are times when a project calls for a material that is stiff and extremely thin, such as in the case of the turtle shell mask and the upholstery cap shell. Carbon fiber fabric was well suited to fit the needs of these projects.

Consider the environment in which CF components will be displayed. If the location is outdoors, will the composite be in direct contact with or contain metal components? Despite all of the impressive properties of CFCs, carbon fiber is situated very high on the galvanic scale (above stainless steel and titanium); its conductivity must be taken into consideration when using it in contact with metals. Due to its extreme conductivity, when a less-noble metal is electrically connected to a carbon fiber composite, it is susceptible to galvanic corrosion. These conditions are exaggerated when the CF has a large surface area and is coupled with a small metallic part, such as a bolt (Yari 2017). In some of the projects described earlier, metal hardware was incorporated into mounting straps, but in those instances, the CFCs were in use within a stable museum environment, posing little to no risk of corrosion. If CFCs are determined to be ideal for an outdoor installation in contact with metals, there are ways to control galvanic corrosion. One simple solution is to disconnect the electrical connection between CF and metal by laminating an electrically insulating material, such as a fiberglass fabric, between those parts. Another method for managing galvanic corrosion might be to use nonconductive fasteners made from nylon or fiber-reinforced plastic.

Consider the use of CF and epoxy in close proximity to sensitive materials. FibreGlast 2000 epoxy resin catalyzed with 2060 hardener was evaluated by The Met's Department of Scientific Research (DSR) in 2017, following their 20170922_OT protocol, a variant of their 20170606_OT protocol as described on the *AIC Wiki* (Buscarino et al. 2017).[1] Duplicate jars heated for 28 days at 60°C resulted in a "Permanent" rating for all coupons. The lead coupon exhibited some darkening; however, the control leads darkened as well. These results indicate that the material may be used indefinitely in the presence of art, though the DSR recommends that the material be retested using their 20171116_OT protocol, in which the control lead coupons more typically remain untarnished (Buscarino et al. 2018). It is important to note that this Oddy testing protocol does not place the specimen in contact with the metal coupons. Therefore, if a project requires that CFCs be in direct contact with sensitive materials, further testing using a contact protocol should be performed before moving forward with the project.

Carefully consider the risks of using alternative resins. A question that conservators often raise about carbon fiber is, "Can it be laminated with other resins? Can I use B-72?" The use of resins other than those specifically designed to laminate carbon fiber fabric is not recommended. With over 60 years of research and development devoted to perfecting the bond between resin and fiber, the resins specified by CF manufacturers can be counted on to perform as stated. If the wrong resin is used to make a carbon fiber composite, the material characteristics of the product will be completely different from what is reported in the literature.

Carbon fiber has grown in popularity not only with aeronautical engineers and boat builders but also in more artistic fields, such as decorative arts, furniture design, and musical instruments. These extraordinary fibers continue to be essential in high-performance applications for everything from airplanes to automobiles, satellites to sporting goods, and artificial limbs. Certainly, the beauty of the material is seductive. Carbon fiber fabric was essential to the success of the conservation projects described in this article. Taking into consideration all of the strengths and drawbacks of carbon fiber fabric, with practice and planning, many conservators will find that carbon fiber is a versatile material with infinite possibilities.

ACKNOWLEDGMENTS

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NOTE

1. FibreGlast 2000 resin was prepared with the 2060 catalyst and allowed to cure for four days in a mold prior to cutting it into 2-mm thick pieces and placing 2 g of material and a mini-vial containing 0.5 mL water into to a Pyrex screw-top jar. Lead, copper, and silver coupons were inserted into a silicone stopper; then, the stopper was inserted into the neck of the jar. A Viton O-ring was fitted into the screw-top as a secondary seal before continuing with the remainder of DSR's 20170922_OT procedure (Buscarino et al. 2017). The Met has since updated their protocol to 20171116_OT, which replaces the silicone stopper with a laser-sintered nylon coupon holder (Buscarino et al. 2018).

REFERENCES

Bahl, O. P., Zengmin Shen, J. Gerard Lavin, and Roger A. Ross. 1998. "Manufacture of Carbon Fibers." In *Carbon Fibers*, ed. J.-B. Donnet et al. New York: Marcel Deckker. 1–6.

Buscarino, Isabella C., Catherine H. Stephens, and Eric M. Breitung. 2017. "Oddy Test Protocol at the Metropolitan Museum of Art (The Met). Current Version: 20170606_OT and former version 20160416_OT." *AIC Wiki, Oddy Test Protocols.* http://www.conservation-wiki.com/wiki/Oddy_Test_Protocols#Metropolitan_Museum_of_Art_.28MMA.29_Protocol

—. 2018. "Oddy Test Protocol at the Metropolitan Museum of Art (The Met). Current Version: 20171116_OT." *AIC Wiki, Oddy Test Protocols.* www.conservation-wiki.com/wiki/Oddy_Test_Protocols#Metropolitan_Museum_of_Art_.28MMA.29_Protocol

Gross, Jason. 2003. *National Historic Chemical Landmark: High Performance Carbon Fibers*. Washington, DC: American Chemical Society. https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/carbonfibers.html#first-carbon-fibers

Harholdt, Katie. 2003. "Carbon Fiber, Past and Future." *Industrial Fabric Products Review* 88 (4): 14–16.

Langley, Marcus. 1971. "Carbon Fibers—The First Five Years." *FLIGHT International* September 9: 406–408.

Lavin, J. Gerard. 2001. "Carbon Fibers." In *High-performance Fibres*, ed. J. W. S. Hearle. Boca Raton, FL: CRC Press. 156–90.

Morgan, Peter. 2005. *Carbon Fibers and Their Composites*. Boca Raton, FL: Taylor & Francis.

Oak Ridge National Laboratory. 2011. *Carbon Fiber: Conventional Carbon Fiber Conversion*. YouTube video, 1:30. Posted June 7, 2011. https://youtu.be/c3SZiRYJzH8.

Quinn, Bradley. 2010. *Textile Futures: Fashion, Design and Technology*. New York: Berg.

Riccardelli, Carolyn, Jack Soultanian, Michael Morris, Lawrence Becker, George Wheeler, and Ronald Street. 2014. "The Treatment of Tullio Lombardo's *Adam*: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49: 48–114.

Riccardelli, Carolyn and Wendy Walker. 2019. "The Treatment of Two Terracotta Architectural Reliefs by Andrea della Robbia at The Metropolitan Museum of Art." *Objects Specialty Group Postprints, Volume Twenty-Four, 2017*. Washington, DC: American Institute for Conservation (AIC). 24: In press.

Yari, Mehdi. 2017. "Galvanic Corrosion of Metals Connected to Carbon Fiber Reinforced Polymers." *Corrosionpedia*. Accessed October 6, 2017. https://www.corrosionpedia.com/galvanic-corrosion-of-metals-connected-to-carbon-fiber-reinforced-polymers/2/1556.

SOURCES OF MATERIALS

Aluminum Honeycomb Panels
Composite Panel Solutions (No longer in business)
7167 Rte. #353
Cattaraugus, NY 14719

Carbon Fiber Fabric and Laminating Resins
FibreGlast
385 Carr Drive
Brookville, OH 45309
http://www.fibreglast.com/

Delikit VPS putty, regular set
Net 32 Dental Supplies
250 Towne Village Dr.
Cary, NC 27513
https://www.net32.com/

Ethafoam 900 (commonly called 9-pound Ethafoam)
Sealed Air
301 Mayhill Street
Saddle River, NJ 07663
www.ethafoam.com

EPO-TEK 301-2
Epoxy Technology, Inc.
14 Fortune Dr.
Billerica, MA 01821
https://www.epotek.com/

Paraloid B-72
    Manufactured by Dow Chemical Company
    Talas
    330 Morgan Ave.
    Brooklyn, NY 11211
    https://www.talasonline.com

Weld nuts, flange nuts, hose clamps, chip brushes
    McMaster Carr
    PO Box 5370
    Princeton, NJ 08543
    https://www.mcmaster.com/

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SO DELICATE, YET SO STRONG AND VERSATILE: THE USE OF PAPER IN OBJECTS CONSERVATION

PAULA ARTAL-ISBRAND

A large variety of acid-free Asian and Western papers offer objects conservators many possible applications in our work. Not only have we borrowed this extraordinary material—*paper*—from the field of paper conservation, but we have also adopted many of the well-developed methods and techniques of handling and manipulating it in our three-dimensional conservation treatments. Paper meets all of the essential criteria for use in modern conservation practice, including reversibility, strength, inertness, long-term stability, minimal change in color over time, and compatibility with the original artwork. Additional characteristics that make paper attractive to objects conservators are that it is lightweight, hydrophilic, conforms well to complex surfaces, is nontoxic, and not affected by the solvents typically used in our work. Also, the cost of the paper varies but is not excessively high. Finally, having the option of using paper in sheet, fiber, or powder form—either in a dry or wet state—allows for even wider applications. This article is a survey of the wide range of applications of paper in the field of objects conservation. Its use in conservation treatments can have two very different functions. It can serve as a restoration material, remaining with the artwork after the treatment is complete, or as a tool during treatment, not remaining with the artwork after the treatment is complete.

KEYWORDS: Paper, Cellulose, Fibrous cellulose, Poultice, Asian paper, Kozo, Gampi, Mitsumata, Objects conservation

1. INTRODUCTION

In North America, most conservation graduate programs train their students specializing in objects conservation to be prepared to care for three-dimensional (3D) objects made of a wide array of materials, including both organic and inorganic materials. While at larger museums and in private practice objects conservators typically become more specialized, in medium-sized or smaller museums objects conservators are usually responsible for the preservation of the museum's entire 3D collections. Because of this reality, objects conservators have often shown to be remarkably resourceful and creative problem solvers by introducing and adapting new materials and techniques—often borrowed from other specialty fields—as we do our work.

Since the 1990s, objects conservators have increasingly incorporated paper as a conservation material in our wide array of treatments. This remarkable material can be used in the restoration and preservation of a large range of 3D works made of materials that, in most instances, are quite different in character than paper—hard, stiff, shiny, coarse, brittle, cold, heavy, dense, or bulky.

In addition to meeting the material criteria for modern conservation practice—including reversibility, strength, inertness, stability, minimal change in color over time, and compatibility with the original artwork—objects conservators resort to paper as a conservation material because of many other properties as well. Finally, having the option of using paper in sheet, fiber, or powder form—either in a dry or wet state—opens the door to even more types of applications. The main goal of this publication is to provide a survey—including a number of case studies I have undertaken—of the numerous applications and adaptations of this unique material in the field of objects conservation.

2. CHARACTERIZATION AND SOURCES OF PAPER

A sheet of paper is typically made of cellulose fibers placed in molds or onto screens from a water suspension and then dried under pressure. The cellulose fibers in paper are held together through a variety of bonds that give the paper both strength and flexibility (Banik and Brückle 2011). Only acid-free papers are used in conservation, preferably those made without binders, additives, or coatings. Papers made from wood fibers are not used because they contain lignin, an acidic component that causes deterioration of the paper itself and potentially deterioration of materials in direct contact with it (Banik and Brückle 2011).

The papers used in the field of objects conservation are divided into Asian and Western papers. All are made from natural cellulose-based fibers derived from plants, each one with unique properties. The Asian papers are primarily made from the inner bark fibers of three plants (Hiromi Paper, Inc. 2017).
The kozo—or mulberry tree inner bark—produces long and strong fibers, yielding an extremely tough paper (figs. 1a, 1b). The gampi shrub inner bark produces thin, short, and lustrous fibers, yielding a strong, crisp, and translucent paper (fig. 1c) (Hiromi Paper, Inc. 2017). The mitsumata tree inner bark produces soft, thin, and lustrous fibers, yielding a smooth and dense paper. Kozo paper, which is produced in a large range of weights and thicknesses, is the Asian paper most used by objects conservators. Gampi and mitzumata papers are used to a lesser degree.

Western papers used in the field of objects conservation are made of natural plant fibers such as linen (flax), hemp, and cotton (Collings and Milner 1978; Hunter 2011). Western papers used by objects conservators include acid-free mat board made from cotton, lab-grade ashless acid-free filtration paper, and fibrous cellulose powders; the latter two products are made from high-quality cotton linters (fig. 2). The archival, pH-neutral Green's lens tissue made from the fibers of the abaca palm tree leaf stalks is also used (Hatchfield and Marincola 1994).

3. PROPERTIES OF PAPER FOR OBJECTS CONSERVATION USE

Paper is not only a material of choice because it meets the basic material stability criteria in modern conservation, but the fact that it is nontoxic to the practitioner and the environment makes it very desirable. Its high absorbency, ability to conform to surfaces, light weight, and that it is minimally affected by the solvents typically used in objects conservation also makes it attractive for specific applications. Compared to other restoration materials, paper is relatively easy to use, and the treatments are often more expedient and can be readily reversible without putting the artwork at risk of damage. The fact that paper restorations can be made to convincingly resemble the appearance of a wide range of materials—including metal, weathered archaeological glass, bone, wood, leather, and ceramic—makes it particularly appealing to modern conservators who intentionally use different materials in their work to distinguish the restoration from the original. Paper is also easy to clean up without leaving residues, though cellulose powder should probably not be used on objects with uneven, rough, or delicate surfaces because clean up can be problematic.

Fig. 1. Kozo paper, thick (a) and medium-thick (b), and gampi paper (c).

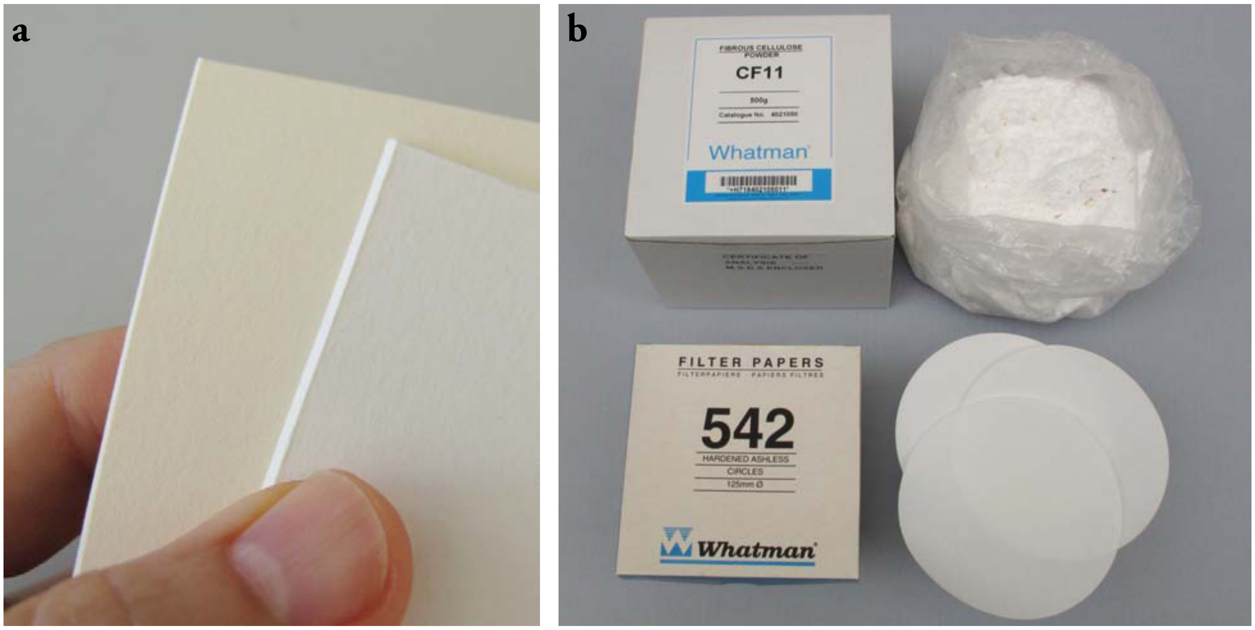

Fig. 2. Western papers used in objects conservation: acid-free mat board (a), and laboratory-grade fibrous cellulose powder and filtration paper (b).

4. CONSERVATION MATERIALS USED IN CONJUNCTION WITH PAPER AND THEIR EFFECTS ON PAPER

Among the conservation materials that are used in association with paper for treatments are coatings, varnishes, adhesives, consolidants, binders, and retouching or inpainting media. For retouching, a wide variety of conservation-grade inpainting media are available, including acrylic emulsion paints (Golden), watercolors (Schminke or Windsor & Newton), aldehyde paints (Gamblin, which are soluble in isopropanol), dry pigments (Kremer), colored pencils (there are many brands—I prefer Caran d'Ache), water-soluble color pencils (Caran D'Ache), or combinations of these.

To impart the desired sheen, translucency, or specific color, a paper-based restoration can be coated or saturated with either water-based acrylics (Golden varnishes or mediums; Acrysol WS-24) or solvent-based acrylics (Paraloid B-72, 2%–30% in acetone:ethanol, 4:1). Adhesives and consolidants used in association with paper are either water-based adhesives (wheat starch paste; methyl cellulose) or solvent-based adhesives (Paraloid B-72, 50% in acetone:ethanol, 4:1; hydroxypropylcellulose is soluble in isopropyl alcohol). If a paper fill needs to remain flexible—for example, for a textile lining or a leather repair—BEVA 371 (a polymer and wax mixture), Paraloid F-10 (acrylic) (Nieuwenhuizen 1998, Kronthal et al. 2003) or Lascaux 303 HV (acrylic) (Baas and Hartman 2019) is recommended. The most widely used binder for cellulose fibers or powder for filling is Paraloid B-72 (30%–50% in acetone:ethanol, 4:1).

All materials discussed in this article have been researched and tested for professional conservation use. However, several recent publications specifically focusing on the interaction of these materials and paper deserve to be mentioned in this context. Soleymani describes her findings in her comprehensive doctoral thesis from 2015 on the subject of paints used by paper conservators (natural dyes, watercolors, and acrylics) in association with kozo paper. She confirms that the use of watercolors and acrylic emulsion paints on kozo paper is not physically or chemically detrimental to the paper after aging tests and exposure to UV radiation were performed. Tear-resistance tests demonstrated that there were no statistically significant differences in the physical properties of the paper painted with watercolors or acrylics. In her joint publication with Ireland and McNevin (2016), Soleymani concludes that watercolors may be more susceptible to fading on paper than acrylics.

Tkalčec, Bistričić, and Leskovac discuss the effects of four adhesives (methyl cellulose; rice starch; hydroxypropyl cellulose; and an acrylic, heat-activated copolymer) widely used in paper conservation on kozo paper in their publication from 2016. They, too, expose their specimen to accelerated aging and UV radiation as part of their experiments. They conclude that the degradation of the paper is retarded by the presence of the first three adhesives and that these adhesives actually improved the mechanical properties of kozo paper in comparison to untreated paper, with hydroxypropyl cellulose faring the best. They also found that the papers treated with methyl cellulose, rice starch, and hydroxypropyl cellulose exhibited enhanced stability against moist heat and UV aging. The study showed inconclusive test results for the acrylic copolymer, probably due to the weak adhesion forces between paper and adhesive (it was not a solvent-based adhesive but rather a heat-activated film). However, it did confirm that artificial aging and exposure to UV radiation did not affect the structure of the acrylic copolymers (which explains why these acrylics are so widely used as conservation materials).

5. APPLICATIONS OF PAPER IN OBJECTS CONSERVATION

As a material used in objects treatments, paper can have two very different functions. It can be used as a restoration material, remaining with the work of art once the treatment is finished, or it can function as a tool during treatment and not remain with the work of art once the treatment is complete. Sometimes paper serves both these roles in the same treatment. The term *restoration* in this article is used very broadly, referring to treatments in which paper is used as a fill material, bulking agent, support, barrier, and the like. It is also important to emphasize that each treatment scenario discussed in the following case studies is unique and that treatment decisions were made on a case-by-case basis. All applications are intended for indoor use only.

5.1 Paper as a Restoration Material

5.1.1 Paper as a Fill Material

Much of the treatment work that objects conservators engage in involves compensating losses in objects that are broken or fragmentary. This effort often consists of replacing restoration materials used by restorers in the past that have proven to be incompatible with the original artwork. Conservators have found that because of its aforementioned attributes, the fabrication of a paper restoration is often faster and less invasive to the original work of art than using other conservation materials. Additionally, paper restorations are typically readily reversible.

5.1.1.1 Bone, Ivory and Antler

Losses in objects made of bone, ivory, or antler can be compensated very convincingly with paper—in board, sheet, fiber, or powder form—depending on the shape of the loss. I used mat board to fill a loss on one of the fan stakes of a 19th century Chinese fan made of bone and retouched it with colored pencils once the fill was adhered with Paraloid B-72 adhesive (50% in acetone:ethanol, 4:1; fig. 3). The mat board was cut to shape with a scalpel.

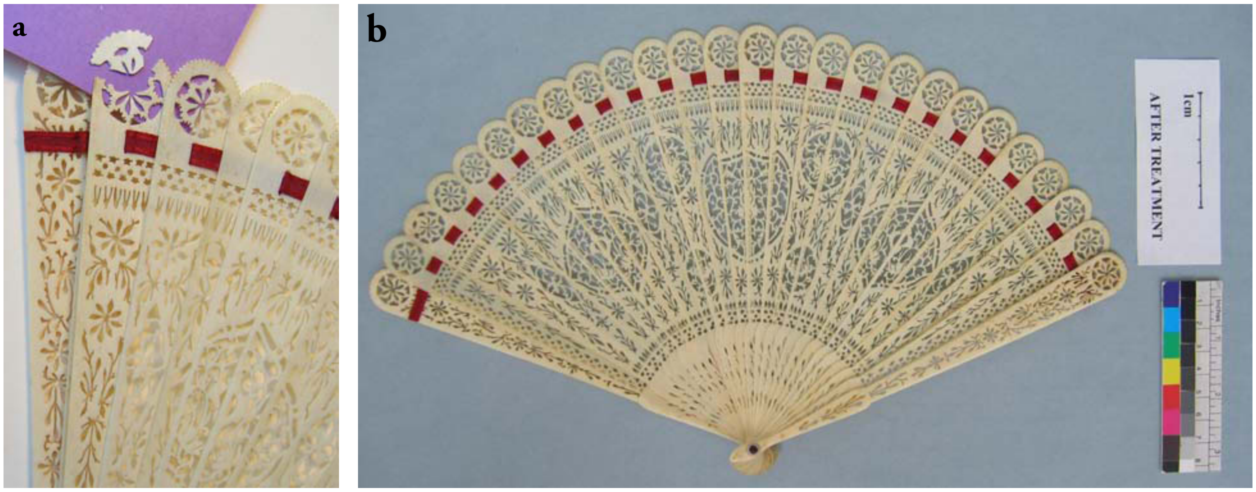

Fig. 3. Fan, Chinese, early 19th century, bone, lace and hardware, 18.7 × 32.0 × 3.3 cm, Worcester Art Museum 1938.100, during (a) and after treatment (b)

5.1.1.2 Ceramic

Occasionally, ceramics can be restored with paper products. The Japanese raku flower vase in figure 4 features an Asian "golden repair"—a technique called *kintsugi* or *kintsukuroi* (Wikipedia 2017), made of gilded lacquer—and had incurred losses in the lacquer decoration (figs. 4b, 4c). The losses were compensated using medium-thick kozo paper painted with acrylics (fig. 4a) using brushes, and cut to the desired shape with scissors. The fills were adhered with Paraloid B-72 (50% in acetone:ethanol, 4:1; fig. 4c).

5.1.1.3 Weathered Archaeological Glass

The semi-translucent quality of medium-thick kozo paper tinted with watercolors and saturated with Paraloid B-72 (30% in acetone:ethanol, 4:1) is especially effective for filling losses in weathered archaeological glass objects (figs. 5a–c) (Artal-Isbrand 1998).

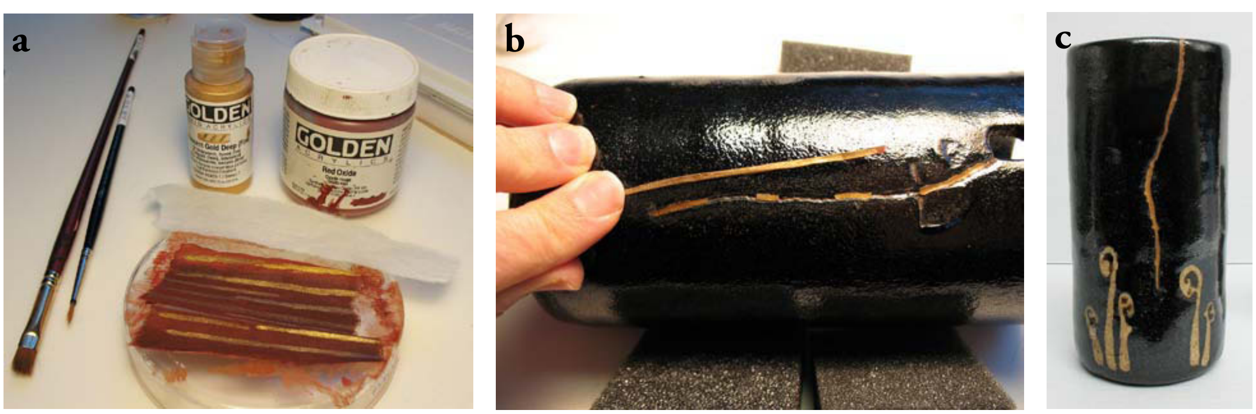

Fig. 4. Flower vase, Japanese, ca. 1800, ceramic (raku ware), lacquer, gold, 12.0 × 39.0 × 13.0 cm. Worcester Art Museum 1954.146, with a kintsugi or kintsukuroi ("golden repair") before (a) and after treatment (b) using kozo paper painted with acrylics (c)

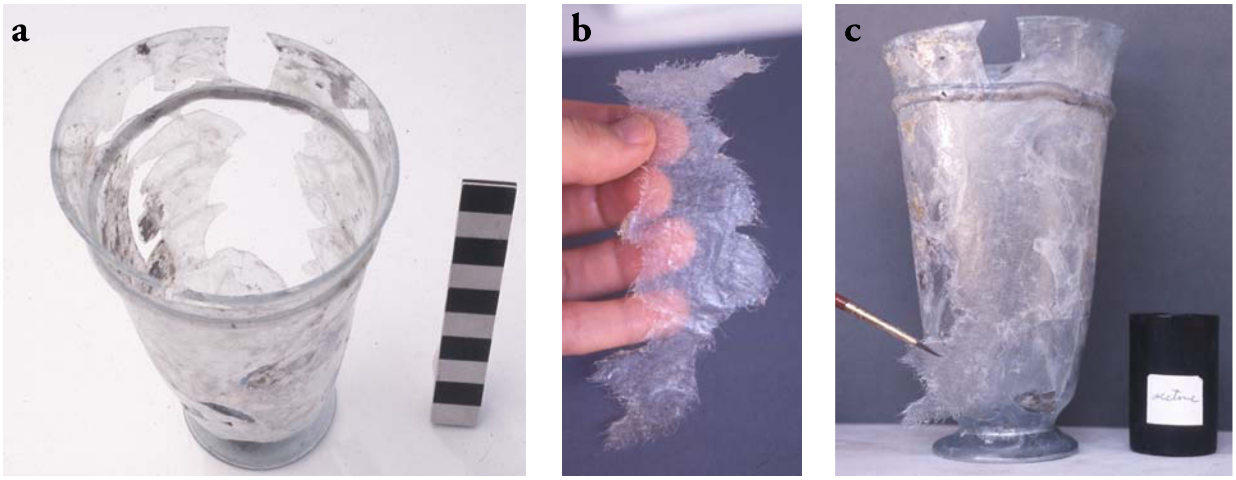

Fig. 5. Beaker, Roman, 3rd to 5th century CE, glass, 15.5 × 7.0 × 6.5 cm. Sardis archaeological site (Turkey), Inv. #AhT67.IV.130N3, before (a) and during treatment using kozo paper saturated with Paraloid B-72 (b and c)

Rather than cutting the paper fill with scissors, it was torn after marking its outline with water using a traditional brush or a water brush (figs. 6a–c)—a technique borrowed from paper conservation—which resulted in a feathered edge of long kozo fibers.

I adhered the fill by overlapping the feathered kozo fiber margin with the edges within the losses of the ancient beaker and reactivating the acrylic consolidant on the paper fill with acetone on a brush (fig. 5c). This technique produces a join that is strong though barely visible (fig. 7). The resulting transparency and consistency of the acrylic-resin–saturated kozo paper is compatible with that of the thin-walled, weathered ancient glass object. This treatment is not only faster and less intrusive compared to a cast epoxy or cast Paraloid B-72 fill but it is also readily reversible without posing any danger of damage to the extremely delicate glass object (Koob 2003; Koob et al. 2013; Bristow and Cutajar 2019).

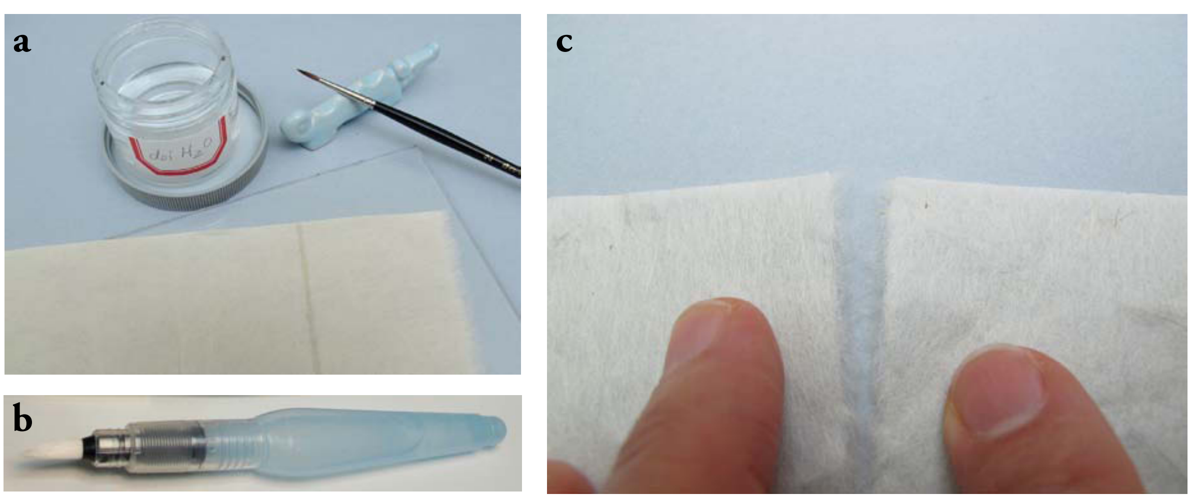

Fig. 6. To produce a paper fill with a feathered edge, the outline is marked with water using a traditional brush (a) or a water brush (b); the paper is then torn along the water mark (c).

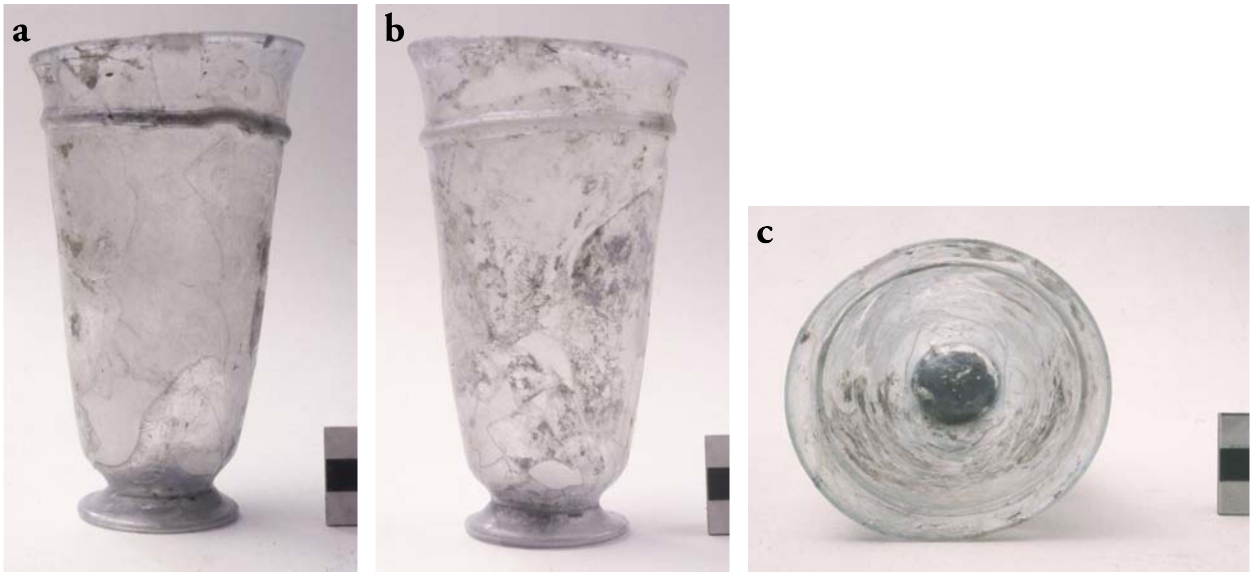

Fig. 7. Beaker, Roman, different views after treatment with kozo paper fills (a–c). (Courtesy of Sardis Archaeological Excavation, photo: Paula Artal-Isbrand)

5.1.1.4 Metal

Thick kozo paper can be a suitable restoration material for losses on archaeological metal objects, not only because of its resemblance to metal when saturated with acrylics and painted with watercolors but also for its remarkable strength. I took this approach on a 16th century Ottoman or Caucasian iron helmet (see fig. 15c) that had previously been repaired with metal sheet stock and wire. After removing all of the old restorations, I used thick kozo paper tinted with watercolors and coated with Paraloid B-72 (30% in acetone:ethanol, 4:1) for structural fills of the earpieces (fig. 8). To increase the thickness of the paper fills, several layers were stacked and adhered with Paraloid B-72. For the chain mail restoration, I cut and twisted strips of the medium-thick kozo paper onto themselves and shaped them into rings (figs. 8a, 9a). All restorations were adhered with Paraloid B-72 (50% in acetone:ethanol, 4:1 fig. 9b).

Fig. 8. Thick and medium-thick kozo paper tinted with watercolors (a) used for the treatment of a Missyurka turban helmet, Ottoman Empire or Caucasus, 16th century, iron, 29.0 × 18.0 × 18.0 cm. Worcester Art Museum 2014.102. Bequest of John A. Higgins, after treatment (red arrow points to the restoration within the earpiece—the visible hole is the original hearing hole) (b).

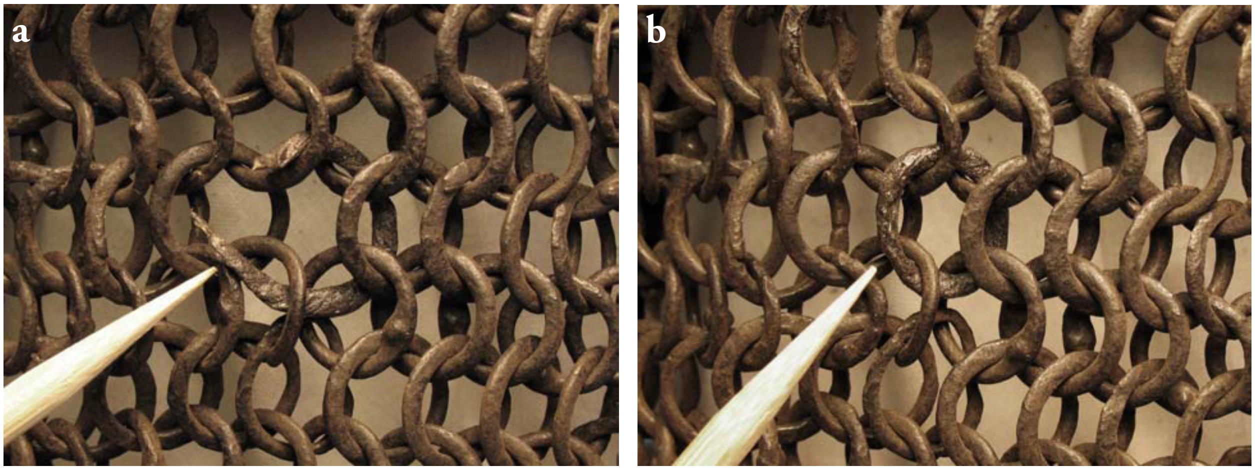

Fig. 9. Missyurka turban helmet, during (a) and after treatment (b).

5.1.1.5 Wood, Paper Mâché, Basketry, Leather, Skin, and Other Organic Materials

As a fill material, paper can also mimic the appearance of wood, paper mâché, basketry, leather, skin, and other organic materials. If it needs to remain flexible, it is coated or adhered with BEVA 371 or Paraloid F-10 (van der Reyden and Williams 1986; Webb 1998; Kronthal et al. 2003). Dignard's annotated bibliography of "Adhesive Backing Treatments for Skin and Leather Objects" is a comprehensive source of publications reporting on the use of paper in the treatment of organic materials (Dignard 2013). In restorations on ancient Egyptian cartonnage made of layers of linen or papyrus and covered with a plasterlike material, Leveque uses layers of kozo paper as a backing for fills made of Paraloid B-72 bulked with 3M microballoons and tinted with dry pigments (Brown, Leveque, and Nau 2019).

5.1.2 Paper as a Reinforcement or Mending Material for Cracks, Weak Joins, Or Breaks

Because of the strength of the long kozo fibers, this Asian paper is very effective for reinforcing cracks or weak joins. I chose this paper in the treatment of an ancient archaeological Italic bronze body armor (fig. 10) that was unstable due to the failing lead solder joins from an extensive past restoration. The

Fig. 10. Torso Armor, Italian Peninsula, ca. 400–200 BCE, bronze and copper, *breast plate (recto)*: 47.5 × 43.5 × 13.0 cm (a), *back plate (verso)*: 49.5 × 45.0 × 8.0 cm, during and after treatment (b and c). Worcester Art Museum 2014.21. Bequest of John A. Higgins

solder had actually never properly bonded to the edges of the bronze fragments (the melting temperature for the lead solder is much lower than that of bronze) but was merely holding them together mechanically. I adhered thick kozo paper strips over the weak solder joins from the back with Paraloid B-72 (50% acetone:ethanol, 4:1) and painted them in situ with Gamblin aldehyde paints. Gamblin paints (used with isopropanol) were chosen because of the water sensitivity of the metal.

5.1.3 Paper as a Support of a Fragmentary Object

Paper lends itself as a permanent support for exceedingly fragile or fragmentary objects in order to keep separated or severely cracked pieces together and to provide a backing to make them safe to handle. I used kozo paper as a support for an ancient curse tablet from Antioch made of thin lead sheet that was rolled upon itself (fig. 11) in the collection of the Princeton University Art Museum (Heintz 2000). The

Fig. 11. Curse tablet, Antioch (Turkey), 4th to 5th century CE, lead, 7.8 × 2.1 × 2.2 cm. Princeton University Art Museum 2011-150 (5555-I 182), overall before treatment (a), and after unrolling, cleaning, and placement on a kozo paper support (b). (Courtesy of Princeton University Art Museum, photo: Paula Artal-Isbrand)

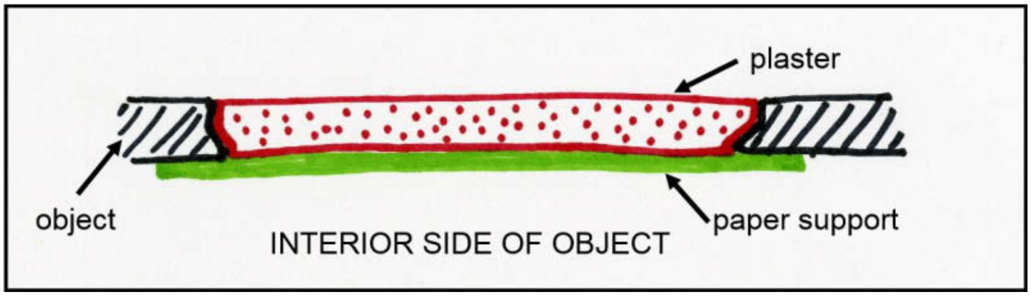

Fig. 12. Cross section of a thick plaster restoration supported with kozo paper in a large hollow ceramic figure

goal of this treatment was to clean and unroll this earth-encrusted and extremely brittle archaeological object in the hope of exposing an inscription on its inner face. The inscription, which had indeed survived, was then captured with the reflectance transformation imaging (RTI) method (Robert and Hollmann, in press). Once the object was cleaned and fully unfolded, I adhered all fragments to a thick kozo paper support with Paraloid B-72 (50% acetone:ethanol, 4:1; fig. 11b).

5.1.4 Paper as a Permanent Support for a Fill Material

Paper can also serve as a permanent support for a fill material, especially if the design of an object does not allow access for the removal of a temporary support or mold for the fill after the treatment is complete. I used this approach to support a large plaster fill on a half-life-sized, hollow 8th century Mesoamerican earthenware figure (Worcester Art Museum, 1964.8). The large figure had been capped off on its underside with an irreversible 20th century structural restoration made of epoxy and wood, making the interior of the object inaccessible. Then I fabricated a multilayer kozo paper support made of thick paper stock saturated with Paraloid B-72 that was adhered to the inside edges of the loss with Paraloid B-72 to hold the plaster fill in place (fig. 12). After the plaster had cured, the paper backing was left in place.

5.1.5 Paper as a Barrier Layer

Paper can also serve as a barrier layer on the interface of an adhesive join to help access it in the future should it be necessary to reverse it or to isolate the artwork from a mounting system used for its display. Both these scenarios presented themselves in the conservation of a monumental polychrome wooden Chinese head of a Guanyin (fig. 13). The glass eyes that make this imposing statue appear lifelike were originally inserted through an access port consisting of a cut-out section within the lower eyelids, which was replaced with a wooden plug. This plug was lost on the proper left eye. The treatment consisted of carving a wooden replacement. Before adhering it with Paraloid B-72 (50%, acetone:ethanol, 4:1), I lined all contact surfaces with a kozo paper barrier adhered with wheat starch paste. If needed, this restoration can easily be removed in the future by saturating the join lined with kozo paper with acetone. A similar barrier, though on a larger scale and solely adhered to the artwork, was also created on the underside of the head to contain the fragile and deteriorated wood of the neck and isolate it from a new exhibition mount.

5.1.6 Paper to "Inpaint"

Asian papers or the archival pH-neutral Green's lens tissue tinted with acrylic emulsion paints have also been used to "inpaint." This application was introduced in the 1990s to compensate extensive paint loss on polychrome wooden sculpture with fragile surfaces. Green's lens tissue fills were adhered to the highly water-sensitive surfaces with the hydroxypropyl cellulose adhesive Klucel G (Hatchfield and Marincola 1994).

Fig. 13. Guanyin, Chinese, 13th century CE, polychrome wood, 60.0 × 51.0 × 51.0 cm. Worcester Art Museum 1932.15. Kozo paper adhered to the underside of the sculpture served as a barrier to protect the fragile wood (a) from an exhibition mount (b). (Courtesy of Paula Artal-Isbrand (a) and Steve Briggs (b))

5.1.7 Paper as a Bulking Agent for Adhesives and Fillers

Paper powder has been used as a bulking material for adhesives and fillers ever since paper was first produced, according to Thornton (1998). Fibrous cellulose powder continues to be used widely in objects conservation for bulking adhesives to serve as fillers in objects of any material (Krumrine and Kronthal 1995; Kronthal et al. 2003). In their publications, Podany et al. (1994, 1995) and Jordan (1999) mention using the proprietary spackling compound Polyfilla, made of calcium sulfate and cellulose fibers, which can be bulked with additional paper pulp to achieve a desired consistency.

5.1.8 Paper as a Pigment

Paper conservators toast fibrous cellulose powder over low heat to achieve different shades of color ranging from tan to brown (fig. 14) to use in their restorations. Futernick and Evans describe the process in the AIC Wiki section of the Paper and Book Group (AIC 1987). Toasted cellulose powder bound with gelatin

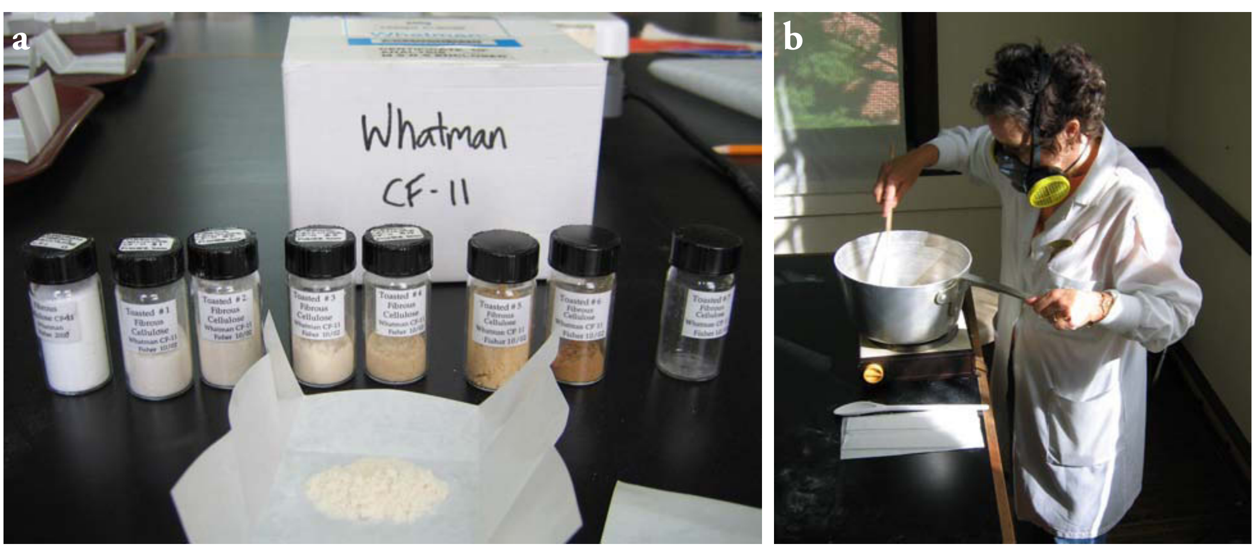

Fig. 14. Whatman CF-11 cellulose powder toasted to different shades (a). Toasting cellulose powder on a heating plate (b)

can be used to “inpaint” or fill stubborn stains that cannot be removed by other means, thereby imparting a textured surface to simulate the appearance of the original surrounding paper (Spaulding 2017). I have mixed toasted fibrous cellulose powder into paint on several occasions to achieve a similar effect.

The low-heat treatment of the cellulose powder during the toasting process should not affect the cellulose structure. According to Shinji, Hitoshi, and Ryusuke (2002), the tensile strength of natural fibers such as hemp is almost unchanged if exposed to heat under 160°C. Only at 200°C do the fibers decrease in tensile strength.

5.2 Paper as a Tool During Treatment

5.2.1 Paper as a Temporary Facing Material

Paper has long been used as a facing material to protect unstable and fragile surfaces of an artwork during transit or storage. For example, I used this approach in my private practice on wall mosaics before their removal from multiple churches in the Boston area that were sold into private hands. The facing paper is adhered to unstable parts of the surface of the artwork using an adhesive that is compatible with the artwork, either a water-based or solvent-based adhesive. After installation in its new permanent location, the paper facing is removed by reversing the adhesive with an appropriate solvent.

5.2.2 Paper as a Temporary Mending or Reinforcement Material

Strips of paper can be temporarily adhered to a fragmentary object during the reassembly process or to reinforce a weak join or crack during the treatment of an object. During the treatment of the turban helmet discussed earlier, I adhered paper “Band-Aids” with Paraloid B-72 to help with the placement and alignment of the fragmentary earpiece during the restoration process (figs. 8b, 15). I also used this

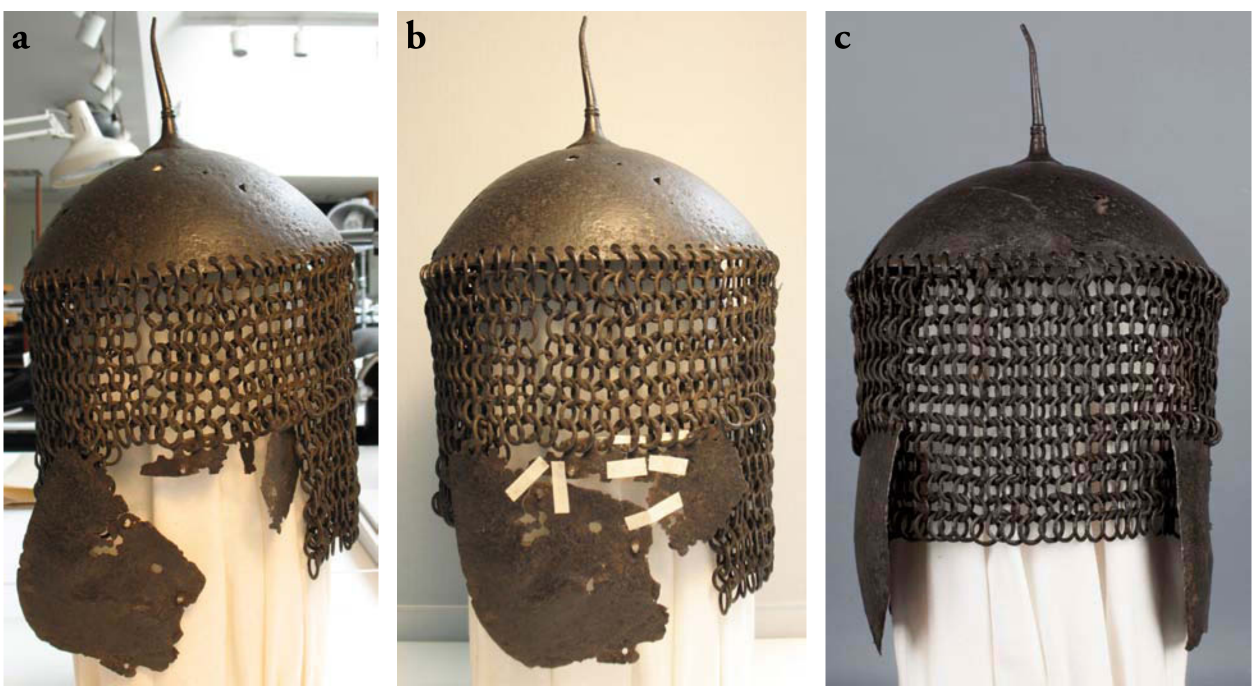

Fig. 15. Missyurka turban helmet, Ottoman Empire or Caucasus, 16th century, iron, 29.0 × 18.0 × 18.0 cm. Worcester Art Museum 2014.102. Bequest of John A. Higgins, before (a), during (b), and after (c) treatment

technique during the unrolling of the lead curse tablet discussed earlier to hold weak parts together during unrolling and cleaning to prevent further damage from occurring. Once the objects were stable, the paper Band-Aids were removed by wetting with acetone.

5.2.3 Paper as a Barrier During Cleaning Treatments with Poultices

For gel treatments, the thinnest of the gampi papers, gampi usouyo paper, serves as an efficient barrier between the surface of the artwork and the poultice. Warda et al. report in their 2007 article that gampi usouyo paper used as a membrane during gel treatments in paper conservation fully blocks the deposition of any gel residues onto the paper substrate. Pouliot also uses this specialty paper in his stain reduction treatments of ceramics to prevent any gel residues from transferring onto the object (2016).

5.2.4 Paper as a Poultice Material or as a Carrier for Cleaning Solutions

Because paper is so absorbent (hydrophilic) and maintains excellent contact with surfaces, it is extensively used in poulticing treatments. Pouliot et al. use a wide range of paper products in their poultice treatments, including fibrous cellulose powders, alpha cellulose powders, wet strength tissue (Kaydry EX-L), various chromatography papers, and specialized cellulosic powders (e.g., diethylaminoethyl cellulose fibers used for rinsing) (Pouliot, Fair, and Wolbers 2013; Pouliot and Wolbers 2016).

I used fibrous cellulose powder mixed with deionized water as a poultice to reduce a water-soluble stain on a Japanese glazed ceramic jar (fig. 16). The poultice material was prepared as described in Section 5.2.5. I had to apply several poultices until the stain was almost entirely gone.

5.2.5 Paper Used to Make High-Quality Molds

Because of the ability of paper fibers to conform to surfaces, paper can be used as a material to make molds. During his popular course "Making high-quality replicas of museum objects," the late Danish objects conservator Erling Benner Larsen demonstrated how to prepare paper fiber pulp from laboratory-grade filtration paper to make a paper mold of an object (Larsen 1981). The filtration paper

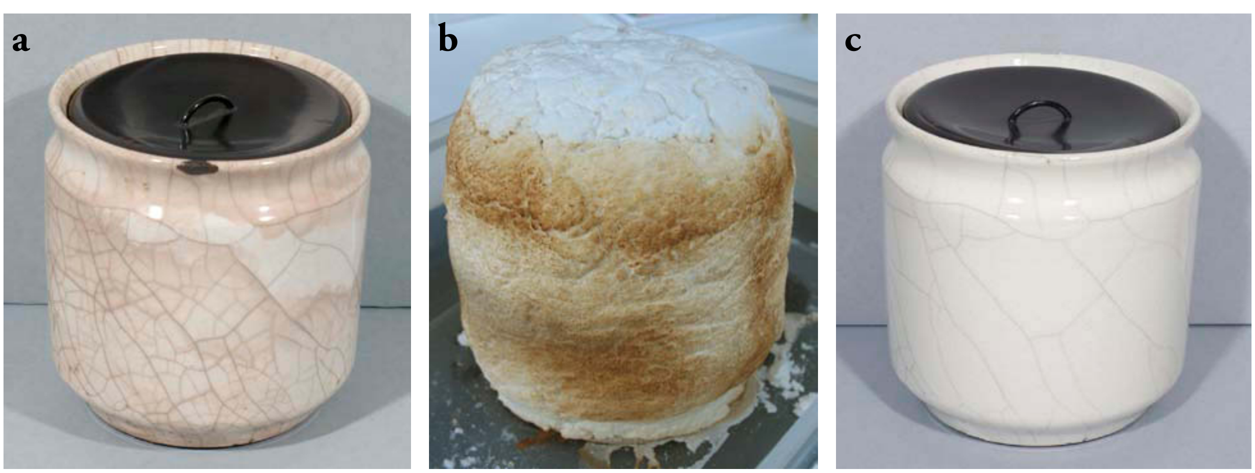

Fig. 16. Water container for tea ceremony, Japanese, 8th century, glazed ceramic with lacquered wooden lid and metal handle, 12.7 × 12.2 × 12.2 cm. Worcester Art Museum 1954.89, before (a), during (b), and after (c) treatment.

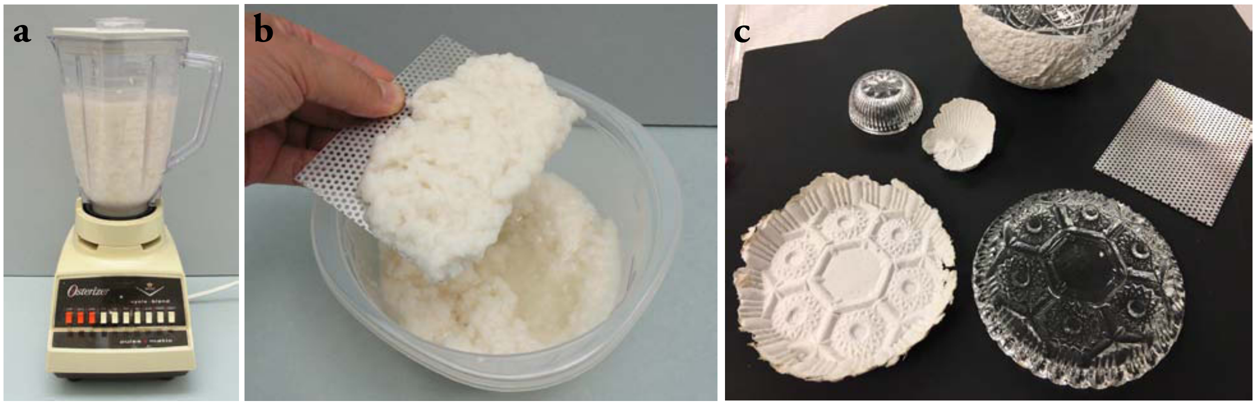

Fig. 17. Filter paper is soaked in water and blended (a). The paper pulp is pressed against the surface of the object with a stiff perforated aluminum sheet. The fibers are compacted as the water is allowed to escape through the perforations, resulting in a paper mold (b and c). (Courtesy of Lauren Fair)

is first torn into pieces that are soaked in deionized water overnight and then blended into a homogeneous paper fiber pulp (figs. 17a, 17b). The mold is made by pressing the pulp through a perforated aluminum sheet onto the surface of the object. This, of course, is recommended only for objects that can withstand getting wet and the pressure exerted on their surface during mold fabrication. Once the pulp dries, a sturdy mold made up of the intertwined polymer network of the long cellulose fibers results (fig. 17c). If a plaster cast is to be produced, the mold needs to be waterproofed first with, for example, a Paraloid B-72 consolidant (15% in acetone:ethanol, 4:1) (Koob 1986) by brush application. Shellac could be used for this purpose as well. Otherwise, the mold would disintegrate upon contact with the wet plaster.

I adapted Larsen's paper mold technique in the treatment of a fragmentary Greek vase (Artal-Isbrand 2010). With about half of the vase missing and in danger of tipping over, the curator and conservator team had agreed that a partial reconstruction of the body, including the missing handle, would help stabilize the vase. Since the full profile of the vase was unknown due to the complete loss of the neck and mouth, the vessel was to be restored only to the shoulder level.

After a full disassembly, a desalination treatment, followed by reassembly of the vase fragments and filling of small losses with plaster, I had to devise a filling strategy for the large loss. The mold materials that I typically use to support the plaster for small fills, such as dental wax sheets or the modeling clay Plasticine, were inadequate for a fill this large. Instead, this treatment called for the fabrication of a large mold that had to be lightweight yet strong enough to hold the weight of the wet plaster. I fabricated a paper pulp mold following the Larsen technique. When the pulp fully dried, the mold was removed from the vase (fig. 18a) and waterproofed with Paraloid B-72 consolidant. This lightweight but strong mold—which also incorporated a separately made plaster handle—was then placed over the area of the large loss and fastened to the object with twill tape (fig. 18b). Plasticine was applied to the edges of the mold to serve as a retaining wall for the plaster, and custom-made thumbtacks were pressed through the mold to indicate the desired thickness of the final cast (fig. 18b). Because of the curvature of the mold, the plaster was poured in two stages. Once the plaster set and dried, the thumbtack holes filled and it was shaped with tools (including scalpels, pottery-making metal scrapers, abrasive paper, etc.), it was consolidated with Paraloid B-72 (8% in acetone:ethanol, 4:1) (fig. 18c), and airbrush painted with Golden acrylic emulsion paints as described by Sigel and Koob (1997) (fig. 18d).

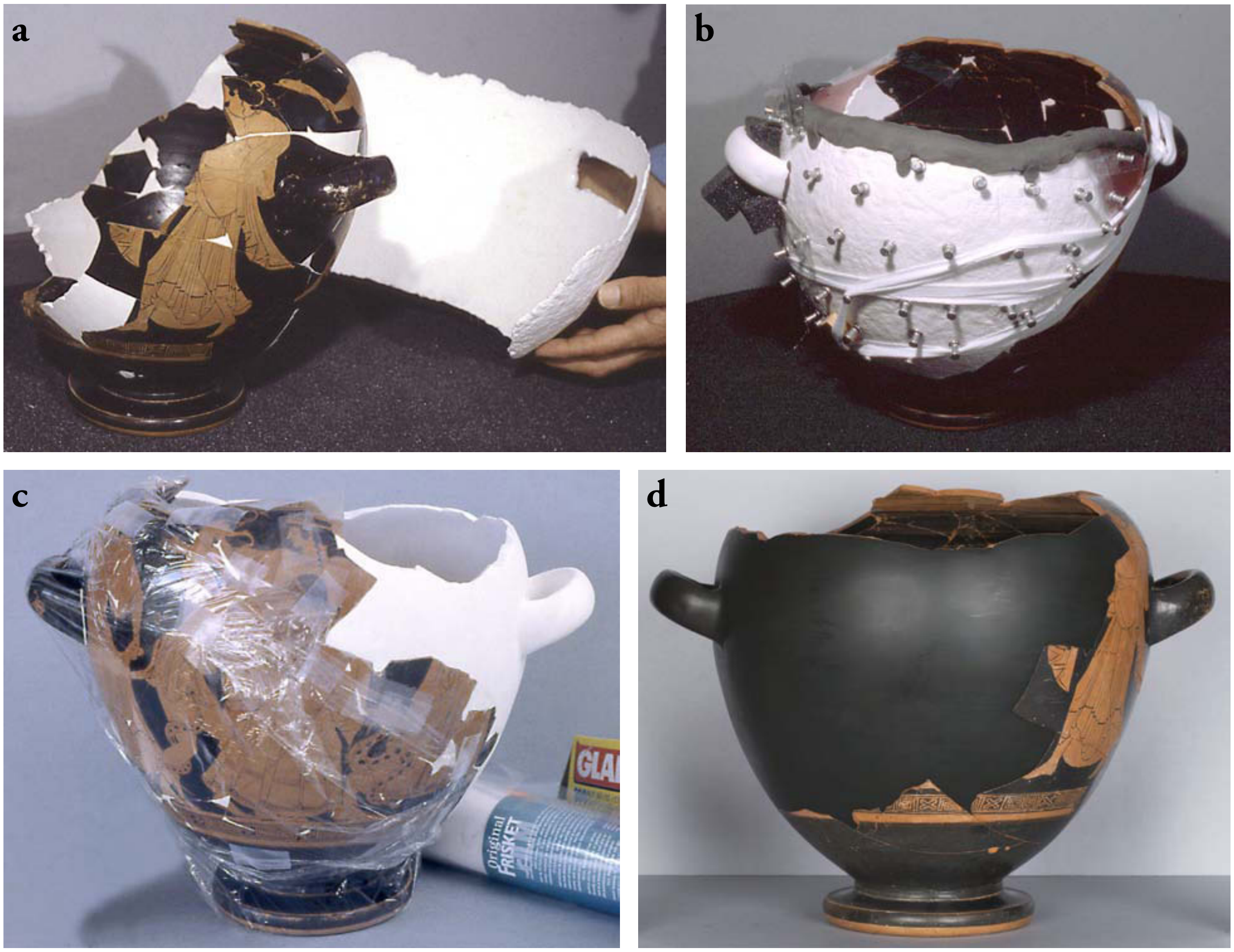

Fig. 18. Stamnos, Tyzkiewicz painter, Athens, Greece, ca. 480 BCE, terracotta, 29.5 × 29.5 × 29.5 cm. Worcester Art Museum 1953.92. Filling a large loss with plaster using a fibrous cellulose paper mold.

6. CONCLUSION

This article has demonstrated the vast potential of paper as a material used in the field of objects conservation by presenting numerous applications employed by objects conservators over the years, complementing them with illustrated case studies of treatments that I carried out. I hope that this article may serve as a reference for objects conservators as we incorporate this extraordinary material borrowed from the field of paper conservation into our repertoire of conservation materials and tools.

Finally, a word of caution. As we plan our conservation treatments, we must also keep the preservation of the paper itself in mind when we use it as a restoration material. Indeed, paper is tough but it, too, is susceptible to deterioration, especially from exposure to acidic materials—as paper conservators well know. It is important that we do not place paper restorations in direct contact with materials that are acidic or that become acidic over time. Art materials that are acidic are typically organic in nature. Such materials are, for example, dark wood (which has a high lignin content), deteriorating leathers, and plastics (which often produce acidic byproducts over time as they break down). Additionally, we ought to understand the makeup of the wide range of unorthodox materials, often composites, used in modern and contemporary art before selecting paper as a material for our conservation treatments. Under such circumstances it is key to fully isolate a restoration made of paper from these materials by creating an appropriate barrier layer between the components. Paper may also be substituted entirely with synthetic materials such as the wide range of polyester products available for conservation purposes (including cast films and woven, nonwoven or spun-bonded fabrics).

ACKNOWLEDGMENTS

I was first introduced to the extraordinary conservation material paper and the clever and elegant techniques of handling and manipulating it by paper conservators Carolyn Long and Lynn Gilliland during a pre–graduate school internship at the National Museum of American History in Washington, DC, in 1988 to 1990. I remain forever grateful to them for all they taught me. I am also indebted to paper conservation professor Irene Brückle at the Buffalo State Art Conservation Program (now at State Academy of Art and Design, Stuttgart, Germany) for building on this knowledge while I was a student there. The contributions of my colleague, paper conservator Eliza Spaulding at the Worcester Art Museum, were invaluable while preparing this article. Finally, I want to thank objects conservation professor Bruno Pouliot at the Winterthur/University of Delaware Program in Art Conservation (WUDPAC) for sharing in my enthusiasm for this unique material—paper—and its vast potential in the field of objects conservation over the years, and for inviting me to teach a yearly seminar on this topic to the object majors. Much of the content in this article is the material that I covered during the WUDPAC seminars.

REFERENCES

AIC, Book and Paper Group. 1989. *Filling of Losses*. Accessed June 16, 2018. http://www.conservation-wiki.com/wiki/Filling_of_Losses

Artal-Isbrand, Paula. 1998. "A Minimally Intrusive Filling and Stabilization Solution for Very Fragile Archaeological Glass Objects." *Proceedings of the Glass, Ceramics and Related Materials: Interim Meeting of the ICOM CC Working Group.* Vantaa, Finland. ed. A. Paterakis. Finland: EVTEK Institute of Arts and Design. 13–16.

—. 2010. "The Use of Fibrous Cellulose as a Mold Material in the Compensation of large losses in ceramics." *Proceedings of the Glass, Ceramics and Related Materials: Interim Meeting of the ICOM CC Working Group.* Corning, NY, Corning Museum of Glass. ed. H. Roemich. Paris: ICOM. 229.

Baas, Fran, and Laura E. Hartman. 2019. "Sitting Pretty: Collaborative Treatment of an Early Yayoi Kusama Soft-sculpture Chair." *Objects Specialty Group Postprints*. Washington, DC: American Institute for Conservation (AIC). in press.

Banik, Gerhard, and Irene Brückle. 2011. *Paper and Water: A Guide for Conservators*. London and New York: Routledge.

Collings, Thomas, and Derek Milner. Collings, T., and D. Milner. 1978/84. "Identification of Oriental Paper-making Fibers." *The Paper Conservator* 3: 51–79.

Bristow, Hana, and Jan Dariusz Cutajar. 2019. "Archaeological Glass Conservation: Comparative Approaches and Practicalities of Using Acrylic Resin Films as Gap Fills." *Objects Specialty Group Postprints*. Washington, DC: American Institute for Conservation (AIC). in press.

Brown J. P., Mimi Leveque, and Morgan Nau. 2019. "Treatment of Two Badly Damaged Egyptian Mummies and Associated Wooden Coffins." *Objects Specialty Group Postprints*. Washington, DC: American Institute for Conservation (AIC). in press.

Daniel, Robert, and Alexander Hollmann. n.d. "Magica Levantina: An Edition of Greek Magical Inscriptions from the Late ancient Levant, with a Web Portal Containing Photographic, Descriptive and Textual Documentation of the Objects." *Abhandlungen der Nordrhein-Westfälischen Akademie der Wissenschaften, Papyrologica Coloniensia*.

Dignard, Carole. 2013. "Adhesive Backing Treatments for Skin and Leather Objects: An Annotated Bibliography." ICOM-CC. Accessed June 16, 2018. http://www.icom-cc.org/54/document/adhesive-repairs-for-leather-annotated-bibliography-may-2013/?id=1211#.WSnkH2jyuUk

Hatchfield, Pamela, and Michele Marincola. 1994. "Compensating Losses: Tissue Paper Fills for Sculpture." *Objects Specialty Group Postprints*. Washington, DC: American Institute for Conservation (AIC). 57–71.

Heintz, Florent. 2000. "Magic Tablets and the Games at Antioch." In *Antioch: The Lost Ancient City*, ed. C. Kondoleon. Princeton, NJ: Princeton University Press. 163–167.

Hiromi Paper Inc. 2017. "Japanese Papers." Accessed June 27, 2018. https://store.hiromipaper.com/collections/japanese-papers

Hunter, Dard. 2011. *Papermaking: The History and Technique of an Ancient Craft*. New York: Dover. 13–39.

Jordan, Fiona. 1999. "Remounting of a Victorian Tile Panel." *Victoria and Albert Museum Conservation Journal* 33: 10-12. Accessed June 16, 2018. http://www.vam.ac.uk/content/journals/conservation-journal/issue-33/the-remounting-of-a-victorian-tile-panel/

Koob, Stephen P.. 1986. "The Use of Paraloid B-72 as an Adhesive: Its application for archaeological ceramics and other materials." *Studies in Conservation* 31 (1): 7–14.

—. 2003. "Tips and Tricks with Epoxy and Other Casting and Molding Materials." *Objects Specialty Group Postprints*. Washington, DC: American Institute for Conservation (AIC). 158–172.

Koob, Stephen P., N. Astrid R. van Giffen, and Robin O'Hern. 2013. "New Developments for Casting Paraloid B-72 for Filling Losses in Glass." *Proceedings of the Glass, Ceramics and Related Materials: Interim Meeting of the ICOM CC Working Group*. Amsterdam, Netherlands. Paris: ICOM. 53–59.

Kronthal, Lisa, Judith Levinson, Carole Dignard, Esther Chao, and Jane Down. 2003. "Beva 371 and Its Use as an Adhesive for Skin and Leather Repairs: Background and a Review of Treatments." *Journal of the American Institute for Conservation* 42 (2): 341–362.

Krumrine, Christina, and Lisa Kronthal. 1995. "What a Relief! A Practical, Inexpensive Approach to the Conservation of a Large 19th Dynasty Sandstone Stela." In *Conservation in Ancient Egyptian Collections*, eds. C. E. Brown, F. Macalister, and M. M. Wright. London: Archetype Publications. 153–163.

Larsen, Erling Benner. 1981. *Moulding and Casting of Museum Objects Using Silicone Rubber and Epoxy Resin*. Copenhagen, Denmark: The School of Conservation, The Royal Danish Academy.

Nieuwenhuizen Linda. 1998. "Synthetic Fill Materials for Skin, Leather, and Furs." *Journal of the American Institute for Conservation* 37 (2): 1935–45.

Podany, Jerry. 1994. "Faked, Flayed or Fractured? Development of Loss Compensation Approaches for Antiquities at the J. Paul Getty Museum." *Objects Specialty Group Postprints,* Washington, DC: American Institute for Conservation (AIC). 38–56.

Podany, Jerry C., Maya Elston, Lisbet Thoresen, and Susan Lansing Maish. 1995. "The Use of Paper Pulp Based Fill Material for Compensation of Losses to Sculpture." In *From Marble to Chocolate: The Conservation of Modern Sculpture*. Tate Gallery. London: Archetype Publications. 59–64.

Pouliot, Bruno, Lauren Fair, and Richard Wolbers. 2013. "Re-thinking the Approach: Techniques Explored at Winterthur for Stain Reduction of Ceramics." *Proceedings of the ICOM Committee for Conservation-Ceramics and Glass Conservation, Interim Meeting.* Amsterdam, Netherlands. Paris: ICOM. 211–223.

Pouliot, Bruno, and Richard Wolbers. December 8–9, 2016. Personal communication during Seminar *Stain Reduction Techniques for Ceramics*, Straus Center for Conservation, Harvard Art Museums, Cambridge, MA.

Shinji O., T. Hitoshi, and N. Ryusuke. 2002. "Mechanical properties of heat-treated natural fibers." *Journal of the Society of Materials Science Japan* 51 (10): 1164–1168.

Sigel, Tony, and Stephen Koob. 1997. "Conservation and Restoration under Field Conditions: Ceramics Treatment at Sardis, Turkey." *Objects Specialty Group Postprints.* Washington, DC: American Institute for Conservation (AIC). 98–115.

Soleymani, Somayeh. 2015. The Effects of Plant Dyes, Watercolours and Acrylic Paints on the Physical, Chemical and Biological Stability of Japanese Tissue Paper Used in Paper Conservation. Ph.D. diss., University of Canberra, Australian Capital Territory, Australia.

Soleymani, Somayeh, Tracy Ireland, and Dennis McNevin. 2016. "Effects of Plant Dyes, Watercolors and Acrylic Paints on the Colorfastness of Japanese Tissue Papers." *Journal of the American Institute for Conservation* 55 (1): 56–70.

Spaulding, Eliza. 2017. Personal communication. Worcester Art Museum, Worcester, MA.

Thornton, Jonathan. 1998. "The Early Practice and Materials of Gap-Filling in the West." *Journal of the American Institute for Conservation* 37 (1): 3–22.

Tkalčec, Marijana Mimica, Lahorija Bistričić, and Mirela Leskovac. 2016. "The Influence of Adhesives on Kozo." *Cellulose* 23: 853.

Van der Reyden, D., and D. C. Williams. 1986. "The Technology and Conservation Treatment of a Nineteenth Century English "Papier Mâché" Chair." *AIC preprints. AIC 14th Annual Meeting, Chicago*. Washington, DC: AIC. 125–42.

Warda Jeffrey, Irene Brückle, Aniko Bezúr, and Dan Kushel. 2007. "Analysis of Agarose, Carbopol, and Laponite Gel Poultices in Paper Conservation." *Journal of the American Institute for Conservation* 46 (3): 263–279.

Webb, Marianne. 1998. "Methods and Materials for Filling Losses on Lacquer Objects." *Journal of the American Institute for Conservation* 37 (1): 117–133.

Wikipedia. 2017. "Kintsugi." Accessed June 16, 2018. https://en.wikipedia.org/wiki/Kintsugi

FURTHER READING

Barrett, T. 1983. *Japanese papermaking—traditions, tools, and techniques*. New York, Tokyo: Weatherhill.

Hunter, D. [1943] 2011. *Papermaking: the history and technique of an ancient craft.* New York: Dover.

Larkin, N. R. 2016. "Japanese tissue paper and its use in osteological conservation." *Journal of Natural Science Collections* 3: 62–67.

Moore, S. 2005. "Japanese tissues: Uses in repairing natural science specimens." *NatSCA Newsletter* 7: 8–13.

Tsu, M. A., D. Fullick, V. Talland, and B. Mangum. 1999. "The conservation of gilt leather wall hangings at the Isabella Stewart Gardner Museum. Part II." *ICOM Committee for Conservation Preprints. 12th Triennial Meeting, Lyon*. Paris: ICOM. 2: 708–13.

Sheesley S. 2011. "Practical application of Lascaux acrylic dispersion in paper conservation." *The Book and Paper Group Annual* 30: 79–80.

SOURCES OF MATERIALS

Acid-free mat board (Rising Museum Board)
Legion Paper
38 E 32nd St.
New York, NY 10016
212-683-6990
https://legionpaper.com/

Asian papers (kozo, gampi, mitsumata papers)
Hiromi Paper, Inc.
9469 Jefferson Blvd. #117
Culver City, CA 90232
310-998-0098
http://store.hiromipaper.com/

Caran d'Ache color pencils, Caran d'Ache water-soluble color pencils, Schminke watercolors, StaWet palettes, pottery tools, and water brush
Dick Blick Art Materials
401 Park Drive
Landmark Center-Fenway
Boston, MA 02215
617-247-3322
http://www.dickblick.com/

Harbutt's Plasticine
Conservation Resources International, LLC, UK
+ 44 123 555 3166
http://www.conservation-resources.co.uk/

Kaydry EX-L (by Kimberly Clark)
Thomas Scientific
1654 High Hill Rd.
Swedesboro, NJ 08085
800-345-2100
https://www.thomassci.com

Klucel G, and Paraloid F-10
Conservation Resources International, LLC
5532 Port Royal Rd.
Springfield, VA 22151
800-634-6932
http://www.conservationresources.com/

Perforated aluminum sheet
Metals Depot International
4200 Revilo Rd.
Winchester, KY 40391
859-745-2650
https://www.metalsdepot.com/aluminum-products/aluminum-perforated-sheet

Pigments
Kremer Pigments
247 West 29th St.
New York, NY 10001
212-219-2394
https://shop.kremerpigments.com/

Paraloid B-72, Paraloid B-10, Gamblin paints, wheat starch, Green's lens tissue, Acrysol WS-24, Lascaux 303 HV, 3M glass microballoons, and BEVA 371, Hollytex, Pellon, Mylar, Reemay

TALAS
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
http://www.talasonline.com/

Polyfilla

Polycell
AkzoNobel
Wexham Rd.
SL2 5DS Slough, UK
+ 44 333 222 717
http://www.polycell.co.uk/contact/

Sculpture House Pristine White Casting Plaster

Amazon
https://www.amazon.com/Sculpture-House-Pristine-Casting-Plaster/dp/B0028MXHH6

Sigma-Aldrich fibrous cellulose-fibers (medium; replaced Whatman CF 11 fibrous cellulose powder), Whatman cellulose filtration paper 542, alpha cellulose powder, diethylaminoethyl cellulose fibers

Sigma-Aldrich
3050 Spruce St.
St. Louis, MO 63103
800-325-3010
http://www.sigmaaldrich.com/catalog/product/sigma/c6288?lang=en&region=US

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ARCHAEOLOGICAL GLASS CONSERVATION: COMPARATIVE APPROACHES AND PRACTICALITIES OF USING ACRYLIC RESIN FILMS AS GAP FILLS

HANA BRISTOW AND JAN DARIUSZ CUTAJAR

The conservation of archaeological vessel glass is notable for the challenges inherent in loss compensation and has seen conservators creatively manipulating many materials with varying degrees of success. Conventional gap-filling techniques using epoxy resins are now widely regarded as inappropriate. One of the latest emerging techniques is the use of customizable Paraloid B-72 films, established by Stephen Koob and his colleagues at the Corning Museum of Glass. This article presents two alternative approaches to loss compensation in archaeological glass using acrylic resin gap fills. The authors reflect on their independent experiences in adapting this technique and consider each against the backdrop of Koob's own recommendations. The approaches described here illustrate the practicalities, challenges, and conclusions drawn from the application—through trial and error—of this technique. It also highlights the similarities and differences in decision making by the conservators working separately at the University College London and the Royal Albert Memorial Museum while replicating a given treatment methodology. Additionally, it advocates the use of collaboration and knowledge sharing in tackling a conservation issue. Ultimately, through sharing these experiences, both case studies serve as a guide for conservators wishing to implement similar treatments in the future. It is hoped that in doing so, the professional conservator's repertoire for the treatment of archaeological glass will be expanded on, allowing for the significance of fragmentary archaeological glass to be better preserved.

KEYWORDS: Glass, Archaeological conservation, Gap fills, Acrylic resins, Paraloid B-72

1. INTRODUCTION

Archaeological glass conservation presents numerous challenges to conservators faced with the task of loss compensation, whether to impart structural reinforcement or visual continuity. The inherent fragility of archaeological glass objects is typified by their degraded condition and weakened internal structure resulting from burial and subsequent excavation, and is further exacerbated by considerable fragmentation and material loss (Davison 1978; Newton and Davison 1989; Cronyn 1990; Oakley 1992; Weijand 1999; Davison 2003; Koob 2006). Where a significant portion of a glass object has survived, the desire to view and study it as a single object, rather than as a collection of fragments, has driven conservators to explore a range of materials and methods for creating gap fills.

For many years, epoxy and polyester resins have been the choice materials for glass gap fills owing to their transparency, close refractive index to glass, high glass transition temperature (T_g), and application in a variety of reconstruction techniques (Fisher 1988; Cronyn 1990; Hogan 1993; Fontaine 1999; Oakley 1999; Tennent 1999; Weijand 1999; Henderson 2000; Ling 2000, 2002; Davison 2003; Koob 2006; Pilosi 2007; Davison 2009; Roemich 2010; Barton, Meek, and Roberts 2013; Roemich and van Lookeren 2013). However, their long-term chemical instability and concomitant yellowing, together with an increased risk of damage to surrounding glass from physical stress as they degrade over time, mean that these materials are in no way ideal when applied to extremely fragile archaeological glass. Furthermore, casting techniques for these resins normally demand a high level of object handling either for direct casting or through creating a mold for indirect casting.

It is also worth mentioning the use of Japanese tissue paper (made from the Asian mulberry tree), either impregnated with acrylic resin or otherwise, as another class of commonly used fill material for archaeological glass (e.g., Barton, Meek, and Roberts 2013; Williams 2015). Tissue paper fills have often intended to address the aforementioned failings of epoxy and polyester fills but have limitations of their own. Notwithstanding that these paper fills impinge less on the glass, are much more chemically stable, and are easily reversed, they remain minimally structurally supportive, they do not take compound curves well despite their versatility, and they are usually successful only in either transmitted or reflected light viewing conditions, but not both.

In light of this, in 2011, Koob and his colleagues at the Corning Museum of Glass advocated a new technique for making custom acrylic films or sheets from Paraloid B-72 (polyethyl methacrylate/polymethyl acrylate copolymer) suitable for gap-filling archaeological glass (Koob et al. 2011). Most notably, when compared to thermosetting resin and paper fills, key advantages of this technique include the ability to prepare casts away from the object, their long-term chemical stability, the versatile working properties of a thermoplastic acrylic resin, and the possibility for easy future removal. The success of this technique and further developments shared by Koob and his team offer an exciting opportunity for conservators elsewhere to adopt the same approach for reconstructing and reinforcing archaeological glass objects (Koob, van Giffen, and Hanna 2013).

This article describes the implementation of two such treatments conducted independently by the authors during their graduate training as objects conservators in the UK. By reflecting on our independent experiences in following and adapting this technique, our evaluations offer an interesting comparison of methods based on Koob's methodology while providing useful examples of the practicalities and challenges of this technique.

2. CASE STUDIES

The two case studies presented here relate to two different glass vessels, hailing from contrasting historical periods, geographical regions, and cultural contexts. Unsurprisingly, then, their respective chemical and physical makeups are also different. Their conservation treatments were likewise carried out in two different contexts, one being the University College London (UCL) Institute of Archaeology (IoA) MSc laboratories in London and the other being the conservation facilities at the Royal Albert Memorial Museum, Exeter. Despite these differences (also reflected in the availability of resources, institutional deadlines, etc.), both vessels exhibited similar states of condition, having been fractured into a large number of fragments, most of which were inherently fragile due to their weakened structure and pronounced thinness.

The first glass vessel (fig. 1) is an example of medieval Sassanid glassware, markedly characterized by its greenish-yellow coloration and stylistic features (Goldstein 2005; Gyselen 2007). The vessel has a wide, teardrop-shaped rim with a thick rounded lip that stems into a long, narrow neck ending in a wide, inverted, pyriform-shaped, thin body with a thick, concave base. A handle with a thick flared tongue at the rim thins and curves its way to the surface of the body, where it thickens once again. Concentric striations around the rim suggest that the glass was blown, which is consistent with its context (*Encyclopaedia Iranica* 2015a, 2015b). The handle was then most likely added after blowing. Portable x-ray fluorescence (*p*XRF) spectrographic analysis was inconclusive in determining its specific provenance but revealed a content of approximately 0.5% to 1% K_2O, 5% CaO, 1% Mn, 0.6% Cl, 0.2% S, and 0.2% Fe, which might suggest a natron glass with trace minerals from raw materials or added colorants.[1]

The vessel formed part of a private Iranian collection; it was then donated to the UCL IoA in the early 1990s. The vessel had been conserved twice before, with one documented treatment taking place at the

Fig. 1. Left: Sassanid vessel before conservation and in fragments. Right: The vessel after conservation in 2015. Artist/title unknown, possibly 3rd to 7th century AD, glass, 99 × 91 × 67 mm (at rim), University College London Institute of Archaeology Conservation Teaching Collection, 6303.

UCL IoA in 1997 and physical evidence on the piece pointing to a prior undocumented intervention. The more recent treatment involved deconstructing and gap filling the object due to failing cellulose nitrate joins, which resulted in its fragmentation into more than 53 pieces (fig. 1). This compromised its continued survival and interpretation as a complete artifact and, thus, its sensory and evidentiary significance. The situation was all the more exacerbated by the very fragile and thin nature of the glass body.

The conservation treatment described in this article hence targeted enhancement of the vessel's sensory and evidentiary layers of significance to allow its appreciation as a whole vessel and, therefore, also permit its study for research purposes. As such, the treatment ideally aimed to join and support all major fragments.

The second case study concerns a 17th century glass beaker (fig. 2) excavated in the city of Exeter, UK, in the 1970s and since stored at the Royal Albert Memorial Museum in Exeter (Allen, Archibald, and Brown 1984). The vessel is an example of *façon de Venise*, a style rooted in the 15th century when Venetian glasshouses perfected the formula for *cristallo* (or crystal glass) to produce extremely thin-walled and colorless glass objects (Willmott 2004; Weller 2008).

Just over half of the beaker survives in 34 fragments—enough material to appreciate its original complete form, with its intact circular concave base and straight tapering body with widely spaced vertical ribs and subtly curved rim. In 1997, the beaker underwent conservation work during which it was reconstructed with cellulose nitrate adhesive and loosely mounted upside-down over a modern glass former. The glass mount was evidently intended to assist in supporting the reconstructed vessel by allowing joined fragments to hang from the vessel's base. By 2015, however, the state of this treatment had significantly deteriorated: failing joins left fragments dangling precariously and made the object extremely vulnerable to structural breakdown and further damage. Furthermore, the mount offered no real support and hindered aesthetic appreciation of the object.

The main objective of the 2015 conservation treatment was to stabilize the object by making it structurally sound and to increase its potential as a research object within the museum's archaeology

Fig. 2. Beaker after 1997 conservation treatment, photographed in 2015. Royal Albert Memorial Museum, 300/1988/G155.

collection. As such, it was desirable to view the object in an upright position to allow viewing of the interior as well as the exterior, without the need for an obtrusive mounting system.

Both case studies clearly demonstrate the shared conservation aims to impart structural stability to the vessels in order to preserve them in a reconstructed state, which intended to enhance their aesthetic and informative value.

Considered together, the two glass conservation treatments highlight how archaeological glass—vessel glass in particular—presents numerous challenges to its conservation in which reconstruction is the primary objective. More specifically, archaeological vessel glass presents an inherent fragility arising from the degraded and structurally weakened constituent glass, which can also be very thin. In our examples, the glass ranged from 0.2 to 0.35 mm at their thinnest points. Furthermore, vessel glass usually suffers from considerable material loss. A substantial proportion of the glass object will often not have survived burial, meaning that large areas of loss require an adequately strong and durable fill material. Our vessels presented at least a 35% loss of original material. Consequently, reconstructed archaeological glass vessels will normally require additional structural support to ensure their preservation. This is all the more so due to their three-dimensional forms, which instills a desire to view them as freestanding objects, without the need for a mounting system. Above all, archaeological glass cannot be re-fused as a means of reconstruction, thus necessitating some form of fill material to provide stabilization.

Clearly, then, each of these requirements will determine the choice of materials used in a gap-filling treatment. Since each archaeological glass object will constitute different compositions, thicknesses, states of condition, and forms of construction, the selection of an adequate fill material and method to manipulate it to the conservator's task at hand necessitates a targeted approach. Furthermore, it must be kept in mind that, as well as the aforementioned highlighted factors and the desired treatment outcome, the choice of fill is sometimes influenced by external factors, such as the availability of time and resources or the skill and confidence of the conservator. The following sections illustrate these points through our direct experiences in replicating Koob's methodology for using acrylic resin films.

3. ALTERNATIVE APPROACHES TO GAP FILLING WITH ACRYLIC RESINS

The long-term success of any reconstructive treatment heavily depends on the materials and methods selected for gap fills intended for structural reinforcement together with their respective compatibility with the material under reconstruction. In contrast to loss compensation for aesthetic purposes, our gap fills were to act as bridges between critically weak areas requiring stability and reinforcement and would simultaneously aid the practical assembly of the vessel. From an aesthetic and ethical standpoint, the addition of modern gap-fill material to the objects was kept to a minimum to avoid detracting from the surviving original glass.

Acrylic gap fills offer key advantages over those made with epoxy or polyester resins for use with archaeological glass (Koob, van Giffen, and Hanna 2013; Down 2015). The latter two material classes have been the most popular to date (cf. Koob 2006, for example) but are often inappropriate for archaeological glass. This is principally due to the long-term chemical instability of epoxies and polyesters, which induces discoloration (usually observed as yellowing) as a result of chemical breakdown (Down 2000, 2001, 2009, 2013, 2015). This, in turn, necessitates retreatment and concomitant excessive handling of the fragile glass together with an associated risk of further damage. Another inherent chemical property that renders the resins of the epoxy/polyester group unfit for this purpose is their high-strength adhesive bond, which inevitably exerts unwarranted physical stresses onto the archaeological glass as they degrade over time.

Associated casting techniques for epoxy and polyester fills present further problems in comparison to the options offered by acrylic resins. Often, the former are cast directly onto the glass object. Epoxy and polyester resins are thermosetting plastics; the related exothermic release of heat may cause damage to adjacent glass fragments. Although indirect casting methods are also possible in a similar manner to direct casting, they involve increased handling and manipulation of the original glass material, which also pose risks to the artifact.

Japanese tissue paper impregnated with resin has also proved to be a popular choice as a cast material for archaeological glass owing to its long-term chemical stability and the fact that it does not exert undue pressure on surrounding glass (Barton, Meek, and Roberts 2013; Williams 2015). However, their lack of physical strength means that they are inappropriate except for use as minimally supportive fills, and they do not take compound curves well.

In light of this discussion, acrylic resins offer a suitable alternative to epoxy and polyester resins when applied to archaeological glass. For these reasons, acrylic resin films were judged by both authors to fulfill the criteria demanded of gap fills with respect to the treatments of the beaker and Sassanid vessel.

Both of us delineated similar criteria for our gap fills. Importantly, fills would need to be lightweight yet strong, with some flexibility for manipulation, as well as being simple to produce and insert with a minimal number of manipulations of the glass to reduce the risk of further damage and disruption of joins through handling. They also had to match the thinness of the glass as closely as possible while offering the possibility of easy removal without needing to dismantle the entire object should retreatment of localized areas in the future be necessary. Finally, both conservators desired the possibility to manipulate the appearance of fills in terms of color (or tint) and opacity to achieve a harmonious and unobtrusive aesthetic. Koob's methodology for producing acrylic films, summarized in the next section, offers the flexibility to fulfill the majority of these criteria.

3.1 Koob's Methodology

As of 2011, Koob and his team at the Corning Museum of Glass have advocated a new technique for making acrylic resin films for gap fills (Koob et al. 2011; Koob, van Giffen, and Hanna 2013). In essence, this methodology entails the following steps:

- First, a 30% w/v solution of Paraloid B-72 in acetone is made up.
- Separately, a small amount of ethanol is poured in a 1:5 ratio (Koob et al. 2013) with respect to the volume of acetone used to prepare the Paraloid B-72 solution. The addition of ethanol slows down the solvent evaporation rate, thus minimizing the formation of bubbles.
- If tinted fills are required, a small amount of dry ground artists' pigment may be added to the ethanol; this is then stirred and the particulate material allowed to settle. The mixture can then be decanted into the Paraloid B-72 solution.
- The final mixture is stirred once more and allowed to homogenize. The resultant solution is then carefully poured into a preprepared, solvent-resistant tray lined with silicone-release paper.
- The tray is inserted into a partially sealed solvent atmosphere and allowed to cure over a period of a minimum of 4 to 5 days.

The following sections deal specifically with our experiences in preparing the acrylic resin mixtures, casting the resin films, and subsequently manipulating them, before finally incorporating them with the glass object in alternative ways to those described by Koob et al. (2011, 2013).

3.2 Experiences of Working With Paraloid B-72 Gap Fills

3.2.1 Resin Mixtures

Despite Koob's insistence on the exclusive use of Paraloid B-72 for making the resin sheets, the resultant cast prepared for the beaker was too flexible to be used as an effective structural fill. In hindsight, this could have been due to the warm temperature conditions inside the laboratory in which the cast was left to set; however, this remains inconclusive. It also appeared that several other variables provided a good opportunity to experiment with materials to establish the best combination for a cast of the correct strength, color, opacity, and thickness.

Consequently, a series of casts were produced to test the range of properties afforded by different additions to the resin mixture. To modify the strength of casts, varying proportions of Paraloids B-72, B-48N (polymethyl methacrylate/polybutyl acrylate) and B-44 (polymethyl methacrylate/polyethyl acrylate) were used to make up resin mixtures, either used neat or in a 2:1 ratio. Several materials were also tested for their effectiveness as opacifiers, including fumed silica, marble dust, whiting, and titanium dioxide. To alter the color (or tint) of fills, three hues of dry ground artists' pigments were added, again either neat or combined, depending on the success of the color match with the beaker. These included Cornelissen pearl lustre Pearl Copper, Cornelissen pearl lustre Gold Pearl, and Cornelissen pearl lustre Platinum Gold.

Parameters that were kept constant throughout the experiment included a 30-mL volume of resin per test batch, a 30% w/v concentration of resin in solvent, the surface area of open box molds (65 × 100-mm base surface area) and the number of molds placed together in a polypropylene box left to cure (fig. 3). The addition of 4 mL ethanol (that amount used in accordance with the methodology set out in Koob et al. 2011) was also kept constant.

After the resin sheets had cured over a period of 4 to 5 days, they were assessed by simple qualitative methods. To test their hardness, each sheet was cut with a pair of scissors, which gave a good sense of their flexibility or brittleness. Simply touching and manipulating the sheets were also effective indicators; all of the sheets were retained in order to make further comparisons as experimentation progressed. Another key quality assessed was the sheet's ability to deform when gently heated and then retain this new form—in other words, its potential for manipulation. If the sheet had a tendency to revert back to its original form, its use as a gap fill would exert undue pressure on the glass and was therefore deemed unsuitable. Assessing appearance was done by comparing the resin sheet side by side with the original glass in good light.

As was to be expected, the addition of Paraloids B-48N or B-44 created less flexible and progressively harder casts. After assessing 16 casts of different resin mixtures, the preferred resin mixture consisted of a 2:1 mixture of Paraloids B-72 to B-48N, respectively, as it gave the cast strength without brittleness. With regard to opacifiers, fumed silica was found to be effective for providing translucency, while marble dust was good for creating an opaque glass effect. Both whiting and titanium dioxide gave a conspicuous speckled effect due to the difficulty in fully homogenizing these materials within the resin mixture. Dry ground artists' pigments were very effective for tinting the casts; however, they should not be depended on for achieving opaqueness as well as color since it is easy to oversaturate the mixture (fig. 4). To avoid this, it is advisable to limit the amount of dry pigment added to a maximum of 1.5 micro spatulas per 30 mL resin mixture batch (1 micro spatula equaling approximately half the size of a pea).

Fig. 3. Acrylic resin test batches placed together in a polypropylene box before the lid is secured by all but one corner to create a vapor chamber with a slow evaporation rate

3.2.2 Casting Procedure

Having determined the appropriate composition of the resin film, the next task is to successfully cast the Paraloid film. We have already highlighted the variables inherent in the constituent materials of the resin mixture. Another characteristic over which we have control is the thickness of the film, which requires some trial and error to cast as required. This is especially difficult since the film's volume decreases upon drying as the solvent evaporates. Indeed, our experiences align with Koob and others, who record a shrinkage in volume of approximately 70% for concentrations of 30% w/v in acetone (Koob, van Giffen, and Hanna 2013; Loeschberger 2014).

The possibilities for casting are limited by one's own sense of creativity and available resources. From our experience, some methods are easier, faster and more cost-effective to implement than others. One possibility is to fashion trays out of cardboard cutouts or solvent-resistant polyethylene trays, and line these with silicone-release paper to facilitate removal of the film once cured. This method was adopted by the authors as a readily available and rapid solution to creating molds for immediate use. A slightly more time-consuming method, which nevertheless allows for customization and texturization of the casting area, involves preparing trays out of silicone rubber, using the base of a tile, for example, to form the casting area. Surface textures on the mold may also be introduced at this stage.

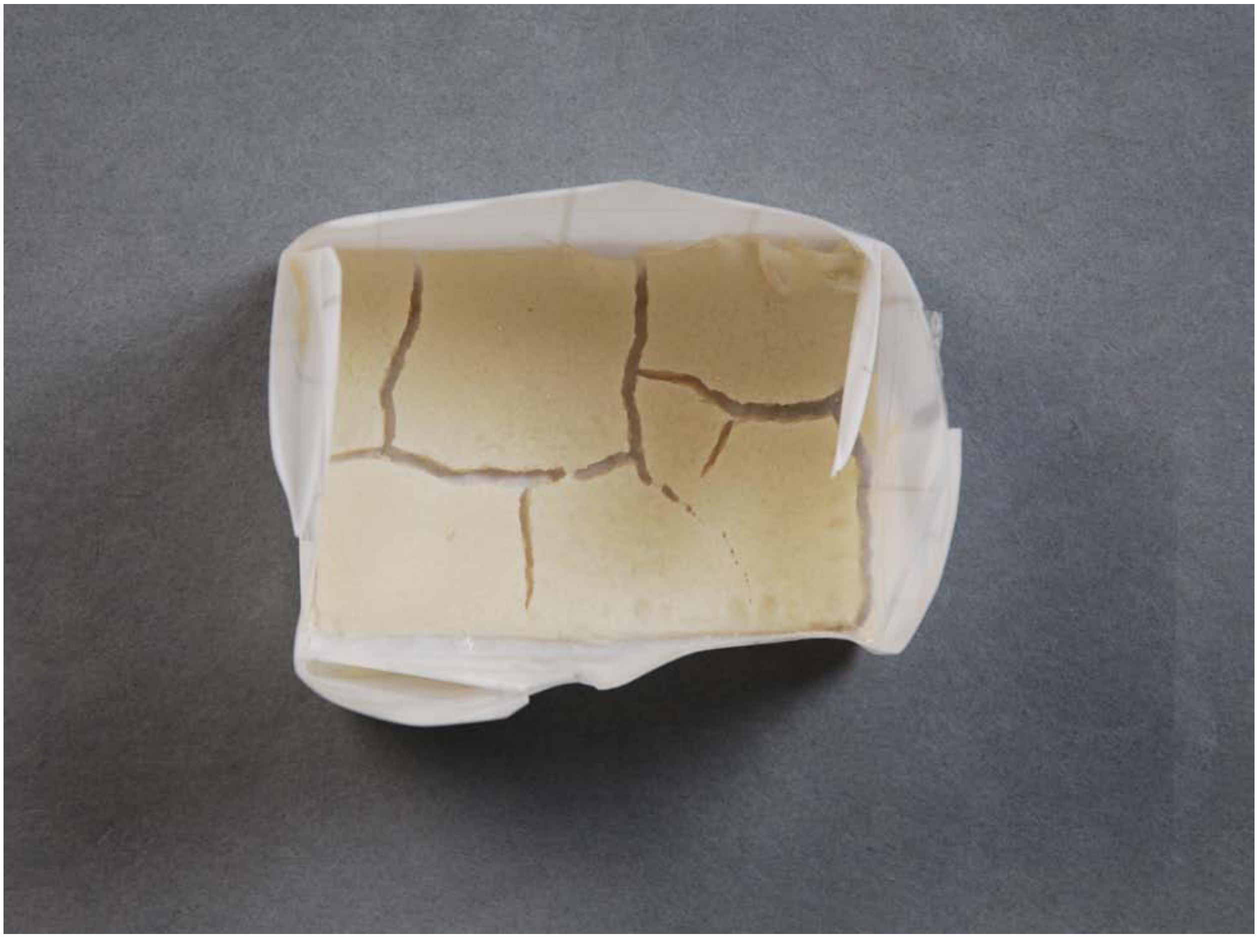

Fig. 4. Cracking caused by the addition of too much dry pigment, resulting in oversaturation and loss of cohesive strength

Once the resin is poured into the tray, it is important to place the trays into an acetone atmosphere by partially enclosing them in either a plastic (e.g., polypropylene) box with the lid on but not fully closed or a Ziploc (polyethylene) bag or polyethylene sheeting. This step is specifically designed to slow down the rate of solvent evaporation, which helps prevent bubble formation in the film. Placing 5- or 10-mL beakers containing acetone and cotton wool as a wick inside the enclosure was found to be a practical way of achieving this.

It is essential to emphasize at this point that films normally require at least 4 to 5 days to cure sufficiently, since any less than this will result in too flimsy a film due to the high concentration of residual solvent. Both for Paraloid B-72–only fills and the 2:1 Paraloid B-72/B-48N fills, it was found that 4 to 5 days of curing provided the best results. Subsequently, the films may be pulled off the tray using tweezers (fig. 5). When the films are still fresh from the solvent atmosphere, they can be textured if necessary. One way of achieving this is by using Plastazote (Ethafoam, expanded polyethylene foam) cutouts to leave a mottled surface impression to imitate weathered glass. Nitrile gloves with added grip marks on the fingertips are also effective for texturing. After further drying, the film is ready for manipulation in preparation for its final incorporation with the vessel.

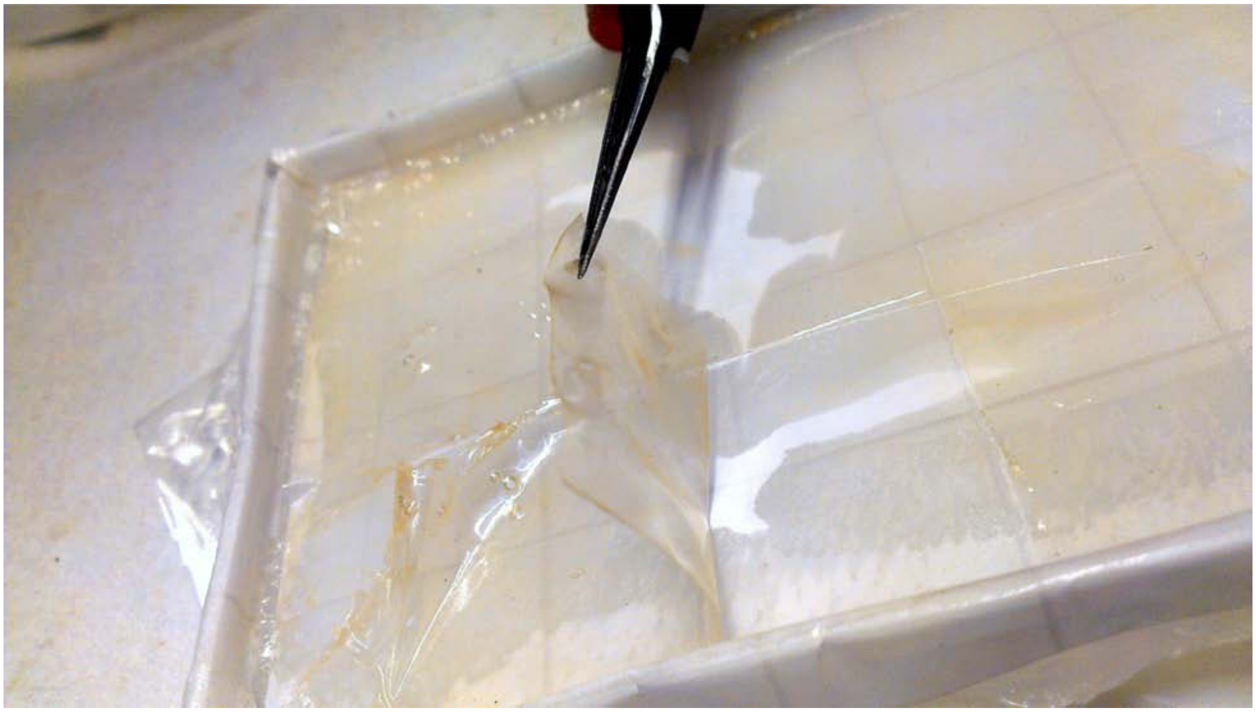

Fig. 5. An example of how the films can be removed from the trays with ease using tweezers

3.2.3 Manipulation

The many ways available to manipulate the acrylic films is a major advantage of this technique—this is what makes it so versatile and essentially less stressful for the conservator than many other casting techniques currently practiced. Through our own experiences, it is possible to share some practical tips and reflections regarding the practicalities of gap filling using acrylic resin casts. The next sections offer guidance for mastering steps following the initial preparation of the cast resin sheets, as explored during the reconstructive treatment of the beaker.

3.2.3.1 Defining the Area of Loss Compensation

A simple but effective method for defining the area of loss compensation on the glass object involves very gently tracing the outline of the loss using either pencil on tracing paper or marker pen on a piece of Melinex (Mylar, polyester film; fig. 6). It is helpful to backlight the object to clearly highlight the area of loss. It is important to factor in any curvature at this stage, which provides another reason for using a rigid yet flexible material such as tracing paper. Extreme care should be exercised throughout this stage so as not to exert pressure on any part of the glass object.

3.2.3.2 Cutting the Fill from the Resin Sheet

Once an approximate tracing for the gap fill is obtained, it can be placed behind the resin sheet, ensuring that the matte side is face up if you want this side to appear on the exterior face of the glass object (fig. 7). It is important to use a very sharp scalpel for cutting to ensure maximum accuracy and reduce the risk of slippage from a blunt blade. The scalpel blade is a versatile cutting tool from this point, due to the variously shaped blades that are commonly available (e.g., #10A and #15). Small sharp scissors may also be used for this task. Another tip is to position the cast resin sheet in such a way that the gap-fill area is positioned left of the cutting line (for right-handed individuals) so that any accidental slips will affect

Fig. 6. Defining the area of loss compensation by carefully taking a tracing using a pencil and tracing paper against the backlit object

only the area outside of the fill. If the resin sheet is too hard to cut easily, it can be softened by heating it with a hairdryer for a few seconds. It is worth remembering at this stage that detailed refinements to the fill edges should only take place once it is manipulated to the correct curvature, discussed in the next section. It is therefore recommended to leave a small margin around the edges for later refinement.

3.2.3.3 Heating to Create Curvature

Once the fill is cut to roughly the right shape, it is time to adjust its curvature. The application of heat takes advantage of the resin's thermoplasticity, making it flexible enough to bend into the correct form, which then hardens again as it cools. This stage involves holding the fill between your fingers under a hairdryer for approximately 20 seconds and letting it cool down. Another advantage is that the resin can be repeatedly heated and cooled, allowing for multiple attempts at finding precisely the right curvature.

3.2.3.4 Inserting the Gap Fill

Before adhering the gap fill to the glass object, it is important to carefully insert it into the area of loss to check for a tight fit. Normally, refinements to the edges of the fill will have to be made at this point. For example, the undulating walls of the beaker meant that each edge of the fill had to take on slightly different angles to align correctly with the surrounding break edges. This stage required patience as edges were carefully trimmed with a scalpel away from the object and repeatedly checked against the area of

Fig. 7. Cutting the gap fill to size

loss. Tips for this stage include having the object well lit so that you can clearly see the quality of edge alignment and handling the fill with tweezers for optimal care (fig. 8).

3.2.3.5 Creating Lipped Fills for Use With Very Thin Break Edges

In cases in which the surrounding glass is much too thin to accommodate the thicker edges of the fill, the fill edges may be manipulated to create a slightly overhanging lip that will bolster support in these particularly vulnerable areas. This was done for the beaker by carefully applying a heated spatula (set to low heat) over silicone-release paper onto the edges of the fill so that it softened and molded around the thin glass break edge (fig. 9).

3.2.4 Alternative Structural Support

The final step in the treatment is to adhere the resin fill into place. Adhesion into the area of loss can take place by activating the edges with solvent (Koob et al. 2011; Koob, van Giffen, and Hanna 2013). This, however, can slightly alter the join edges. Therefore, it is often preferable to introduce additional Paraloid B-72 as an adhesive. This is especially important if the cast constitutes a mixture of resins—for example, Paraloids B-72 and B-48N—since B-72 has optimal properties as a strong but flexible adhesive for archaeological glass, while its marginal difference in chemical composition will assist in the neat removal of the fill in the event of future retreatment. The Paraloid films can also be used to perform other structural roles; these were trialed on the Sassanid jug as described in the next section.

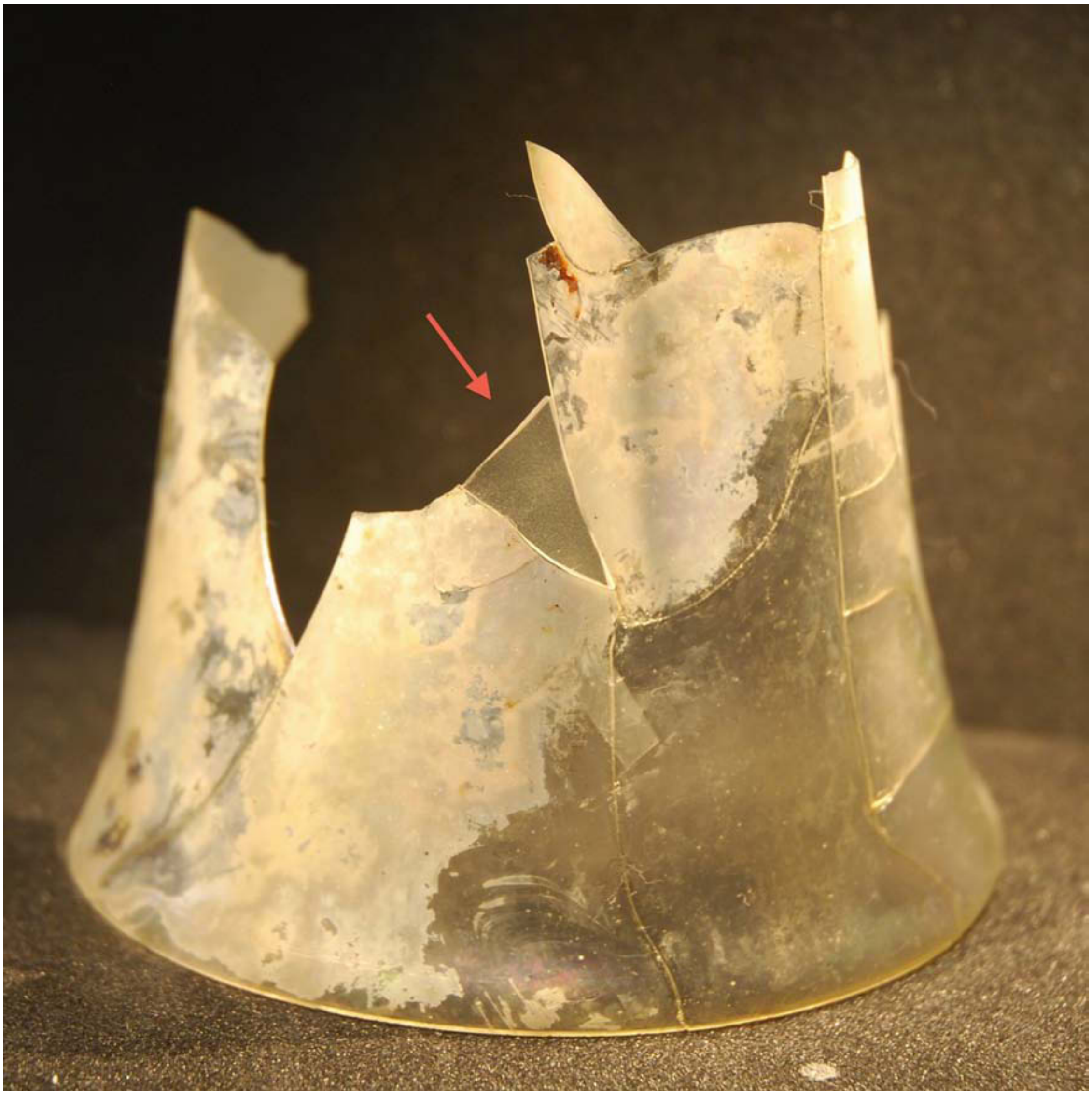

Fig. 8. A prepared gap fill ready to be adhered to the surrounding glass, indicated by the red arrow

3.2.4.1 Tabs

Looking at the Sassanid jug's construction, the handle and rim at the top are the heaviest components on the vessel. This exerted a lot of tension on the rest of the glass body, which caused reconstructed joins to buckle even though the adhesive had set. As a result of experimentation with casting the resin films, a very thin sheet of 30% w/v Paraloid resin (of only a few millimeters' thickness) had been cast. This was too thin to provide any structural role in its own right. However, it was found to be highly effective when cut into small supporting tabs placed across breakage joins. Performing the same function that tape strips would during a dry reconstruction, these permanent Paraloid tabs, applied perpendicular to the direction of the stress, permitted the stabilization of the thin, curved surface of the vessel. Their thin nature and customizable tinting also means that they are virtually invisible to the naked eye (fig. 10) but remain visible under UV radiation and via their documentation. The method of application of the tabs is quite straightforward. Tabs may be cut with a fresh scalpel blade (ideally to the length of a few millimeters long and wide), laid across a join using tweezers, and then very gently solvent activated using the tip of a fine-pointed brush.

Fig. 9. Heated spatula applied to the edges of a gap fill to create a lip

3.2.4.2 Adhesion via Backing on the Vessel Interior

The resin films can also be applied as recessed, supporting fills rather than directly in plane within an area of loss. This form of adhesion is particularly suited to the backing of very thin glass. This is because very thin films, such as the ones used as tabs described earlier, can become brittle upon drying if used as in plane fills and therefore do not provide enough physical strength to fulfill their role as a structural gap fill.

To create a recessed fill, the film is tailor cut, as described in section 3.2.3.2, to fit the area presenting losses in such a fashion so as to structurally stabilize the local area (fig. 11). Given that the area is accessible, the fill is then attached to the interior edges around gaps in the vessel. Recessed fills proved extremely useful for curved surfaces, where the vessel glass thinned significantly and could not bear its own weight without additional support (fig. 12). Recessed fills were found to be much more easily applied when fresh from the solvent atmosphere, as they were still slightly tacky, providing a satisfying adhesion to the glass surface without the need for solvent activation, which can cause bubbling. Plastazote can also be used to delicately press the film into the correct angle of curvature against a

Fig. 10. Left: The tabs highlighted to indicate their placement on the vessel. Right: The tabs as they look to the naked eye.

Melinex sheet covering the vessel. The film can then be cut to follow join lines and weathering patterns, which allow facile blending with the glass material. Admittedly, from an aesthetic viewpoint, this technique is suitable only where weathering affects the archaeological glass. Fills were never applied over iridescence so as not to interfere with this form of glass deterioration.

Fig. 11. Left: Recessed fill (A) indicated by the blue arrow is stabilizing the fragments in the area where it was locally applied. Right: The same fill seen from the reverse side.

Fig. 12. An example of using a recessed fill to stabilize the curved surface on the Sassanid vessel, where the glass was too thin to attach any in-plane fills

In this manner, the recessed fill spans the area of loss, stabilizing overhanging edges while helping to distribute the weight of the body more evenly. Interestingly, this technique can also be used to support nonadjacent joins in sprung glass, where a conventional resin fill would not fit well.

4. CONCLUSION: REFLECTIONS AND CRITIQUE

Acrylic resin gap fills hold much promise for delivering safer, more versatile conservation treatments on archaeological glass objects than is possible with epoxy or polyester resins. The approach is also much less time-consuming and stressful than many other casting techniques. Once the preferred resin composition is established and the casting and manipulation stages are mastered, the possibilities for application are numerous.

In this article, we have drawn attention to the many advantages of this technique. Most of the preparation is done without direct contact with the glass and there are no complex molding operations involved. Casts can withstand multiple reworkings at the manipulation stage; thus, making adjustments is straightforward and there is no need to be worried about having to get the exact curvature perfect the first time round. In this way, it is a more forgiving method. The fills are easily removable should future retreatment be necessary, particularly if adhered with a resin of a slightly different chemical composition to that of the fills (e.g., using Paraloid B-72 to adhere a B-72/B-48N cast). Multiple casts can be cut from a single resin sheet or sheets can be stored for future use, which ultimately enhances the efficiency of this technique. Further investigation into the optimal storage recommendations for the preprepared resin casts would be welcome. Of particular note from the case studies presented here is the use of lipped fills, tabs, and recessed fills to overcome potential difficulties.

Some important considerations should nevertheless be borne in mind when implementing this technique. Depending on the size and thickness of the cast resin mixture upon curing, adequate time is needed for a sufficient amount of solvent to evaporate before the cast is ready to be extracted from its mold. If this stage is rushed, the resultant fills will be too flexible and could end up slumping over a short period of time following the treatment. The rate of solvent evaporation is affected by the material and thickness of the container used as a vapor chamber as well as the number of casts left to cure inside. For example, multiple casts placed inside a thick polypropylene box will take longer to cure than one cast placed inside a thin polyethylene bag.

Through sharing these experiences, it is hoped that both case studies presented here offer a complementary guide for conservators wishing to implement similar treatments, thus expanding the professional conservator's repertoire of gap-filling techniques and allowing for the significance of fragmentary archaeological glass to be better preserved.

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NOTE

1. The glass was analyzed directly on the surface using an Innov-X Systems/Olympus Delta Premium DP-4000 handheld *p*XRF, using the built-in "Soils" mode with 20 seconds per setting for a total time of 60 seconds per analysis. Beam 1 operates at 40 kV and 89 μA with a copper filter, Beam 2 operates at 40 kV and 52 μA with a 2.0-mm aluminum filter, and Beam 3 operates at 15 kV and 68 μA with a 0.1-mm aluminum filter.

REFERENCES

Allen, John P., Marion Archibald, and Duncan H. Brown. 1984. *Medieval and Post-Medieval Finds from Exeter, 1971–1980*. Exeter Archaeological Reports: 3. Exeter: Exeter City Council.

Barton, Julia, Andrew Meek, and Paul Roberts. 2013. "Examination and Experimentation: Conservation of an Archaeological Glass Unguentarium for Display." *The British Museum Technical Research Bulletin* 7: 69–78.

Cronyn, J. M. 1990. *The Elements of Archaeological Conservation*. London: Routledge.

Davison, Sandra. 1978. "The Problems of Restoring Glass Vessels." *The Conservator* 2 (1): 3–8.

— 2003. *Conservation and Restoration of Glass*. Oxford: Butterworth-Heinemann.

— 2009. "A History of Joining Glass Fragments." In *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, eds. J. Ambers, C. Higgitt, L. Harrison and D. Saunders. London: Archetype Publications in association with the British Museum. 107–112.

Down, Jane. 2000. "Toward a Better Emulsion Adhesive—A Preliminary Report on the Effect of Modifiers on the Stability of a Vinyl Acetate/Ethylene (VAE) Copolymer Emulsion Adhesive." Technical Report (CCI) 1.

"Review of CCI Research on Epoxy Resin Adhesives for Glass Conservation." *Reviews in Conservation* 2: 39–46.

——2009. "Poly(vinylacetate) and Acrylic Adhesives: A Research Update." In *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, eds. J. Ambers, C. Higgit, L. Harrison, and D. Saunders. London: Archetype Publications with the British Museum. 91–98.

——. 2013. *The Effect of Modifiers on the Stability of a Vinyl Acetate/Ethylene (VAE) Copolymer Dispersion.* Unpublished report, Ottawa, Ontario, Canada: CCI.

——. 2015. "The Evaluation of Selected Poly(Vinyl Acetate) and Acrylic Adhesives: A Final Research Update." *Studies in Conservation* 60 (1): 33–54.

Encyclopaedia Iranica, 2015a. "Glass." Accessed April 24, 2017. http://www.iranicaonline.org/articles/glass

——. 2015b. "Japan xi. Collections of Persian Art in Japan." Accessed April 24, 2017. http://www.iranicaonline.org/articles/japan-xi-collections-of-persian-art-in-japan

Fisher, P. 1988. "Advances in the Restoration of Glass Vessels." In *Conservation Today: Preprints of the UKIC 30th Anniversary Conference*, ed. V. Todd. London: UKIC. 81–83.

Fontaine, C. 1999. "Conservation of Glass at the Institut Royal du Patrimoine Artistique (Bruxelles): From the Earthquake in Liege to the Stained Glass of Loppem." In *The Conservation of Glass and Ceramics: Research, Practice and Training*, ed. N. H. Tennent. London: James & James. 198–207.

Goldstein, Sidney M. 2005. *Glass: From Sasanian Antecedents to European Imitations*. London: Nour Foundations.

Gyselen, Rika. 2007. *The Sasanian World. Glass, Gilding and Grand Design: Art of Sasanian Iran (224–642)*. New York: Asian Society. 13–20.

Henderson, Julian. 2000. *The Science and Archaeology of Materials: An Investigation of Inorganic Materials*. New York: Routledge. 24–108.

Hogan, L. 1993. "An Improved Method of Making Supportive Resin Fills for Glass." *Conservation News* 50: 29–30.

Koob, Stephen P. 2006. *Conservation and Care of Glass Objects*. London: Archetype Publications.

Koob, Stephen P., Sarah Benrubi, Astrid R. van Giffen, and Nathalie Hanna. 2011. "An Old Material, a New Technique: Casting Paraloid B-72 for Filling Losses in Glass." In *Proceedings of CCI Symposium 2011: Adhesives and Consolidants for Conservation: Research and Applications, Ottawa, Canada*. Ottawa: CCI. 1–14.

Loeschberger, Zara. 2014. "Paraloid B 72: Platten als Ergaenzungsmaterial." *Restauro.* Accessed May 15, 2017. https://www.restauro.de/paraloid-b-72-platten-als-ergaenzungsmaterial/.

Ling, D. 2000. "Conservación de Vidrio Hueco en el British Museum de Londres." In *Jornadas nacionales sobre restauración y conservación de vidrios: La Granja de San Ildefonso, 30 de septiembre-2 de octubre 1999*, ed. J. M. Fernández Navarro and P. Pastor Rey de Viñas. La Granja: Fundación Centro Nacional del Vidrio. 135–143.

— 2002. "Conservation of Hellenistic Vessel Glass at the British Museum." In *1st International Conference on the History, Technology and Conservation of Glass and Vitreous Materials in the Hellenistic World*, ed. K. George. Athens: Glassnet Publication. 289–293.

Newton, R. G., and Sandra Davison. 1989. *Conservation of Glass.* London: Butterworth-Heinemann.

Oakley, V. 1992. "The Deterioration of Vessel Glass." In *Glass and enamel conservation: collected papers from a one-day meeting on the conservation of glass and enamels held on 11 November 1989*, edited by C. Daintith. London: UKIC. 6–9.

——. 1999. “Five Years On: A Reassessment of Aspects Involved in the Conservation of Glass Objects for a New Gallery at the Victoria and Albert Museum.” In *The Conservation of Glass and Ceramics: Research, Practice and Training*, ed. N. H. Tennent. London: James & James. 217–228.

Pilosi, L., ed. 2007. *Glass and Ceramics Conservation 2007. Interim Meeting of the ICOM-CC Working Group, August 27–30, 2007, Nova Gorica, Slovenia.* London: Archetype Publications.

Roemich, H., ed. 2010. *Glass and Ceramics Conservation 2010. Interim Meeting of the ICOM-CC Working Group, October 3–6, 2010, Corning, New York*. Paris: ICOM-CC.

Roemich, H. and K. van Lookeren, eds. 2013. *Recent Advances in Glass, Stained Glass, and Ceramics Conservation 2013. Preprints of the ICOM-CC Working Group Glass and Ceramics and Forum of the International Scientific Committee for the Conservation of Stained Glass (Corpus Vitrearum-ICOMOS), Amsterdam, the Netherlands*. Zwolle, Netherlands: SPA Uitgevers.

Tennent, N. H., ed. 1999. *The Conservation of Glass and Ceramics: Research, Practice and Training*. London: James & James.

Weijand, R. 1999. “Challenges and Solutions in the Restoration of Vessel Glass.” In *The Conservation of Glass and Ceramics: Research, Practice and Training*, ed. N. H. Tennent. London: James & James. 198–207.

Weller, A. 2008. *History of Venetian glass making*. Accessed August 3, 2015. http://www.bigbeadlittlebead.com/guides_and_information/history_of_venetian_glass.php.

Williams, Emily. 2015. *Japanese Tissue Paper – A Glass Puzzle from Tell Fara*. Accessed June 6, 2018. https://uclconservation.wordpress.com/tag/japanese-tissue-paper/

Willmott, H. 2004. “Venetian and *Façon de Venise* Glass in England.” In *Beyond Venice: Glass in Venetian Style 1500–1750*, ed. R. Price. New York: The Corning Museum of Glass. 270–307.

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PRACTICAL EVALUATION AND APPLICATION OF CLEANING TECHNIQUES FOR MARBLE SCULPTURE

RAINA CHAO

Cleaning marble is an involved process that can require complex decision-making along with multiple tests and treatment steps to arrive at the desired outcome. The type of object, source of soiling, desired appearance, manner of carving and finishing, and even the properties of the stone itself are factors affecting treatment choices and results. There are many treatment options for cleaning marble that can be tailored to the specific needs of an object, including vinyl erasers, aqueous solutions, chelators, surfactants, poultices, solvents, and lasers. This article will explore the advantages and limitations of these techniques, which were investigated in preparation for the treatment of *La Première Pose* (1873–1876) by Howard Roberts, a life-size marble figure in the collection of the Philadelphia Museum of Art. This case study will be contextualized by a literature review of published cleaning techniques. While the treatment of *La Première Pose* necessitated a combination of cleaning methods executed in sequence, additional treatment examples that used different methodologies will also be discussed, highlighting the complex nature of the decision-making process.

KEYWORDS: Marble, Cleaning, Erasers, Lasers, Poultices, Surfactants, Methyl cellulose, Agar, Citrate, Diethylenetriaminepentaacetic acid (DTPA), Ethylenediaminetetraacetic acid (EDTA)

1. INTRODUCTION

In 2014, the Philadelphia Museum of Art reinstalled two of its galleries of American Art, prompting the treatment of two large-scale white marble sculptures, Howard Roberts's *La Première Pose* (fig. 1) and Randolph Rogers's *The Lost Pleiad.* The bulk of the treatment needed for both sculptures was cleaning to remove or reduce surface grime and accretions accumulated over approximately 80 years of display and handling. The timescale for the treatments and extent of surface area to be cleaned prompted an investigation into the best and most efficient method for cleaning these marble surfaces. After literature review and consultation with colleagues, numerous cleaning methods—including organic solvents, mechanical action, aqueous solutions, gelled aqueous systems, and lasers—were tested on Howard Roberts's *La Première Pose*. The testing and evaluation of multiple cleaning options not only aided the determination of a treatment methodology for *La Première Pose* but also helped inform subsequent marble cleaning projects and form the basis for this article. This article will present observations on the strengths and weaknesses of the cleaning techniques and illustrate the decision-making process through case studies.

2. CLEANING METHODS IN THE LITERATURE

The following review of published marble cleaning methods was done in preparation for the treatment of *La Première Pose* and other case studies discussed in this article. While it includes a variety of publications and cleaning methods, it should not be considered a comprehensive study of all publications on the subject.

2.1 Aqueous Cleaning

When approaching aqueous cleaning of marble, the effect of water alone on the marble itself must be considered. Marble is primarily calcite ($CaCO_3$), which is somewhat soluble in water alone and soluble in dilute acidic solutions (Lide 2005, 4–54). For these reasons, a saturated calcium carbonate solution at elevated pH (~ pH 9) is recommended in lieu of deionized water for surface cleaning or clearance to

Fig. 1. Before treatment, Howard Roberts, *La Première Pose*, 1873–1876, marble, 133 × 76 × 66 cm. Philadelphia Museum of Art, Gift of Mrs. Howard Roberts, 1929-134-1 (Courtesy of Philadelphia Museum of Art, photograph by Joe Mikuliak)

protect the surface of the marble from dissolution and etching. Gervais et al. describe the preparation of such a solution (2010, 172). In addition to protecting the marble surface, solutions at an elevated pH also tend to be more effective for the removal of aged and oxidized soiling (Stavroudis, Doherty, and Wolbers 2005, 18).

Aqueous cleaning methods for marble can be tailored to the specific condition issues of an object. Incorporation of chelators to aid in the removal of surface soiling and reduce staining plus surfactants to remove soiling, particularly greasy handling grime, is often necessary. The Modular Cleaning Program (MCP) developed by Chris Stavroudis and colleagues provides a useful tool for determining an appropriate aqueous cleaning system. The program aids in formulating and testing aqueous solutions accounting for variables such as pH, established with buffers, and the addition of chelators and surfactants (Stavroudis, Doherty, and Wolbers 2005).

2.1.1 Chelators

Chelating solutions have been shown to effectively remove surface soiling. A helpful discussion of chelators used on marble is provided by the 2010 article entitled "Cleaning marble with ammonium citrate," by Gervais et al. While the authors focus on ammonium citrate, another common chelator, ethylenediaminetetraacetic acid (EDTA) is also discussed. As both citrate and EDTA are known to chelate calcium ions (Gervais et al. 2010, 165), the study focused on the effect of chelating solutions of different formulations on marble. The authors found that elevated pH, lower concentrations of ammonium citrate, and reduced airflow caused the least damage to the marble surface. Multiple cleanings in succession showed more damage than a single cleaning, and EDTA proved more harmful than citrate even under ideal conditions (Gervais et al. 2010, 170–171).

2.1.2 Surfactants

Surfactants can help remove surface soiling—particularly nonpolar, greasy soiling that could result from handling or applied coatings. Stavroudis's 2009 article "Sorting out surfactants" gives a useful overview of surfactant chemistry and comments on the properties and potential applications of individual surfactants. The surfactants discussed fall into one of two categories: nonionic surfactants that are usable at any pH and anionic surfactants that are usable at elevated pH. Thus, they are suitable for aqueous cleaning of marble that should, ideally, occur at an elevated pH. Additionally, aged and oxidized material is typically more readily removed at an elevated pH (Stavroudis, Doherty, and Wolbers 2005, 18).

Chelators, surfactants, and other additives to water have the potential of crystallizing on the surface if residues of solutions remain and are allowed to dry. Marble surfaces should always be cleared after aqueous cleaning but clearance solutions should also account for the solubility of marble. The carbonate-saturated water discussed earlier or pH-adjusted water, a solution whose pH is set with volatile components and therefore leaves no residue (Stavroudis 2016), are both viable options.

2.2 Gels

Gelled aqueous formulations have also been used as poultices to clean marble, offering extended dwell time and uniformity in cleaning that can be applied overall or in specific passages. These poultices can be removed while still wet or allowed to dry completely before removal. Since a gel is a thickened aqueous solution, the same parameters discussed for designing aqueous cleaning solutions must be considered. In addition to the action of the aqueous solution in the gel, alteration of the marble surface due to mechanical removal of crystals attached to the poultice film is also a concern, particularly with methyl cellulose-based poultices.

2.2.1 Methyl Cellulose

Useful discussions of methyl cellulose based poultices are offered by Goldberg's 1989 article "A fresh face for Samuel Gompers: Methyl cellulose poultice cleaning" and Lauffenburger, Grissom, and Charola's 1992 article "Changes in gloss of marble surfaces as a result of methylcellulose poulticing." The primary concern addressed by both sources is alteration of the marble surface due either to mechanical removal of crystals attached to the poultice film or to etching of the stone by the aqueous solution itself. Lauffenburger, et al. tested a variety of poultice formulations and their effects on marble surfaces when removed wet or dry. The authors found that poultices removed while still wet generally exhibited less etching of the marble surface than those allowed to dry fully, likely due to the mechanical adhesion of calcite crystals to the dried films (Lauffenburger, Grissom, and Charola 1992, 159-160). Calcite crystals were detected on removed poultice films by touch, sight, and SEM by Lauffenburger, et al. (Lauffenburger, Grissom, and Charola 1992, 160) and with PLM and SEM by Goldberg (21–22). In addition to removing poultices while still wet, Goldberg successfully used additives such as bulking agents and plasticizers to prevent damage due to mechanical adhesion when using methyl cellulose (1989).

2.2.2 Agar

Another aqueous gel option is agar or agarose gel applied as precast sheets of gel or as a molten liquid that cools and conforms to an object's surface. Much of the literature on the use of agar in objects conservation is devoted to treating plaster. The 2013 article, "Cleaning plaster surfaces with agar-agar gels: evaluation of the technique," by Tortajada Hernando and Blanco Dominguez, provides a useful discussion of agar and its application (Tortajada Hernando and Blanco Dominguez 2013). Cindy Lee Scott, who recently used agar gels to clean a marble sculpture at the Detroit Institute of Arts (Detroit Institute of Arts 2013), discusses agar more generally in her 2012 article entitled "The use of agar as a solvent gel in objects conservation." Scott explores the use of agar gel with a range of aqueous solutions and added solvents, finding that agar behaves well under most aqueous conditions, including solutions with elevated or depressed pH and incorporating oxidizers and chelators; however, the addition of surfactants caused the gel to dissociate (76). One benefit of agar over other aqueous gels is the ease of clearance. Regardless of the mode of application, the agar gel is not adhered to the surface and can be easily peeled away without the concern of mechanical damage to the surface (78–79). Though the gelling agent (agar) appears to leave no residues, it should be noted that the aqueous solution employed within the agar might still require clearance.

2.3 Mechanical Cleaning—Vinyl Erasers

Mechanical surface cleaning of marble using vinyl erasers is also an option. Eraser cleaning can be executed dry on objects for which aqueous cleaning may pose a concern as well as in combination with other cleaning techniques. Using erasers, the cleaning can be easily controlled as the results are readily apparent, allowing for discrete control over extent of cleaning and enabling selective cleaning of variable surfaces (Williams and Lauffenberger 1996). These strengths have recently been demonstrated on the cleaning of *Adam*, by Tullio Lombardo (ca. 1455–1532), at the Metropolitan Museum of Art, where vinyl eraser strips were used in combination with saliva (Riccardelli et al. 2014, 103–104).

Despite these strengths, there are some potential drawbacks to cleaning with vinyl erasers, specifically concerns about residue deposition and abrading the surface. These issues were investigated by Williams and Lauffenberger in their 1996 article entitled "Testing erasers used to clean marble surfaces." In the article, surfaces cleaned with a variety of erasers are evaluated using specular gloss measurements, magnification with a binocular microscope, and SEM to gauge surface abrasions; and SEM-EDS, FTIR, and longwave UV to investigate potential residues. Though no residues were identified by the methods employed, the authors observed that areas treated with vinyl erasers did have a higher surface tension than untreated areas, suggesting that there may, in fact, be a minute amount of residue (121). Nevertheless, vinyl erasers behaved well, were recommended by the authors for cleaning marble, and have many strengths, as noted earlier.

2.4 Laser Cleaning

There are numerous articles that discuss laser cleaning of marble surfaces, many of which focus on the removal of encrustation from outdoor marble, the impetus behind the development of the type of laser most familiar to conservators, the Nd:YAG (neodymium-doped yttrium aluminum garnet) laser (Cooper 1998, 57). Laser cleaning, when using a properly configured unit, has many strengths, including the ability to selectively limit what is removed from the surface, instantaneous results, speed, and lack of mechanical action on the surface (62). Wetting the surface prior to laser cleaning can also improve the results and is sometimes referred to as "steam laser cleaning" (48–49).

The main concern regarding the laser cleaning of marble, aside from the obvious issue of access to an instrument, is the potential yellowing of marble surfaces after laser cleaning. There are a variety of possible causes for this phenomenon, including light scattering from voids, staining from organic compounds, and the transformation of iron-containing components within the stone (Pouli et al. 2007, 106; Vergès-Belmin and Labouré 2007, 116–117). While there is investigation into methods that would prevent this issue (Pouli et al. 2007), aqueous poultices have also been used to mitigate or remove the yellowing (Vergès-Belmin and Labouré 2007).

3. THE FIRST CASE STUDY

After review of published treatment techniques, cleaning tests were performed on the back of *La Première Pose* to determine the most effective way to remove soiling from the sculpture (fig. 2). The sculpture's composition fortuitously provided a relatively flat, evenly soiled surface—the back of the chair—on which to compare and contrast the cleaning techniques (fig. 3). After initial testing, promising methods were tested in additional locations to ensure that an even overall cleaning could be achieved and to assess their efficacy on different types of soiling.

La Première Pose's surface exhibited two types of soiling: overall darkening from accumulated grime and an uneven, yellow, and glossy appearance in distinct areas produced by repeated handling. The goal of the treatment was to remove these layers as completely as possible in order to present the sculpture close to its originally intended appearance. To this end, numerous cleaning methods—including organic solvents, vinyl erasers, lasers, and aqueous solutions—were tested on both types of soiling.

3.1 Cleaning Tests and Observations

3.1.1 Solvents

Polar and nonpolar organic solvents were tested first, as marble surfaces can have applied coatings that are not readily apparent under examination with visible or UV light. The solvents tested had no effect on either type of soiling, nor did the tests indicate the presence of a surface coating that could be holding grime onto the surface. Saliva also had no appreciable effect on either type of soiling.

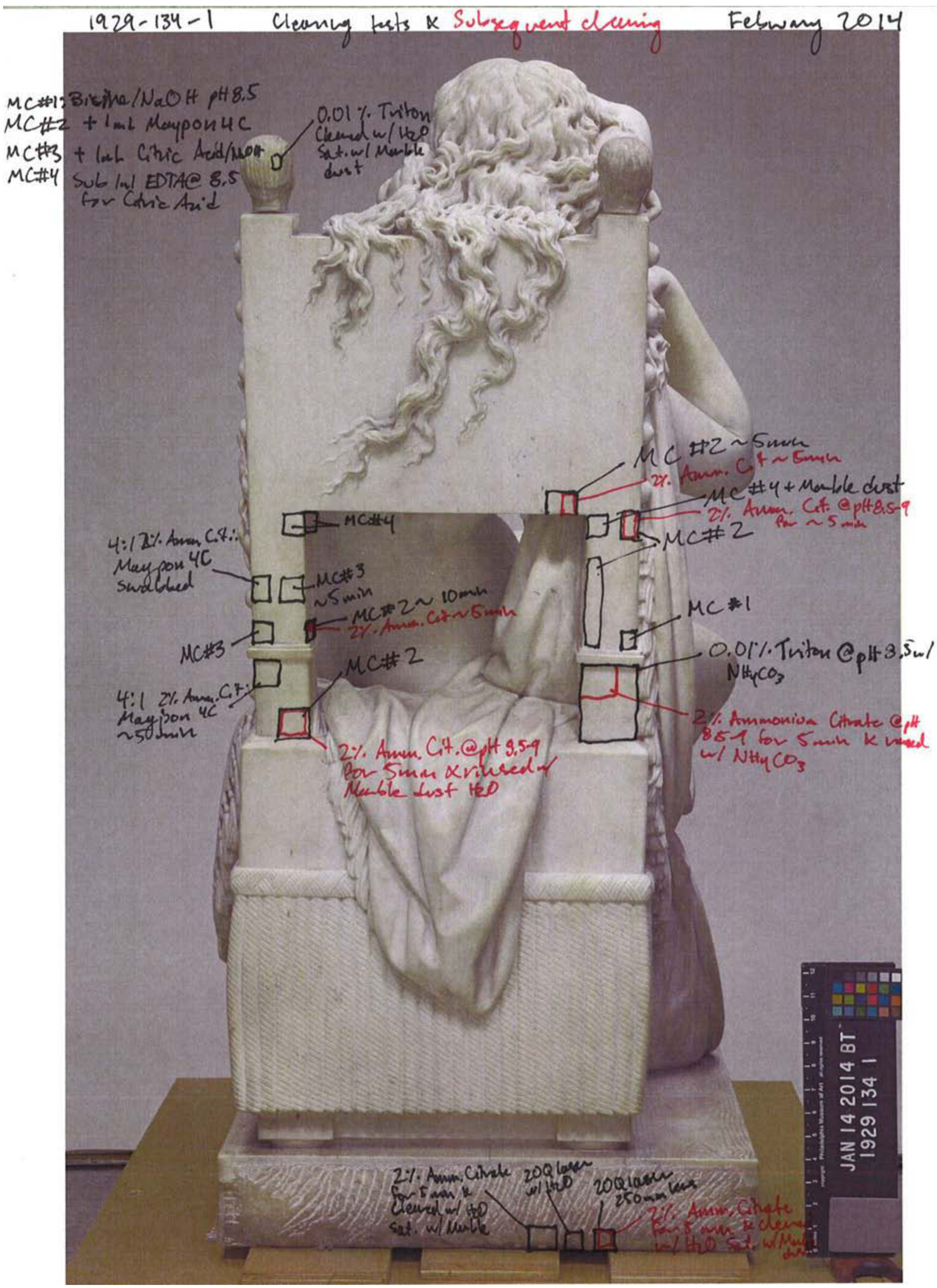

Fig. 2. Diagram of cleaning tests for *La Premire Pose* (Courtesy of Philadelphia Museum of Art)

Fig. 3. Detail of cleaning test results on the back of *La Première Pose* (Courtesy of Philadelphia Museum of Art, photograph by Raina Chao)

3.1.2 Aqueous Cleaning

As a complete, overall cleaning of the marble was desired, aqueous solutions formulated for the particulars of the surface soiling were a good option, and the challenge of limiting the cleaning to a specific area was not a concern. Various aqueous solutions were tested to gauge the efficacy of different chelators, surfactants, application methods, and dwell times, as well as their effects on the marble surface.

Table 1 summarizes the aqueous cleaning tests. From review of the literature and observations on the nature of the soiling, testing focused on chelators and surfactants. The tests moved from less aggressive to more aggressive in terms of components, concentration, and dwell time. Some of the solutions tested were prepared following the MCP, while others were custom mixed for the cleaning tests. In general, custom solutions were prepared with ammonium carbonate and ammonium hydroxide to prevent dissolution of the marble surface by saturating the solution with carbonates and raising the pH to 8 to 9. Solutions prepared using the MCP were buffered to pH 8.5 with bicine and sodium hydroxide. In order to assess the differences between modes of application and dwell time, solutions were tested up to three ways depending on results: (1) swabbed, (2) applied to the surface on a saturated pad for dwell times of 5 minutes, and (3) applied to the surface on a saturated pad for dwell times of 10 minutes.

All cleaning solutions were cleared with "carbonate-saturated water," a solution of ammonium carbonate adjusted to approximately pH 9 with ammonium hydroxide and added marble dust to saturate it with calcite

Table 1. Aqueous Solutions and Application Methods Tested on *La Première Pose*

	Major Components of Test Solutions	Application Method: Swabbed	Saturated Pad (5-min dwell)	Saturated Pad (10-min dwell)
1	0.01% Triton XL-80N[a]	x		
2	3.2% Maypon 4C[b]	x	x	x
3	2% ammonium citrate[a]	x	x	x
4	5% ammonium citrate[a]	x	x	x
5	1% citric acid + Maypon 4C (3.2%)[b]	x	x	
6	~2% ammonium citrate + Maypon 4C (3.2%)[a]	x	x	
7	1.5% EDTA + Maypon 4C (3.2%)[b]	x	x	

[a]Solution prepared with $(NH_4)_2CO_3$ and NaOH and set to pH 8–9
[b]Solution buffered to pH 8.5 with bicine and NaOH according to the MCP

and prevent dissolution of the marble surface (a detailed recipe can be found in appendix 1). This solution performed the same function as the one described by Gervais et al. (172); however, by using more readily soluble chemicals—ammonium carbonate and ammonium hydroxide—as the primary sources for carbonate ions and pH adjustment, the solution could be mixed more quickly than by using marble dust alone.

Of the two surfactants tested, Maypon 4C, an anionic surfactant, proved much more effective in removing greasy soiling than the nonionic surfactant, Triton XL-80N. Application on a saturated pad with a dwell time of approximately 5 minutes provided more complete cleaning than swabbing alone; however, no appreciable improvement was achieved by increasing the dwell time further to 10 minutes. Because the nonionic surfactant demonstrated minimal efficacy when swabbed, it was not tested at longer dwell times.

From the chelating solutions tested, the EDTA-based cleaning solutions—both swabbed and applied on a saturated pad—overcleaned the surface, leaving a bright white but raw surface likely due to dissolution of marble. The citrate-based chelating solutions proved successful in removing the accumulated grime without any perceptible adverse effects on the marble surface. The extent and efficiency of cleaning could be altered by changing concentration of the chelator and dwell time. Lower concentrations of citrate required longer dwell times to be as effective as a more concentrated solution at shorter dwell time. While vinyl erasers had previously been tested on their own or with saliva and proved minimally effective, they quickly rolled up soiling after application of a citrate solution.

3.1.3 Laser Cleaning

The Philadelphia Museum of Art owns a laser, which removed the major obstacle to laser cleaning. Tests were undertaken using a CleanLaser 20Q backpack laser (1062-nm wavelength) with a 250-mm lens on a small area on the back of the base. Two distinct areas were laser cleaned, one dry and one pre-wet with carbonate-saturated water for steam laser cleaning. An adjacent patch of surface was cleaned aqueously with the 2% ammonium citrate solution for comparison (fig. 4).

Laser cleaning removed the soiling quickly but left a yellow appearance when compared with the adjacent aqueously cleaned area. Steam laser cleaning resulted in less yellowing than laser cleaning the dry surface,

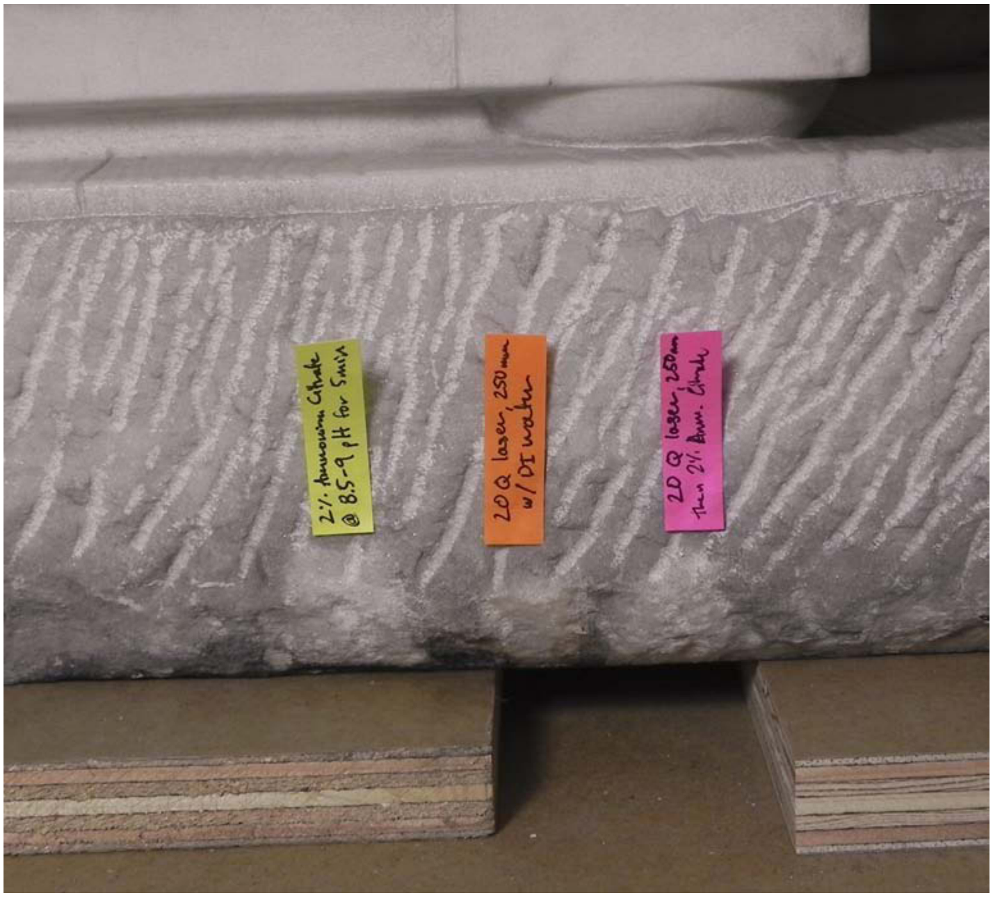

Fig. 4. Detail of laser-cleaning tests on *La Première Pose*, left to right: aqueous cleaning, steam laser cleaning showing yellowed surface, laser-cleaned area after subsequent aqueous cleaning to remove yellowing (Courtesy of Philadelphia Museum of Art, photograph by Raina Chao)

but was still noticeably more yellow than the aqueously cleaned area. The yellowing effect was easily removed with a subsequent aqueous treatment with the 2% ammonium citrate test solution described earlier. Laser cleaning was not tested on an area of particularly heavy handling residues.

3.2 Treatment

Based on these tests, aqueous solutions were chosen as the most efficient and safest method for cleaning *La Première Pose*. Citrate-based solutions were very effective in reducing the overall grime but less so on areas with greasy residue. The residue appeared to act as barrier to the chelating solution, preventing it from effectively and uniformly accessing the soiled surface and producing an unevenly cleaned surface. This result was found in areas of greasy residue even when a surfactant was added to the solution. Similarly, the anionic surfactant was successful in removing the greasy residue but the resultant surface still had a darkened appearance from accumulated grime. Therefore, a two-step treatment process was devised.

First, a buffered detergent solution consisting of 3.2% Maypon 4C solution at pH 8.5 (Solution 2 from table 1) was applied on a saturated pad for approximately 5 minutes. Maypon 4C was later replaced with sodium lauryl sulfate, another anionic detergent, as finding a supplier for a reasonable quantity of Maypon 4C proved difficult. Tests showed that a 1% buffered solution of sodium lauryl sulfate behaved similarly to the 3.2% Maypon 4C and the substitution proved satisfactory.

Second, a saturated pad of 2% ammonium citrate solution (Solution 3 from table 1) was applied to the surface with a stencil brush for 5 to 10 minutes, depending on the extent of soiling in that area. The soiling was then rolled off with a vinyl eraser and/or cotton swabs and the surface cleared with carbonate-saturated water after both steps. More tenacious soiling was removed with longer dwell times during the second (chelating) step and/or a more concentrated chelating solution of 5% ammonium citrate (Solution 4 from table 1). Detailed recipes for the aqueous solutions used in the treatment are included in appendix 1.

3.2.1 Protecting the Surface with Marble Dust

In addition to the ammonium carbonate added to these chelating solutions to prevent the dissolution of the marble surface, marble dust was added to the bulk solutions used for cleaning. The amount of marble dust varied but was always in excess of that needed to fully saturate the solution, and a layer of marble dust was visible at the bottom of the jar. This addition was intended to provide a more readily accessible source (due to the high surface area of a powder) of calcium to fill the chelating site on the citrate ion that could otherwise cause damage to the marble surface. The formation constants for citrate complexes indicate that their affinity for calcium is lower than for many other ions (Gervais et al. 2010, 165). Therefore, theoretically, the calcium ion could be displaced by other ions within the soiling for which citrate had a higher affinity. The treatment was successfully carried out without any perceptible alteration to the surface from the chelating solution; however, it is unlikely that the addition of marble powder contributed to this result as intended.

It was learned after treatment that the calcium citrate complex is minimally soluble in water (Lide 2005, 3–84) and therefore forms a precipitate, effectively removing citrate from the solution rather than allowing it to preferentially chelate for other ions within the soiling. This also retroactively explains a light-colored precipitate that seemed to form in older solutions directly above the marble dust. At the time, the precipitate was thought to be biological growth and the solutions were discarded. Nevertheless, though the addition of marble dust to the chelating solution did not achieve its intended purpose, it did not adversely affect the cleaning. Thus, the concept of preventing the chelation of calcium from the marble surface by loading the solution with calcium remains viable for other chelators, as discussed later.

3.2.2 Reduction of Yellowing with Methyl Cellulose Gels

The sculpture was treated overall with the procedure described earlier, generally producing an even, dramatically brighter surface (fig. 5). Some areas of greasy residue remained yellowed after overall cleaning, likely due to greater penetration of discolored oils from handling. This yellowing was reduced with methyl cellulose poultices consisting of approximately 10% (w/v) Methocel A4C in carbonate-saturated water. Poultices were applied to the surface, allowed to dry fully, peeled away, and the surface cleared with carbonate-saturated water. The dried poultice films were examined under magnification to ensure that no marble crystals were being removed from the surface, and the marble surface was not perceptibly altered by this treatment. Remaining yellowing was further reduced with a methyl cellulose poultice consisting of approximately 10% to 15% (w/v) Methocel A4C in the 2% ammonium citrate solution. The poultices were applied and cleared in the same manner.

The addition of the chelator to the methyl cellulose poultice had two observable effects: it took more methyl cellulose to reach a similar viscosity than without the chelator, and the dried poultice did not form a coherent film and sprang away from the surface upon drying (fig. 6). Though the incoherent dried films could not be examined for the presence of marble crystals, no alteration of the surface was observed visually or by touch after two applications. Following the third application, a slight alteration in the surface texture was noted by touch, but not visually, and the treatment was halted.

Fig. 5. Details showing progression of cleaning on *La Première Pose,* left to right: before, during, and after treatment (Courtesy of Philadelphia Museum of Art, photograph by Joe Mikuliak)

Despite the yellowish cast that remained in some areas, the marble's surface appeared much improved and homogenous overall (fig. 7).

4. CONTINUING CASE STUDIES

The literature review, in-depth cleaning tests, and observations made during the treatment of *La Première Pose* provided a foundation of experiential knowledge and a methodological template that influenced subsequent marble treatments undertaken by the author. The following case studies illustrate how this methodology was applied, adapted, and expanded for the specific parameters of each project. The features that affect the decision-making process include the type of soiling, level of carving and finish of the marble, the circumstances of its manufacture and intended appearance, and the context of its display.

4.1 Case Study: The Effect of Carving and Finish

Randolph Rogers's *The Lost Pleiad* (fig. 8) was treated immediately after *La Première Pose* for installation in the same gallery. The sculptures have a number of formal similarities, are roughly contemporary in manufacture, and were to be in close proximity. Thus, there was a desire for consistency in their appearance. *The Lost Pleiad* also had similar condition issues to *La Première Pose*—an overall layer of accumulated grime on its surface and yellow, greasy residues from repeated handling. In this case, the residues were restricted to localized areas on the base, likely due to the sculpture's elevated display height.

Due to the similarities between the sculptures, soiling, and their display contexts, testing for *The Lost Pleiad* focused on aqueous methods. The cleaning tests were similar to those executed as described earlier, except that they replaced Maypon 4C with sodium lauryl sulfate and were expanded to include methyl cellulose poultices. Following the relatively successful application of methyl cellulose poultices in the treatment of *La Première Pose*, these tests attempted to determine how effective and efficient poultices

Fig. 6. Dried methyl cellulose poultice on the foot of *La Première Pose* illustrating film disruption from addition of a chelator (Courtesy of Philadelphia Museum of Art, photograph by Raina Chao)

Fig. 7. *La Première Pose* after treatment (Courtesy of Philadelphia Museum of Art, photograph by Joe Mikuliak)

Fig. 8. Before treatment, Randolph Rogers, *The Lost Pleiad,* c. 1874–1882, marble, 173 × 113 × 91.5 cm. Philadelphia Museum of Art, Gift of Lydia Thompson Morris, 1929-162-1 (Courtesy of Philadelphia Museum of Art, photograph by Joe Mikuliak)

would be on a soiled, rather than a precleaned, surface. The solutions and gels tested are summarized in table 2 and results are shown in figure 9. All cleaning tests were cleared with carbonate-saturated water.

It was found that a methyl cellulose poultice without an added chelator did not fully clean the surface, while the poultice with a chelator appeared to overclean the surface (fig. 10). Subsequent applications of the same gel over the same areas did not produce any further visible change. Otherwise, the results of aqueous cleaning tests were similar to those of *La Première Pose.*

As methyl cellulose poultices proved unsuitable, a protocol similar to that used on *La Première Pose* was devised, but modified to suit the particulars of *The Lost Pleiad*'s condition. The greasy residues, more minimal in location and extent, could be addressed by swabbing with the anionic surfactant solution (Solution 4 in table 2), only in areas that were visibly yellowed and glossy. Then a 2% ammonium citrate solution (Solution 2 in table 2) was applied overall on saturated pads for 5 to 10 minutes and the soiling rolled off with a vinyl eraser and/or cotton swabs. Recesses and areas of complex carving retaining more tenacious soiling were addressed with the 5% ammonium citrate solution (Solution 3 from table 2) on cotton swabs. The surface was cleared with carbonate-saturated water after all treatment steps. Detailed recipes for the aqueous solutions used in the treatment are included in appendix 1.

During the cleaning, it was noted that the accumulated soiling was generally easier to remove from *The Lost Pleiad* than from *La Première Pose*. This was particularly noticeable in areas of higher polish and simpler carving. As most sculptures have some degree of variation in the complexity of their carving and finish of the marble surface, this was a useful reminder that these differences can be a factor in the extent and uniformity of cleaning achievable on a piece. In this case, the variations influenced the ease or difficulty of cleaning but did not impair the ability of the treatment to achieve a homogenously clean overall appearance that was consistent with that of its neighbor, *La Première Pose* (fig. 11).

4.2 Case Study: Using Agar Gels

In 2016, the Saint Louis Art Museum reinstalled its galleries of American art, prompting the treatment of a marble bust, *Joan of Arc Listening to the Voices* by Robert Porter Bringhurst (1855–1925; fig. 12). Records indicated that the marble bust had previously been treated to remove superficial surface soiling; however, the surface remained yellowed, particularly on the high points, and dark soiling remained trapped in point defects and cracks. Though the surface was not dramatically soiled, there was a desire to reduce the yellowing to better meld with adjacent works in marble.

Table 2. Aqueous Solutions and Application Methods Tested on *The Lost Pleiad*

	Major Components of Test Solutions	Application Method		
		Swabbed	Saturated Pad (5-min dwell)	Methyl Cellulose Gel (removed dry)
1	Carbonate-saturated water	x	x	x
2	2% ammonium citrate[a]	x	x	x
3	5% ammonium citrate[a]	x	x	
4	1% sodium lauryl sulfate[b]	x	x	

[a]Solution prepared with $(NH_4)_2CO_3$ and NaOH and set to pH 8–9
[b]Solution buffered to pH 8.5 with bicine and NaOH according to the MCP

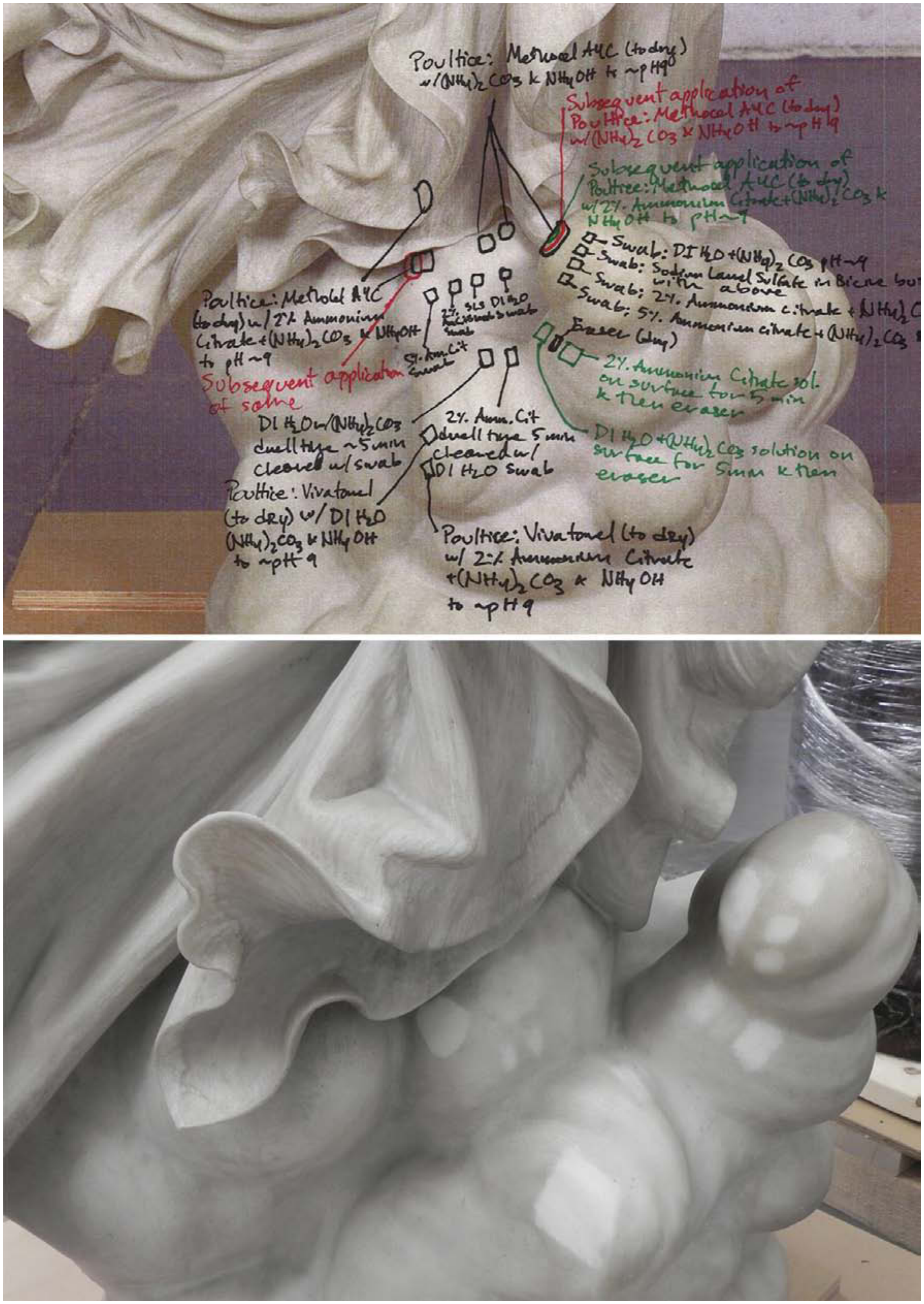

Fig. 9. Detail of cleaning tests conducted on *The Lost Pleiad*, diagram (top) and results (bottom) (Courtesy of Philadelphia Museum of Art, photograph by Raina Chao)

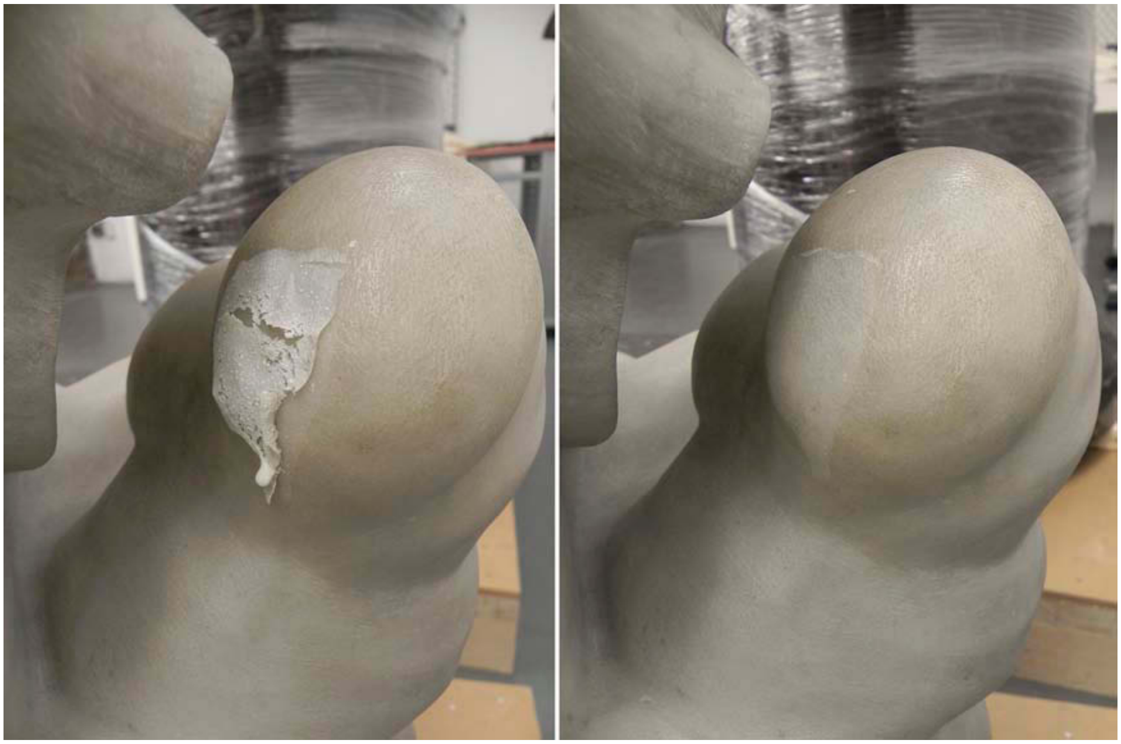

Fig. 10. Detail of methyl cellulose poultice tests on *The Lost Pleiad* (Courtesy of Philadelphia Museum of Art, photograph by Raina Chao)

The successful reduction of tenacious yellowing on areas of *La Première Pose* indicated that poultices of aqueous solutions might be effective in reducing the yellowing. However, because of the risk of damaging the marble surface and the chelator's observed disruption of the methyl cellulose gel, a different type of poultice was preferred. Therefore, the use of agar gels was explored since, as discussed earlier, agar gels are

Fig. 11. Progression of cleaning on *The Lost Pleiad*, left to right: before, during, and after treatment (Courtesy of Philadelphia Museum of Art, photograph by Joe Mikuliak)

Fig. 12. Robert Porter Bringhurst, *Joan of Arc Listening to the Voices*, 1885, marble, 38.1 × 19.7 × 19.1 cm, Saint Louis Art Museum, Gift of Friends of the Artist, 50:1924 (Courtesy of Saint Louis Art Museum, photograph by Jean-Paul Torno)

compatible with chelators and are not adhered to the marble surface, alleviating concerns about mechanical damage to the marble surface.

In order to assess the effect of an agar gel on the surface, a 2% (w/v) agar gel in pH-adjusted water at pH 8.5 was prepared, applied to the surface molten, and removed after 30 minutes. The gel successfully removed trapped soiling but had little effect on the yellowing. A 2% (w/v) agar gel made with 2% citrate solution in deionized water adjusted to a pH of 8.5 with ammonium hydroxide proved more effective in reducing the yellowing when allowed to dwell on the surface for approximately 15 minutes. Once the gel was removed, the area was cleared with pH-adjusted water at pH 8.5. The gel was applied to yellowed areas 1 to 2 times to achieve an even surface overall.

The treatment was successful, but improvement in the surface was relatively subtle and achieved slowly through multiple applications of agar gel (fig. 13). A batch of agar was made up by dispersing the dry agar in the intended cleaning solution; then, it was heated in a microwave until the agar dissolved and a molten solution was formed. The solution was applied molten to the marble surface, where it quickly formed a rigid gel upon cooling. After the designated dwell time, the agar was easily peeled off the surface along seams cut with a wooden skewer.

To reduce waste, the remaining gel that was not applied to the surface could be subsequently reheated and used for treatment. It was observed that the reheated gels containing the chelator were sometimes more effective than the gel as first applied, likely due to an increase in the concentration of the chelator from water evaporating during reheating. Evaporation during reheating is variable; thus, the concentration of chelator is difficult to quantify after reheating. Though it did not pose a problem in this treatment, the variability could be eliminated by always using newly mixed solutions or by adding the chelator or other additional components after the agar is molten, as recommended by Scott (2012, 73).

4.3 Case Study: Nuanced Partial Cleaning

In early 2017, the Saint Louis Art Museum installed the exhibition *Learning to See: Renaissance and Baroque Masterworks from the Phoebe Dent Weil and Mark S. Weil Collection*, a show primarily composed of promised gifts of prints and sculpture. One of the sculptures, a monumental white marble bust of the Roman emperor Marcus Aurelius (fig. 14), was cleaned in preparation for exhibition.

The *Bust of Marcus Aurelius*, as an earlier work reflective of antiquity, required a different type of treatment methodology than that presented in the other case studies. The goal of the treatment was to reduce and even out the overall soiling accumulated on the surface, but not to remove it completely. After discussion with the lender and curators, it was deemed most appropriate to retain some of the surface soiling as an indicator of age and the sculpture's history.

In order to accomplish this goal, cleaning tests focused not on how to most effectively clean the marble but rather on determining the most controllable method to execute a nuanced cleaning of the surface.

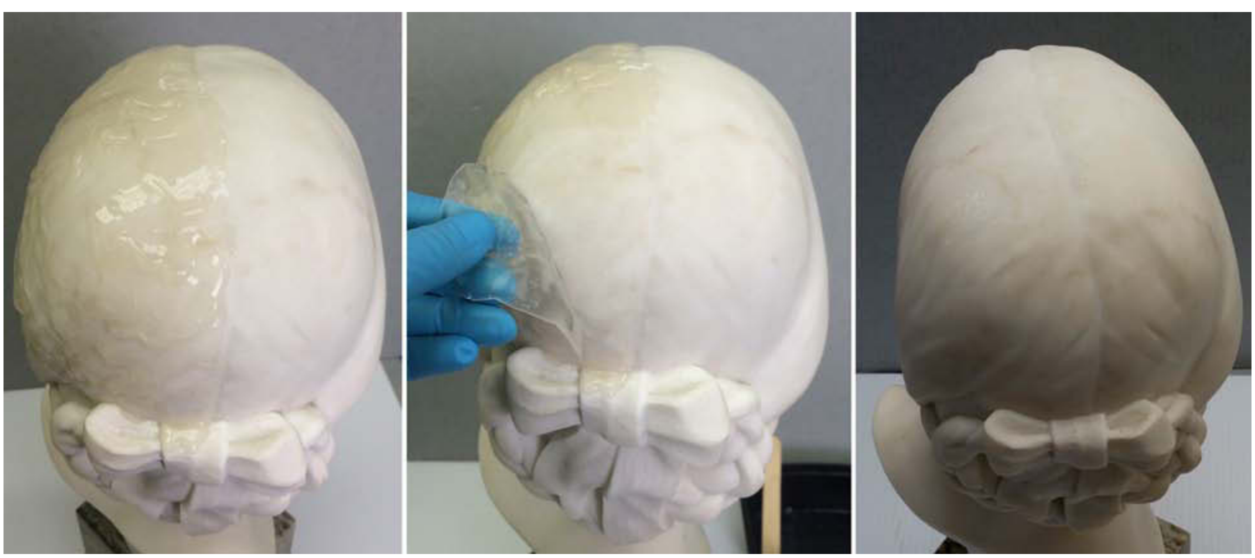

Fig. 13. During treatment details of *Joan of Arc*, left to right: agar gel applied to the proper left side, agar gel being removed, image of the partially cleaned surface, showing subtle reduction of yellowing (Courtesy of Saint Louis Art Museum, photograph by Raina Chao)

Fig. 14. Unknown Italian Artist, *Bust of Marcus Aurelius*, late 18th–early 19th century, marble, 80.6 × 40 × 37.9 cm, Private Collection, Promised gift of Phoebe Dent Weil and Mark S. Weil to Saint Louis Art Museum, 2016.21 (Courtesy of Saint Louis Art Museum, photograph by Jean-Paul Torno)

Tests performed on the back of the sculpture indicated that vinyl erasers and saliva produced the most controllable cleaning (fig. 15). However, as cleaning commenced and extended beyond the back of the sculpture, the efficacy of cleaning with this method decreased dramatically. More conspicuous areas of the sculpture appeared to have a protective layer, preventing the saliva and erasers from cleaning effectively. Solvent cleaning with odorless mineral spirits readily removed this layer (likely wax) and the dark soiling above it, greatly improving the appearance of the surface. After solvent cleaning, saliva and erasers were successfully used to reduce more entrenched soiling and even out the surface (fig. 16).

This case study highlights the importance of testing treatment methods in more than one area, as variations in soiling or surface treatment can lead to diverse responses to the same treatment method. Such unexpected results are particularly problematic in cases such as this in which a nuanced partial, rather than complete, cleaning is desired.

4.4 Case Study: New Methods

The case studies presented contain observations on the use and adaptation of published techniques tailored to the needs of specific objects. Yet, there are also new techniques that could be applied in marble treatments, if appropriately tested.

One such innovative approach to the use of chelators to treat marble was presented by Chris Stavroudis during the Modular Cleaning Program workshop held at the Saint Louis Art Museum in March 2017. As described earlier, the attempt to prevent citrate ions from chelating calcium from the

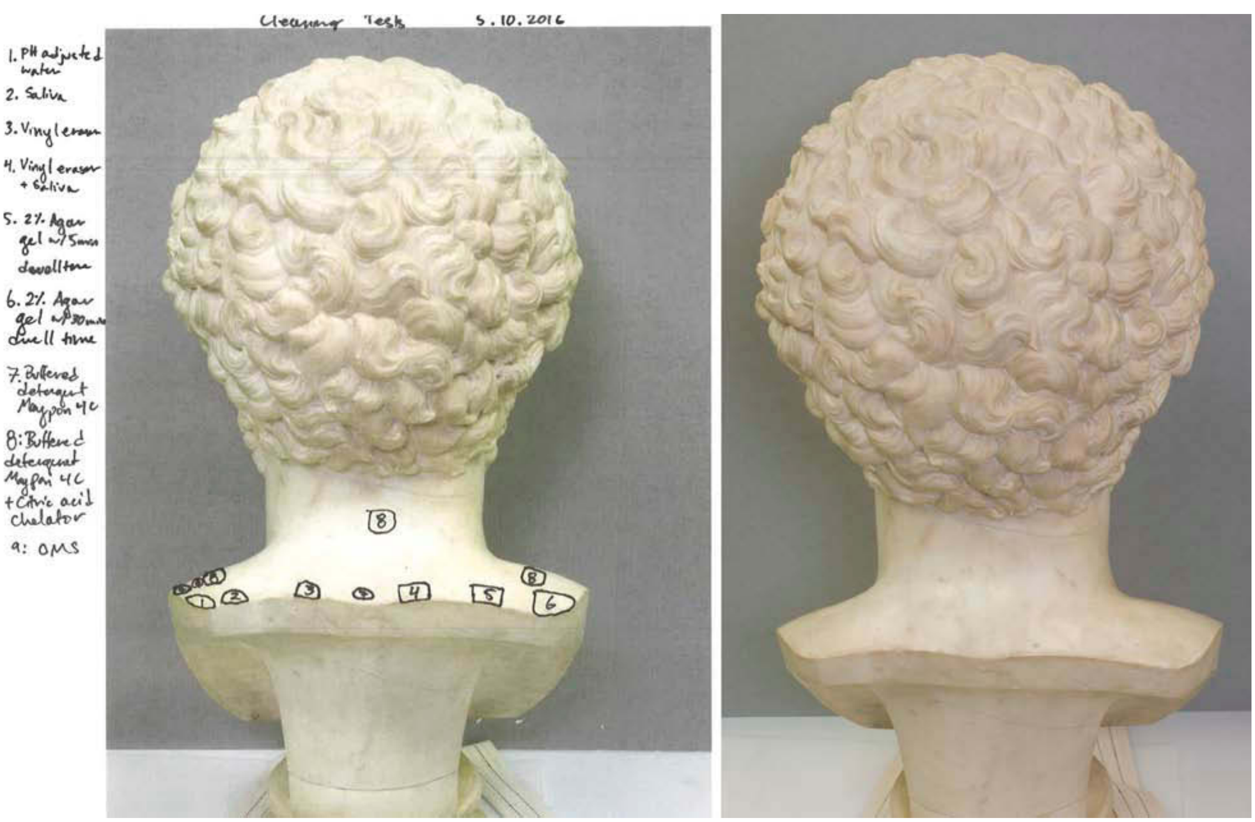

Fig. 15. Detail of cleaning tests on *Marcus Aurelius*. Left: diagram. Right: results. (Courtesy of Saint Louis Art Museum, photograph by Raina Chao)

Fig. 16. *Marcus Aurelius*. Left: partially solvent cleaned. Right: after treatment. (Courtesy of Saint Louis Art Museum, photograph by Raina Chao)

marble surface by adding a source of calcium to the solution was not effective. However, other chelating agents, such as ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA), form soluble complexes with calcium, allowing the calcium-chelator complex to remain in solution. The calcium-chelator complex in solution remains capable of effectively solubilizing other ions from the soiling layer, which will then displace the calcium. Through this method, it is possible that EDTA and DTPA, previously shown to cause damage to marble surfaces, could be safely used for aqueous cleaning of marble.

To investigate this possibility, several aqueous solutions at pH 8.5 containing EDTA and DTPA with and without a reserve of calcium (from calcium hydroxide) were placed on a highly polished marble surface for 15 and 30 minutes (solutions and results are summarized in table 3). As shown in

Table 3. Observations of the Effect of Chelating Solutions Tested on Polished Marble

Solution	Effect after 15 Minutes	Effect after 30 Minutes
Deionized water	None	Not tested
pH-Adjusted Water (pH 8.5)	None	Surface slightly matte Notable change in texture
pH 8.5 EDTA[a]	Matte surface Slightly rough texture	Very matte surface Rough texture
pH 8.5 EDTA + $Ca(OH)_2$[a]	Barely noticeable Minimal texture change	Surface slightly matte Notable change in texture
pH 8.5 DTPA[a]	Matte surface Slightly rough texture	Very matte surface Rough texture
pH 8.5 DTPA + $Ca(OH)_2$[a]	Barely noticeable Minimal texture change	Slightly noticeable Minimal texture change
pH 8.5 Citric acid[a]	Slightly noticeable Minimal texture change	Matte surface Slightly rough texture

[a] Solution buffered to pH 8.5 with bicine and NaOH according to the MCP; recipes in appendix 1

figure 17, the chelating solutions without added calcium visibly etched the surface, but the solutions with calcium showed almost undetectable etching at 15 minutes. At 30 minutes, EDTA with added calcium appreciably etches the marble surface while the DTPA still has a barely perceptible effect on the surface.

When compared with citric acid, at 15 minutes the EDTA and DTPA solutions with calcium have similar or less effect on the surface. However, at 30 minutes, the DTPA with added calcium

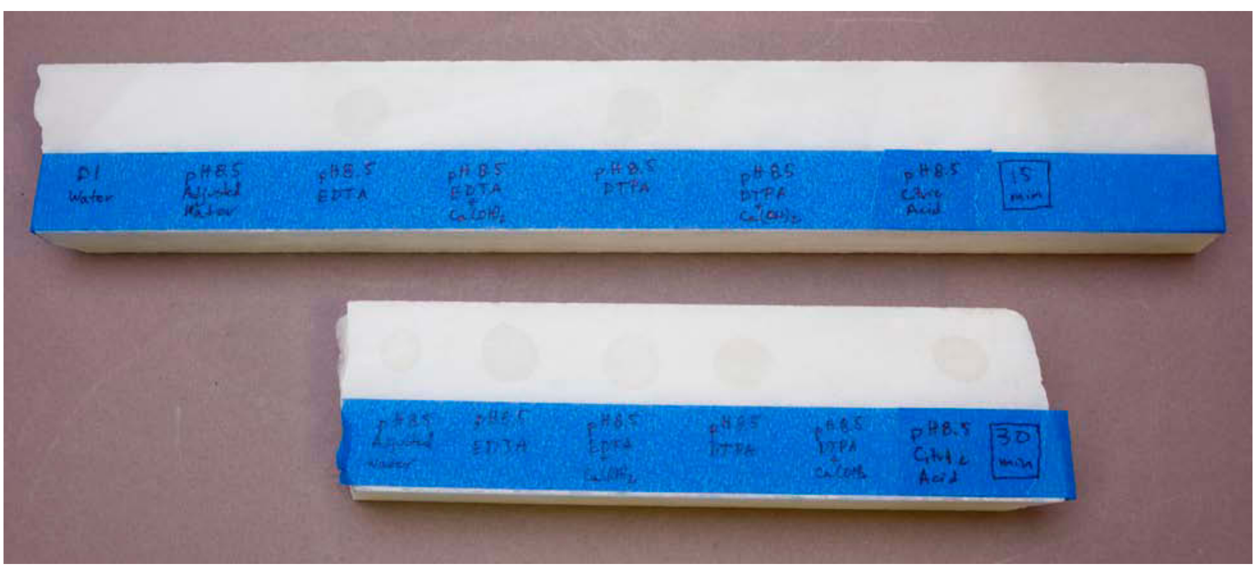

Fig. 17. Test results showing effects on a polished marble surface by buffered pH 8.5 chelating solutions with and without added calcium hydroxide at dwell times of 15 and 30 minutes

performs much better than citric acid. Disturbingly, pH-adjusted water at pH 8.5 also seemed to etch the surface after 30 minutes (though it had no effect after 15 minutes), indicating that it may be prudent to investigate the inclusion of calcium or carbonates to further discourage dissolution of the marble surface for longer dwell times. This preliminary test indicates that the technique, particularly used with DTPA, shows great promise and could, after further investigation with more detailed and rigorous experiments, become a useful addition to the arsenal of marble cleaning options.

5. CONCLUSIONS

The literature review and initial case study of *La Première Pose* presented in this article informed and heavily influenced subsequent marble treatments undertaken by the author. Though the process of assessment and testing to determine the desired treatment methodology remains the same, individual treatment procedures are continually adapted to suit the specific needs of each object and as new treatment approaches arise. New techniques, such as the addition of calcium or carbonates to cleaning and clearance solutions, can be easily incorporated into the testing framework but should first be tested more thoroughly on samples and evaluated for their suitability for use on marble.

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APPENDIX 1: Recipes for Solutions

La Première Pose and *The Lost Pleiad*

Carbonate-Saturated Water
Deionized water adjusted to ~ pH 9 with ammonium carbonate and ammonium hydroxide with added marble dust

Recipe for a final volume of 200 mL
200 mL deionized water
6 g ammonium carbonate
~ 1.5 mL ammonium hydroxide
Marble dust

Buffered Detergent Solution
0.8% (0.5 M) bicine/sodium hydroxide pH 8.5 buffer
3.2% Maypon 4C

Recipe for a final volume of 200 mL
200mL deionized water
1.6 g bicine
6 mL Maypon 4C
Adjust to pH 8.5 with 1 M sodium hydroxide

Adjusted Buffered Detergent Solution
0.8% (0.5 M) bicine/sodium hydroxide pH 8.5 buffer
1% (0.355 M) sodium lauryl sulfate

Recipe for a final volume of 200 mL
200 mL deionized water
1.6 g bicine
2.1 g sodium lauryl sulfate
Adjust to pH 8.5 with 1 M sodium hydroxide

2% Ammonium Citrate Solution
2% (w/v) ammonium citrate in deionized water adjusted to ~ pH 9 with ammonium carbonate and ammonium hydroxide

Recipe for a final volume of 200 mL
200 mL deionized water
4 g ammonium citrate
6 g ammonium carbonate
~ 1.5 mL ammonium hydroxide
Marble dust

5% Ammonium Citrate Solution
5% (w/v) ammonium citrate in deionized water adjusted to ~ pH 9 with ammonium carbonate and ammonium hydroxide

Recipe for a final volume of 200 mL
200 mL deionized water
10 g ammonium citrate
6 g ammonium carbonate
~ 1.5 mL ammonium hydroxide
Marble dust

Joan of Arc Listening to the Voices
2% Agar Gel with 2% Ammonium Citrate
2% (w/v) agar dissolved in 100 mL of 2% (w/v) citric acid solution adjusted to ~ pH 8.5 with ammonium hydroxide

Recipe for a final volume of 100 mL
100 mL deionized water
2 g agar
2 g citric acid
Ammonium hydroxide to pH 8.5

2% Agar Gel with pH 8.5 Adjusted Water
2 g agar in 100 mL of pH 8.5 adjusted water

Recipe for 3000 mL of pH 8.5 adjusted water (Stavroudis 2016)
1 mL glacial acetic acid
3000 mL deionized water
Set pH to 8.5 with 10% ammonium hydroxide (~ 14 mL)

REFERENCES

Cooper, Martin, ed. 1998. *Laser Cleaning in Conservation: An Introduction*. Oxford: Butterworth-Heinemann.

Detroit Institute of Arts. 2013. "Detroit Institute of Arts Sculpture the Lost Pleiad Being Cleaned in Gallery for Visitors to Observe – Conservator Available for Public to Ask Questions about Delicate Cleaning Process." http://artdaily.com/news/62520/Detroit-Institute-of-Arts-sculpture-The-Lost-Pleiad-being-cleaned-in-gallery-for-visitors-to-observe#.XYlP3kZKiUl

Gervais, Claire, Carol A. Grissom, Nicole Little, and Melvin J. Wachowiak. 2010. "Cleaning Marble with Ammonium Citrate." *Studies in Conservation* 55 (3): 164–176.

Goldberg, Lisa A. 1989. "A Fresh Face for Samuel Gompers: Methyl Cellulose Poultice Cleaning." *Journal of the American Institute for Conservation* 28 (1): 19–29.

Lauffenburger, Julie A., Carol A. Grissom, and A. Elena Charola. 1992. "Changes in Gloss of Marble Surfaces as a Result of Methylcellulose Poulticing." *Studies in Conservation* 37 (3): 155–164.

Lide, David R. ed. 2005. *CRC Handbook of Chemistry and Physics.* 86th ed. Boca Raton, FL: Taylor & Francis.

Pouli, P., G. Totou, V. Zafiropulos, C. Fotakis, M. Ouija, E. Rebollar, M. Castillejo, C. Domingo, and A. Laborde. 2007. "A Comprehensive Study of the Coloration Effect Associated with Laser Cleaning of Pollution Encrustations from Stonework." In *Lasers in the Conservation of Artworks: Lacona VI Proceedings, Vienna, Austria, Sept. 21–25, 2005,* edited by Johann Nimmrichter, Wolfgang Kautek, and M. Schreiner. New York: Springer: 105–114.

Riccardelli, Carolyn, Michael Morris, George Wheeler, Jack Soultanian, Lawrence Becker, and Ronald Street. 2014. "The Treatment of Tullio Lombardo's Adam: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49 (1): 48–116.

Scott, Cindy Lee. 2012. "The Use of Agar as a Solvent Gel in Objects Conservation." *Objects Specialty Group Postprints, Volume Nineteen, 2012.* Washington, DC: American Institute for Conservation (AIC). 71–83.

Stavroudis, Chris. 2009. "Sorting Out Surfactants." *WAAC Newsletter* 31 (1): 18–21.

Stavroudis, Chris. 2016. Technical Note: pH Adjusted Water Recipes. Cleaning of Acrylic Painted Surfaces. Sarasota, FL. http://www.getty.edu/conservation/our_projects/education/caps/pH_water_recipes.pdf

Stavroudis, Chris, Tiarna Doherty, and Richard Wolbers. 2005. "A New Approach to Cleaning I: Using Mixtures of Concentrated Stock Solutions and a Database to Arrive at an Optimal Cleaning System." *WAAC Newsletter* 27 (2): 17–28.

Tortajada Hernando, S. and M. M. Blanco Domínguez. 2013. "Cleaning Plaster Surfaces with Agar-Agar Gels: Evaluation of the Technique." *Ge-conservación* 4: 111–126.

Vergès-Belmin, Véronique and M. Labouré. 2007. "Poultices as a Way to Eliminate the Yellowing Effect Linked to Limestone Laser Cleaning." In *Lasers in the Conservation of Artworks: Lacona VI Proceedings, Vienna, Austria, Sept. 21-25, 2005,* edited by Johann Nimmrichter, Wolfgang Kautek, and M. Schreiner. New York: Springer: 115–124.

Williams, Jane and Julie Lauffenburger. 1996. "Testing Erasers Used to Clean Marble Surfaces." *Objects Specialty Group Postprints, Volume Three, 1995.* Washington, DC: American Institute for Conservation (AIC). 118–124.

SOURCES FOR MATERIALS

Agar-Agar
Myco Supply
PO Box 15194
Pittsburgh, PA 15237
888-447-7319
www.mycosupply.com

Ammonium Carbonate [$(NH_4)_2CO_3$], CAS Number 506-87-6; Ammonium Hydroxide (NH_4OH), CAS Number 1336-21-6; Calcium hydroxide [$Ca(OH)_2$], CAS Number 1305-62-0; Diethylenetriamine-pentaacetic Acid (DTPA; $C_{14}H_{23}N_3O_{10}$), CAS Number 67-43-6; Glacial Acetic Acid ($C_2H_4O_2$), CAS Number 64-19-7; Sodium Hydroxide (NaOH), CAS Number 1310-73-2; Sodium Lauryl Sulfate ($C_{12}H_{25}NaSO_4$), CAS Number 151-21-3
Fisher Scientific
Fair Lawn, NJ 07410
201-796-7100
www.fishersci.com

Ammonium Citrate Tribasic ($C_6H_{17}N_3O_7$), CAS Number 3458-72-8; Bicine ($C_6H_{13}NO_4$), CAS Number 150-25-4; Citric Acid ($C_6H_8O_7$), CAS Number 77-92-9
Sigma-Aldrich
3050 Spruce St.
St. Louis, MO 63103
800-325-5832
www.Sigma-aldrich.com

Ethylenediaminetetraacetic acid (EDTA; $C_{10}H_{16}N_2O_8$), CAS Number 60-00-4
Bioland Scientific, LLC
14925 Paramount Blvd. Suite C
Paramount, CA 90723
562-602-8882
www.bioland-sci.com

Maypon 4C
Inolex Chemical Company
2101 S. Swanson St.
Philadelphia, PA 19148
215-271-0800
www.inolex.com

Methocel A4C; Triton XL-80N
The Dow Chemical Company
2030 Willard H. Dow Center
Midland, MI 48674
800-258-2436
www.dow.com

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THE USE OF MEDICAL CHELATING AGENTS FOR THE REMOVAL OF IRON STAINS FROM MARBLE

ANNA FUNKE, LEAH POOLE, JASON CHURCH, DR. MARY STRIEGEL, AND MARTHA SINGER

Chelating agents have long been used by conservators to remove iron stains from historic stone. The chemical composition of marble, however, presents a particular challenge because its main component—calcium carbonate—is highly sensitive to acidity and chelating agents are acidic by nature. Chelators chemically bond with metal ions, making them removable with water. This allows conservators to simply wash away metallic stains. While chelating agents are generally extremely effective at removing iron stains, their acidity can be damaging to the marble substrate. While these effects can be minor and limited to dulling a marble surface, they can be much more severe and even result in the permanent etching of the stone. This study looks specifically at the use of chelating agents, which are chemically analogous to chelators used in the medical profession to treat heavy metal poisoning and similar conditions. These products are therefore highly stable and well understood, as they have been through rigorous analysis and testing to gain approval for medical use.

This study investigates the use of five different chelating agents for their efficacy in the removal of iron stains as well as their physical and chemical effects on marble surfaces: ammonium citrate, cysteine, maltol, picolinic acid, and thioglycolic acid. One group of samples cut from Colorado Yule marble is artificially stained with iron oxide while another group is left unstained. Each chelating agent is tested at two different pH values that were chosen through UV-visible spectroscopy. The samples are analyzed before and after cleaning. Colorimentry, glossimetry, and laser profilometry readings are taken of all samples at each state of this study in order to establish a thorough understanding of how these chelating agents affect the physical properties of the marble surface and to quantify the effectiveness of the chelators in removing the iron stains. Surface readings of the pH values of the samples as well as FTIR spectra are also taken at each stage in order to gain a better understanding of the chemical effects that the chelating agents have on the marble surface.

KEYWORDS: Iron stains, Marble, Chelating agents, Chelators

1. INTRODUCTION AND REVIEW OF PREVIOUS RESEARCH

Conservators have long used chelating agents to remove metal stains from stone. However, when applied to marble, this poses complex chemical challenges. Calcium carbonate, which makes up a large proportion of marble, has a pH of approximately 10.3. Chelating agents, however, are acidic by nature. This means that, unless highly buffered, they can cause significant damage to marble by etching or even dissolving the calcium carbonate of which it is composed. Therefore, the goal of this study was to identify a chelating solution that effectively reduces iron stains without causing significant damage to the marble substrate.

This research was started by Martha Singer several years ago, who investigated the use of medical chelating agents for the removal of iron and copper stains from marble. Medical chelating agents are used for the treatment of heavy metal poisoning and similar afflictions. They are chemically engineered to target specific harmful metal ions while leaving behind all others (Crisponi and Remelli 2008, 1227). This potential for a more targeted approach held great promise for nuanced treatments in the conservation of historic objects and structures.

Singer identified two medical chelating agents to test: the copper chelator d-penicillamine (Merck) and the iron chelator Desferal (Novartis Pharmaceuticals). However, these products are too expensive for most conservators. Singer therefore identified two alternative chelating agents with analogous functional groups to use instead of the more expensive medical products. The copper chelator cysteine was used instead of d-penicillamine, and the iron chelator acetohydroxamic acid was tested instead of Desferal. Interestingly, despite their specific design, Singer found that cysteine performed significantly better at the removal of iron stains than acetohydroxamic acid.

Singer's research was continued by Leah Poole in 2014. Poole focused on establishing the pH value at which different iron chelating agents could be effectively used on marble while causing minimal effect on the calcium carbonate. She did so through test tube–based analysis using UV-visible spectroscopy. Poole tested the chelators from Singer's original study, cysteine and acetohydroxamic acid, as well as ammonium citrate, maltol, and picolinic acid, which are more commonly used in conservation. She tested each chelating agent at the pH values 7.4, 8.5, 9.2, and 10. Her tests determined that ammonium citrate, cysteine, maltol, and picolinic acid performed best at pH 9.2 and pH 10. Acetohydroxamic acid, however, was most effective at pH 8.5 and pH 9.2. Acetohydroxamic acid was once again among the least successful treatment solutions.

2. MATERIALS

As acetohydroxamic acid did not show promising results in either the Singer or Poole study, further testing on this chelating agent was not pursued. Instead, thioglycolic acid was added to the study because this agent had shown promising results in conservation (Thorn 2005, 891). The agents tested were, therefore, ammonium citrate, cysteine, maltol, picolinic acid, and thioglycolic acid.

3. EXPERIMENTAL METHOD

3.1 Preparation of Treatment Solutions

Each chelating agent was prepared at a concentration of 0.15 M (mol). This concentration was established by Poole using visible spectroscopy. Different ratios of chelating agent were added to ferric nitrate to establish how the chelating agent complexes with iron (III). Maltol, however, was prepared at a concentration of 0.09 M owing to its very low solubility in water. A small amount of sodium hydroxide had to be added to the maltol solution from the beginning because it dissolves more readily in alkaline solutions. A solution of 1 M sodium hydroxide was used to buffer these solutions to the desired pH values: one solution of pH 9.2 and one solution of pH 10 was prepared for each chelating agent based on optimal pH values determined in the Poole study. Thioglycolic acid and picolinic acid both have buffer zones just above pH 7, which made their adjustments more difficult. Once the pH reached the buffer zone, it became extremely sensitive and would fluctuate significantly with the addition of every drop of sodium hydroxide. Therefore, a 5% solution of hydrochloric acid was used for back titration to bring the solutions to the desired pH value.

An electrode pH reader was used to continuously monitor the pH of the solutions as they were being prepared. It would have been very difficult to achieve the precise values with less precise equipment.

3.2 Samples

3.2.1 Sample Preparation

A total of 63 samples were prepared from Colorado Yule marble, which is a white stone with crystalline inclusions but without veins. This makes it easier to observe physical changes and provides greater consistency across the samples. The marble samples were approximately 4 cm in diameter and just under 1 cm thick (fig. 1). The back of each sample was engraved with a unique identification number. A notch was also engraved into the bottom rim of each sample to help me consistently position the samples in the same way throughout the data collection process. The surface of the samples was then polished to a

Fig. 1. Image of marble sample before staining or stain removal

smooth finish and placed in an ultrasonic cleaner to remove any loose marble dust. After this, they were left in the oven overnight at 70°C to remove any excess water and facilitate staining.

3.2.2 Staining

As has already been mentioned, both unstained and iron-stained samples were used in this study so that the chelating agents' effects on the iron stain as well as on the marble surface could be evaluated. Thirty samples were left unstained, three samples for each of the 10 treatment solutions. Thirty-three samples were artificially stained with iron oxide. This included three controls and three samples for each treatment solution to control for inconsistencies within the data.

Replicating natural iron staining was somewhat challenging. Ultimately, an effective system was devised using steel wool and timed sprinkling with water. I used steel wool because it is a readily available source of low-quality metal that both corrodes quickly and allows the free passage of water, carrying the staining corrosion product onto the marble. It turned out that the coarser steel wool corroded too rapidly; therefore, it was impractical. It quickly went beyond red iron (III) oxide (Fe_2O_3) and turned into black iron (II, III) oxide (Fe_3O_4). This caused a dark-gray deposit on the marble, which caused only very limited staining. Grade 0 (fine) proved to be the best for this study, as it corroded much slower and, therefore, only had to be exchanged once or twice a day. It also resulted in more staining with red iron (III) oxide.

The Grade 0 steel wool was fluffed up and placed evenly over the samples, which were placed on an elevated wire mesh so that they would not sit in a pool of water (figs. 2, 3). Allowing the water to drain was important because otherwise the samples would stay saturated and the marble wouldn't absorb the stain as readily. Fluffing out the steel wool turned out to be an important step as it allowed for more oxygen to enter the system, which produced more iron (III) oxide as opposed to iron (II) oxide.

The water was delivered into the system through automatic sprinklers that were operated on a timer. After several different settings were tested, the sprinklers were finally set to "on" for two seconds and "off"

Fig. 2. The setup for staining the marble samples

Fig. 3. The marble samples during the staining process

for 30 seconds. It was important to let the samples dry slightly throughout the process and for the water to work on the steel wool before being washed away. The staining process took a total of 10 days. This included several days of testing and adjusting the sprinkler settings and changing back and forth between different grades of steel wool. Nevertheless, this process should be expected to take at least a week.

Once the staining was completed, the samples were placed in an oven overnight at 60°C. They were taken out the next morning and all loose iron oxide powder that had formed was brushed off, leaving behind only the engrained iron stain (fig. 4).

3.3 Methodology

3.3.1 Photography

Each sample was photographed before and after staining, as well as after each treatment. Photographs were taken from a consistent distance with a Nikon D5000 DSLR and a 35-mm lens. A gray scale and color scale was included in each image. These photographs provided an important record and reference throughout the study. They also helped to put into context the changes detected through other scientific methods and, thereby, determine what changes in data should be viewed as significant or noticeable to the naked eye.

3.3.2 Colorimetry

Colorimetry data were collected to quantify the visual changes that were affected on both the stained and unstained marble samples due to treatments with the different chelating solutions. The data were collected using a Chroma meter CR400, using the CIE L*a*b* color space. This model determines color by defining a point in three-dimensional space. It places the color along three axes: light to dark, red to green, and yellow to blue. Three readings were taken per sample. These readings were arranged in a vertical line down the center of each sample, as shown in figure 5.

Fig. 4. Marble samples after staining

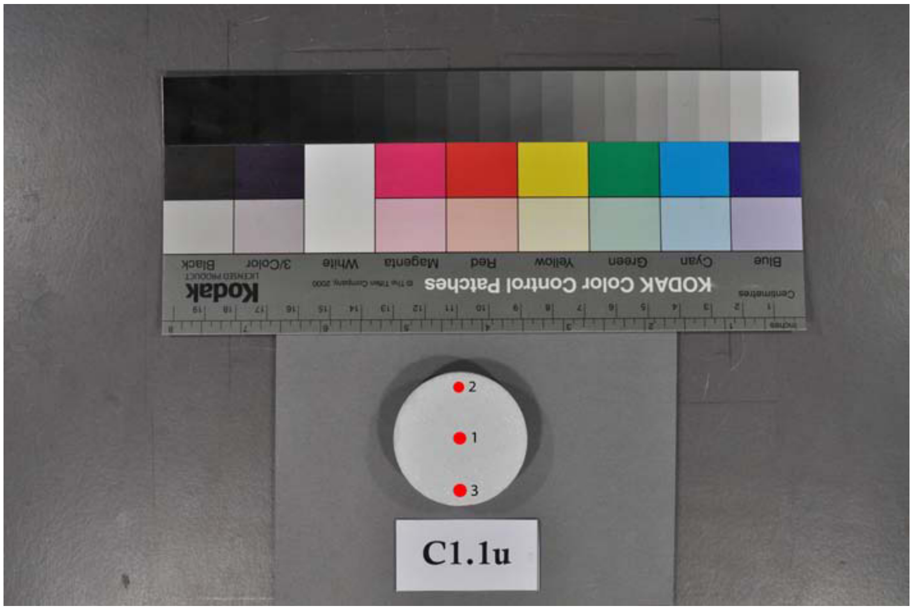

Fig. 5. Marble sample with red dots indicating the points where colorimetry data were collected

3.3.3 Glossimetry

Glossimetry was an additional method of analysis that was used to determine the physical changes undergone by the marble surface during treatment. The instrument used was a Gardener BYK micro-tri-gloss. This instrument can collect readings at three different angles of impact: 20°, 60°, and 85°. After some testing, it turned out that the readings taken at 85° were the most nuanced for the Colorado Yule marble, which is consistent with its low-gloss surface. The instrument automatically takes the average of three readings for each point that it measures. One reading was taken approximately in the center of each sample.

3.3.4 Laser Profilometry

Unlike the methods described so far, laser profilometry data were collected on only the first sample from each set of duplicates because of the length of time that it took to take the readings—approximately two hours per sample. This form of analysis collects an exact laser scan of a surface. These data were collected to determine whether the chelating agents were causing significant amounts of etching during treatment. Each reading was taken of an area 0.9 in. × 1.2 in. in the center of the sample. Within this space, 920 lines were scanned. Both the horizontal and vertical spacing was 25 mm, which results in a very high resolution.

3.3.5 Surface pH

The surface pH of each sample was taken before and after treatment. The natural pH of Colorado Yule marble is generally between 9.4 and 9.6. Therefore, any substantial decrease or increase would indicate significant chemical changes in the marble surface. The instrument used was a Thermo Scientific Orion Star A326 pH/RDO/DO meter with an Orion 8135BNUWP Electrode. Before each test, the electrode was calibrated using pH 4.01, pH 7, and pH 10.01 buffers. Five drops of deionized water were placed in the center of the sample; then, the reading was taken. It could take a surprisingly long time for the reading to stabilize. Especially after treatment, it could take up to several minutes. The electrode was rinsed with deionized water after each reading and kept in storage solution while each sample was prepared. After approximately 30 samples, the readings would sometimes start to become inconsistent. In this case, the electrode would be recalibrated before further readings were taken.

3.3.6 FTIR

FTIR data were collected to determine whether the chemical composition of the marble was altered in any way by the treatments. The instrument used was a PerkinElmer Spectrum One FTIR Spectrometer. The background reading was taken using a 2.5-cm golden mirror. Three samples were selected to provide the readings for the marble before treatment. Only three were randomly selected because all samples were cut from the same stone and, therefore, should be chemically identical. This hypothesis was consistent with the results of the readings, which yielded three nearly identical spectra (fig. 6). The samples selected were C1.2s, L1.2u, and M1.2u. As with laser profilometry, only one sample from each set of duplicates was used to collect FTIR data because of the high levels of consistency with this form of analysis. However, when unusual results occurred, further duplicates were tested to ensure the accuracy of those results. The second sample from each set of duplicates was used for the collection of FTIR data. Transmittance spectra were collected for this study as a matter of instrumental convenience.

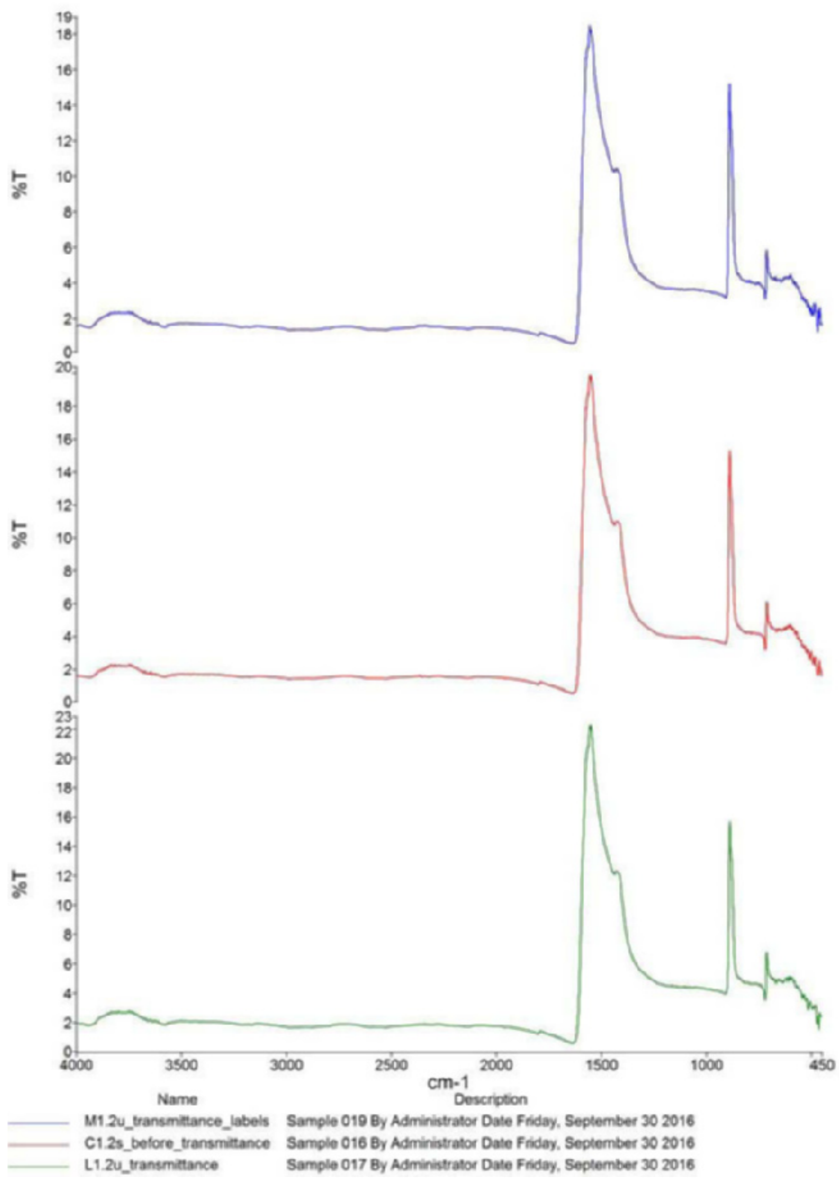

Fig. 6. FTIR spectra of the three marble samples without staining or treatment

Fig. 7. Setup of the treatment

3.4 Treatment Setup

The samples were suspended so that the lower half of the sample was submerged in the treatment solution. They were held in suspension for 30 minutes. This long dwell time was chosen to replicate a worst-case scenario in which a poultice might be left on for too long or a treatment solution is accidentally spilled on the object. Shorter dwell times and different application methods were not studied, although these would be interesting avenues for future investigation. The setup of the treatment can be seen in figure 7.

Once the samples were removed from their treatment bath, they were thoroughly rinsed with deionized water. Any excess treatment solution was dabbed off the samples with tissue paper. The samples were then air dried. Every sample was treated once, and one sample from each set of duplicates was treated a second time several days later to determine whether any of the treatment solutions would affect the samples differently after repeat treatments.

4. RESULTS

4.1 Colorimetry

The colorimetry data were crucial because they quantified the visual changes that took place both on the unstained and stained marble. For the unstained samples that underwent treatment, the final data readings were compared with those of pure marble that had not been treated in any way. The final data readings of the stained samples were compared with those taken of the freshly stained samples that had not been treated with a chelator. The difference between these values is expressed by the ΔE value. The formula to establish this value is as follows:

$$\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}.$$

Most of the unstained samples were not changed significantly by the different treatments. The exceptions were those chelated by the cysteine and maltol solutions. Both the pH 9.2 and pH 10 solutions of these two chelators caused obvious yellow staining on the white marble. While this yellow staining could not be detected in the iron-stained samples, it should be kept in mind when treating artifacts that have only very light staining. It could also affect the marble surrounding an iron stain and affect its aesthetic integrity.

For the stained samples, the best results were achieved by ammonium citrate pH 9.2, thioglycolic acid pH 9.2, cysteine pH 9.2, and picolinic acid pH 10. The success of cysteine pH 9.2, however, needs to be weighed against the yellowing that it caused in the unstained samples. This may not be of great significance in heavily stained objects but, once again, it should be kept in mind when working on only mildly stained objects.

4.2 Glossimetry

The results of the glossimetry readings varied widely. There were several instances in which the gloss levels of some samples within a duplicate set increased while those of another sample in the same set decreased. Furthermore, while there is no standard value of variation at which the human eye can detect changes in gloss level, the manufacturer of the instrument used states that a change in approximately three gloss units can be detected by the human eye. Only a very small minority of samples showed a change greater than three gloss units. Owing to the inconsistencies across the gloss data, I decided that it should not be included in the final interpretation of the data, as results may vary so widely during application in conservation practice. The changes that take place in the gloss levels were generally more significant in the stained samples than in the unstained ones. This may be a result of gloss being more easily detected in darker surfaces, or it could suggest that the changing gloss levels are more closely related to the iron staining and its removal than the specific chelating agent that is used.

4.3 Laser Profilometry

Laser profilometry was a particularly important form of analysis because etching of the marble substrate is the primary concern when using chelating agents to remove iron stains from marble. While this instrument quantifies the surface profile in several different ways, the key value on which this interpretation is based is the standard deviation of the height distribution. This value defines the difference between the lowest pits and the highest peaks. Laser profilometry showed that significantly more etching occurred on the unstained samples. This is defined by the numeric value assigned to the surface roughness—also referred to as the sq value—which increased with each treatment round. While the changes in surface roughness were not significant enough to be perceptible with the naked eye, it should be taken into consideration when working on only lightly stained objects. Maltol performed very well in this analysis. Cysteine pH 10 also did very well on the unstained samples, where it was second only to maltol 9.2. Picolinic acid pH 10 performed very well on the unstained samples. Thioglycolic acid performed well at both tested pH values. However, it caused substantially more etching after the second treatment. Therefore, a single application would be more prudent with this substance.

4.4 Surface pH

The staining process itself lowered the pH of each sample by approximately 0.5 for each sample. Maltol was the only chelating agent that did not lower the surface pH of the untreated samples at all. However, the other solutions lowered it only by relatively small margins. There was only one sample—which was treated with ammonium citrate pH 9.2—that had its surface pH lowered by slightly more than 1. Interestingly, fewer of the treatment solutions seem to lower the pH of the surface of the iron-stained samples than that of the unstained ones. This happens even when both sets of data are compared with the original surface pH of the marble, that is, before it was stained with iron (III) oxide. Therefore, the most significant change in surface pH seems to be caused by the iron stain itself. Nevertheless, maltol pH 10 performs the best both on the stained and unstained samples. Cysteine pH 10 performs very well on the stained samples but not on the unstained ones. Thioglycolic acid pH 10 and ammonium citrate 10, however, perform well on both. In this form of analysis, the chelating solutions prepared at pH 10 consistently perform better than those prepared at pH 9.2.

4.5 FTIR

The FTIR data were consistent across the board. The marble itself—calcium carbonate—was always the dominant component, showing up as a broad stretching band around 1600 to 1350 cm^{-1} with a sharp band around 900 to 700 cm^{-1}. This is typical of carbonates.

The edge in the shoulder of the broad band was raised and slightly smoothed out in the stained samples, as can be seen in figures 8 and 9. The smoothing out of the broad band caused by the iron staining made it somewhat harder to detect any additional changes caused by the chelating agents on the stained set of samples. These were easier to detect on the unstained set of samples.

The data collected from duplicate samples were remarkably consistent. The only difference tended to be the intensity of the bands, and these differences were very minor.

Picolinic acid and maltol, however, showed different levels of intensity compared with the other chelating agents. While the highest band for all other chelating agents averaged out at around 20%T, the highest band for maltol averaged at around 25%T and those of picolinic acid at around 15%T. The difference in the intensity of the bands did not seem to be linked to the pH values of the treatment solutions but rather to the chelating agent used.

The only chelating agent that seems to have a chemical effect on the marble surface is picolinic acid. Both at pH 9.2 and pH 10, treatment with this chelating agent adds a peak to the FTIR spectrum of the unstained samples. The broad band around 1500 cm^{-1} shows a small, sharp off-shoot at around 1600 cm^{-1}. Picolinic acid is the only chelating agent tested whose chemical structure could be broken up to form a N=C bond, which may be causing this peak. This small additional peak, however, is obscured in the iron-stained samples.

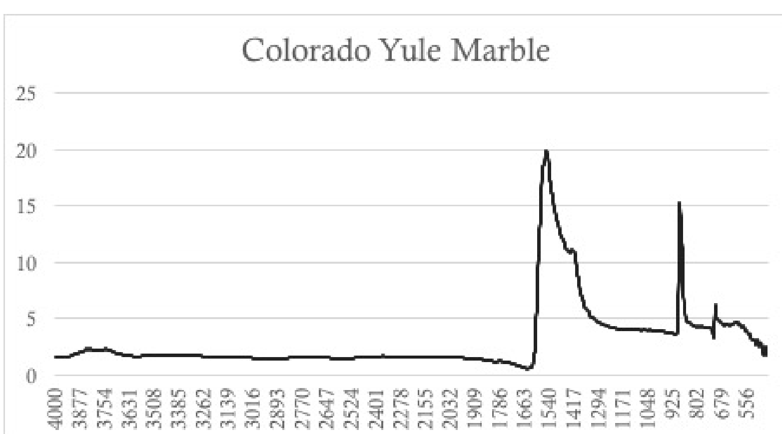

Fig. 8. FTIR spectrum taken on an unstained and untreated sample of Colorado Yule marble

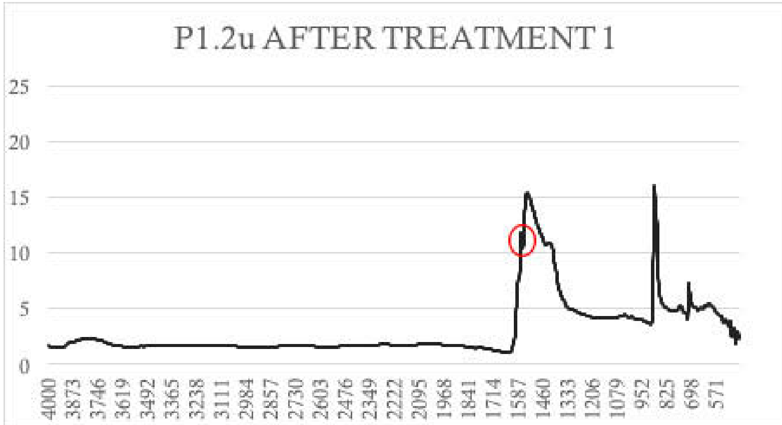

Fig. 9. FTIR spectrum of an unstained sample of Colorado Yule marble after it was treated with picolinic acid

It must be noted that, at this point, it is unclear what new compound forms on the marble surface as a result of the treatment with picolinic acid. While it is perfectly possible that this compound is safe and stable, we do not know at this writing. Therefore, I would recommend against the use of picolinic acid on historic objects until further research has been done. The use of picolinic acid could also interfere with future analysis if the chemical structure of the surface is altered through a treatment.

5. DISCUSSION

5.1 Maltol

While it can be said that maltol does not have any significant negative effects on a marble surface other than the yellow staining, it also does not seem to perform its key function of stain removal in a way that would justify its use.

5.2 Picolinic Acid

I would recommend against the use of picolinic acid in the removal of iron stains from marble until further research has been conducted on the results of the FTIR data owing to the compound that formed on the surface and its unknown effects on marble.

5.3 Ammonium Citrate

Ammonium citrate handles well as a product. It has a strong acidic smell when it is being prepared, but it is not very bothersome. It is easy to adjust its pH, as it does not have a buffer zone. It can cause eye and respiratory irritation but can safely be used outdoors and in well-ventilated spaces or with fume extraction.

While it did not cause any discoloration on the unstained samples in the form of yellowing, it did seem to darken the samples very slightly. Both the pH 9.2 and pH 10 solutions were among the top three performing solutions in terms of reducing the visual effects of iron staining.

The pH 10 solution caused negligible changes in surface pH and even increased it on the stained samples. However, the pH 9.2 solution caused some of the highest decreases in surface pH in the study. It should be kept in mind, however, that these changes were still below 1 point and, therefore, can be considered within the acceptable range of change.

The pH of the solution did not seem to matter with regard to the effect that the treatment had on the surface structure of the stained samples. Interestingly, the pH 10 solution seemed to cause more damage on the unstained samples than the pH 9.2 solution, which is rather counterintuitive. The changes caused to the surface of the stained samples were much more significant than those caused to the unstained ones. This is likely due to the removal of iron from the surface.

5.4 Cysteine

Cysteine does not pose any health or environmental hazards. It simply needs to be handled with care. Cysteine has quite a strong smell that lingers on the samples for a little while after treatment. However, it is not a particularly uncomfortable one. The pH can be adjusted very consistently, as it does not have a buffer zone.

Cysteine caused obvious yellow staining to the unstained samples. The staining seemed to remain water soluble, but this is nevertheless a very significant downside to this product if used on lightly or partially stained surfaces. It produced good results in terms of stain removal and the yellowing is not visible through heavy iron staining.

Cysteine pH 9.2 was the treatment that caused the most significant decreases in surface pH in this study on the unstained samples and the second most significant decreases in pH on the stained samples. Cysteine causes the second most significant change to the surface structure of both the stained and unstained samples after ammonium citrate. The exception to this was the use of cysteine pH 10 on the unstained samples, where it hardly caused any changes at all.

Cysteine is a surprisingly effective chelating agent for the removal of iron stains given that it is specially formulated to chelate copper ions. Nevertheless, it is a very successful product and could well be used both in the lab and in the field.

5.5 Thioglycolic Acid

Thioglycolic acid is the most hazardous substance in this study. It can cause severe damage to eyes and skin and is toxic when swallowed. It is also acutely toxic to aquatic life (category 3). This means that it can cause acute damage to aquatic life at concentrations of less than 100 mg/L. Thioglycolic acid is used at a much higher concentration when used as a chelating agent. However, it can easily be diluted. When used in a lab, it can be left to evaporate off in the fume hood. However, when used in the field, it must be managed carefully to limit the amount that enters the environment. A solid poultice should be taken back to the lab and allowed to dry out in the fume hood. Any liquid residue should be diluted as much as possible to prevent problematic amounts of contamination.

It should also be noted that thioglycolic acid has a very strong and unpleasant rotten smell, which requires fume extraction when working in the lab. This should also be considered before planning to do any big treatments in the field.

Like picolinic acid, thioglycolic acid has a buffer zone just above pH 7, which makes it difficult to adjust the pH of the solutions. Thus, it will require some back and forth adjustments using an acid (HCl) and a base (NaOH). A sensitive pH reader will be necessary to prepare these treatment solutions.

Finally, it should also be noted that while other chelating agents in this study can be purchased in solid form, thioglycolic acid is available only as a premade ~80% solution.

Thioglycolic acid hardly caused any color change on the unstained samples. Its pH 9.2 solution was very successful at reducing the iron stains. Its pH 10 solution did well after one application but did not seem to reduce any additional staining during the second application.

It caused only minimal changes to the surface pH of the samples. The pH 10 solution was particularly good in this regard, as it increased the pH of the stained samples and reduced the surface pH of the unstained samples by an average of only 0.05.

Thioglycolic acid also performed well in laser profilometry. It was consistently in the top five for both the stained and unstained samples. Again, it was much more successful in the first round of treatments, which suggests that if it were chosen for a treatment it should be applied only once and that repeat applications are probably not worthwhile.

6. CONCLUSION

As with most conservation treatments, no chelating agent provides the perfect solution for the removal of iron stains from marble. Using these agents at these high pH values reduces their efficiency substantially; however, this will often be a sacrifice worth making to preserve the original surface of the object by preventing serious damage through etching. It would be valuable to conduct further research on the best application methods for these chelating agents. This would be particularly interesting for cysteine, which caused heavy yellow staining of the white marble in this study but did not do so in the study run by Martha Singer. Applying the agent with a poultice may reduce or prevent staining. It would also be very interesting to further investigate the chemical changes caused by picolinic acid. This could help determine whether the resulting compound is stable or not. It could thereby help to establish whether this product should no longer be used in conservation and whether objects treated with it in the past may require retreatment.

ACKNOWLEDGMENTS

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REFERENCES

Crisponi, Guido, and Maurizio Remelli. 2008. "Iron Chelating Agents for the Treatment of Iron Overload." *Coordination Chemistry Reviews* 252 (10): 1225–1240.

Thorn, Andrew. 2005. "Treatment of Heavily Iron-Stained Limestone and Marble Sculpture." In *14th Triennial Meeting, The Hague, 12-16 September 2005: Vol. 2/Preprints*. London: James & James. 888–894.

FURTHER READING

Abu-Baker, Ahmad, Ian MacLeod, Robyn Sloggett, and Russell Taylor. 2013. "A Comparative Study of Salicylaldoxime, Cysteine and Benzotriazole as Inhibitors for the Active Chloride-Based Corrosion of Copper and Bronze Artefacts." *European Scientific Journal* 9 (33): 228–251.

Cappitelli, Francesca, Pamela Principi, Roberta Pedrazzani, Lucia Toniolo, and Claudia Sorlini. 2007. "Bacterial and Fungal Deterioration of the Milan Cathedral Marble Treated with Protective Synthetic Resins." *Science of the Total Environment* 385 (1): 172–181.

Cushman, Matt, and Richard Wolbers. 2007. "A New Approach to Cleaning Iron-Stained Marble Surfaces." *WAAC Newsletter* 29 (2): 23–28.

D'Alessio, A., F. Turchi, P. Narducci, P. Vergamini, F. Ciardelli, and S. Catanorchi. 2004. "Fluorinated Polymers as Stone-Protective Materials: An FTIR Study on Intermolecular Interactions." *Polymer International* 53 (10): 1567–1571.

Derrick, Michele R., Dusan Stulik, and James M. Landry. 1999. *Infrared Spectroscopy in Conservation Science*. Los Angeles: Getty Conservation Institute.

Favaro, Monica, Stefan Simon, Claudio Menichelli, Vasco Fassina, and Pietro A. Vigato. 2005. "The Four Virtues of the Porta della Carta, Ducal Palace, Venice: Assessment of the State of Preservation and Re-Evaluation of the 1979 restoration." *Studies in Conservation* 50 (2): 109–127.

Konica Minolta. n.d. Precise Color Communications—Color Control from Perception to Instrumentation.

Matero, Frank G., and Alberto A. Tagle. 1995. "Cleaning, Iron Stain Removal, and Surface Repair of Architectural Marble and Crystalline Limestone: the Metropolitan Club." *Journal of the American Institute for Conservation* 34 (1): 49–68.

Ricci, Camilla, Costanza Miliani, Brunetto G. Brunetti, and Antonio Sgamellotti. 2006. "Non-invasive Identification of Surface Materials on Marble Artifacts with Fiber Optic mid-FTIR Reflectance Spectroscopy." *Talanta* 69 (5): 1221–1226.

Salvadori, Barbara, Daniela Pinna, and Simone Porcinai. 2014. "Performance Evaluation of Two Protective Treatments on Salt-laden Limestones and Marble After Natural and Artificial Weathering." *Environmental Science and Pollution Research* 21 (3): 1884–1896.

Stambolov, Todor. 1968. "Notes on the Removal of Iron Stains from Calcareous Stone." *Studies in Conservation* 13: 45–47.

Stambolov, Todor, and B. van Rheeden. 1968. "Note on the Removal of Rust from Old Iron with Thioglycolic Acid." *Studies in Conservation* 13 (3): 142–144.

SOURCES OF MATERIALS

All chelating agents used in this study were purchased from Sigma-Aldrich.

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WELL, THAT DIDN'T WORK, NOW WHAT? STAIN REDUCTION ON A 10TH CENTURY IRANIAN CERAMIC

CLAIRE CUYAUBÈRE AND ELLEN CHASE

This article presents the treatment of an Iranian 10th century dish from the Freer Gallery of Art in Washington, DC. The dish bore disfiguring stains along most of the joins and, as a result of its appearance, had not been on view since 1982. An investigation of the stains and subsequent treatment was undertaken to reduce their visual impact. Analyses were conducted in order to identify the nature and source of the staining. Although a specific material was not identified, analyses provided clear indications that the stains were caused by earlier treatments. Various methods of stain reduction were investigated. Of the methods deemed safe for the object, none was completely effective at removing the staining, but one reduced it somewhat. Thus, the ceramic was treated in order to obtain a consistent appearance. After the sherds were joined back together and the losses and cracks were filled, several approaches to loss compensation were considered, from different levels of integration of the stained areas to covering the most disfigured ones. A dialogue with the curator and several conservators led to the decision to paint over the stained areas to allow for the display of the object and for the public and scholars to appreciate it.

KEYWORDS: Ceramic, Stain, Stain reduction, Stain removal, Chelator, Bleach, Inpainting, Loss compensation, Sodium citrate, Carbamide peroxide, Agarose, Gel, Poultice

1. INTRODUCTION

The Smithsonian's Freer Gallery of Art and the Arthur M. Sackler Gallery (Freer|Sackler) in Washington, DC together form the national museum of Asian arts. The collection consists of the arts of both East and West Asia, including Islamic art. An Iranian 10th century dish in the Freer collection was badly stained along its joins, leaving a distracting and disfiguring appearance that limited its ability to be exhibited (fig. 1).

Indeed, the curator for Islamic Art had been asking for several years whether the staining could be removed or reduced, but the stain reduction treatment was expected to be complex and time-consuming. For this reason, treatment had not yet been undertaken. However, conservation of the dish was made possible by a two-year fellowship that was funded by the Hagop Kevorkian Fund and dedicated to the conservation of Islamic ceramics. The dish was one of the highlights of this fellowship.

2. DESCRIPTION

The object is a shallow, wide-rimmed dish of about 43 cm (17 in.) in diameter. The reddish-buff and porous body is covered completely with a white slip. A transparent, lead-based glaze, characterized qualitatively using portable XRF analysis, is applied on the whole ceramic except for the foot. The only decoration is a line of Kufic inscription that runs horizontally across the dish, from rim to rim, and two letters, at the top and bottom. The inscription is executed in brownish-black slip, except for three letters in red slip.

3. CONDITION

The object was broken into 40 sherds and displayed only a few small losses. Glaze losses were present along many of the breaks and on the rim, as well as some chips of glaze and body. Losses, chips, and glaze

Fig. 1. Iran, *Dish*, 10th century, earthenware painted underglaze, 5 × 42.7 cm. Freer Gallery of Art, F1954.16. Obverse before treatment. (Photo by Claire Cuyaubère, Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery)

losses represent approximately 5% of missing original surface. The dish was joined, filled, and inpainted, but the appearance of the repairs was not satisfactory. The staining that prompted the current treatment of the object is light- to medium-dark-brown and located along most of the break lines. The brown stain lines do not start right at the edge of the sherds but rather one to a few millimeters in from the edge. On several sherds, there is a lighter-brown line of staining a couple of millimeters further in from the edge, and even a third line in a few cases (fig. 2).

Other areas of staining in addition to the edges are located across some, but not all, of the sherds. In general, this staining is more yellow and more diffuse than the staining on the edges. Finally, a few areas show dark-gray staining.

Light iridescence of the glaze was observed on several of the sherds and a few show a more matte and rough surface that indicates some chemical degradation of the glaze, which could be due to an acidic burial environment or to the composition of the glaze. The surface of the brown inscriptions has a matte and whitish appearance, also likely due to chemical degradation. The degradation noted appeared to be stable.

The glaze has craquelure overall and many very small pin holes, both most likely due to the firing process of the ceramic. Overall the surface of the ceramic is relatively clean of grime or dust. On the underside of

Fig. 2. Detail before treatment, dark lines of staining, secondary lighter-brown lines, and third lines are indicated by arrows (from the bottom up). (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

the unglazed foot, however, a reddish-brown accretion is present that appears to be iron based and possibly burial related (fig. 3).

4. PREVIOUS TREATMENTS

A review of the conservation records and the removal of restoration materials were helpful in tracing a history of successive campaigns of repair, at least four. During a first campaign, sometime after excavation of the object, the sherds were joined with an unknown adhesive that later started to discolor with age.

Fig. 3. Reverse before treatment (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

It appears that a second intervention attempted to remove this first adhesive; quite probably, the use of a solvent caused the adhesive to migrate into the porous sherds. Further attempts at cleaning adhesive residues seem to have pushed them further in, up to a few millimeters away from the sherds' edges. The sherds were then joined using a second adhesive.

The residues of the first adhesive progressively darkened and cross-linked within the ceramic body. At some point, it seems that about a dozen additional breaks to the dish occurred; a third repair campaign consisted of joining these new breaks with a third adhesive. These joins can easily be distinguished from older ones, as they do not have associated staining. The losses and cracks were filled and painted, with the paint extending over the stained areas on the entire dish in order to mask them.

These first three campaigns of restoration must have occurred before 1954, when the object was acquired by the Freer Gallery of Art. When the dish was examined in 1964, it was noticed that some of the fills and overpaint were flaking. It was found to be extensively broken, repaired, and overpainted along all joins and fills, as visible on a before-treatment photograph from 1964 (fig. 4).

All of the overpaint was removed at that time, which revealed the staining; during this treatment, the fills were resurfaced. The inpainting approach on these fills was to mimic the dark staining rather than cover it. The Department of Conservation and Scientific Research holds records dating back to the beginning of the Freer Tech Lab in 1951—quite fortunately, there is a good treatment record for this object. The

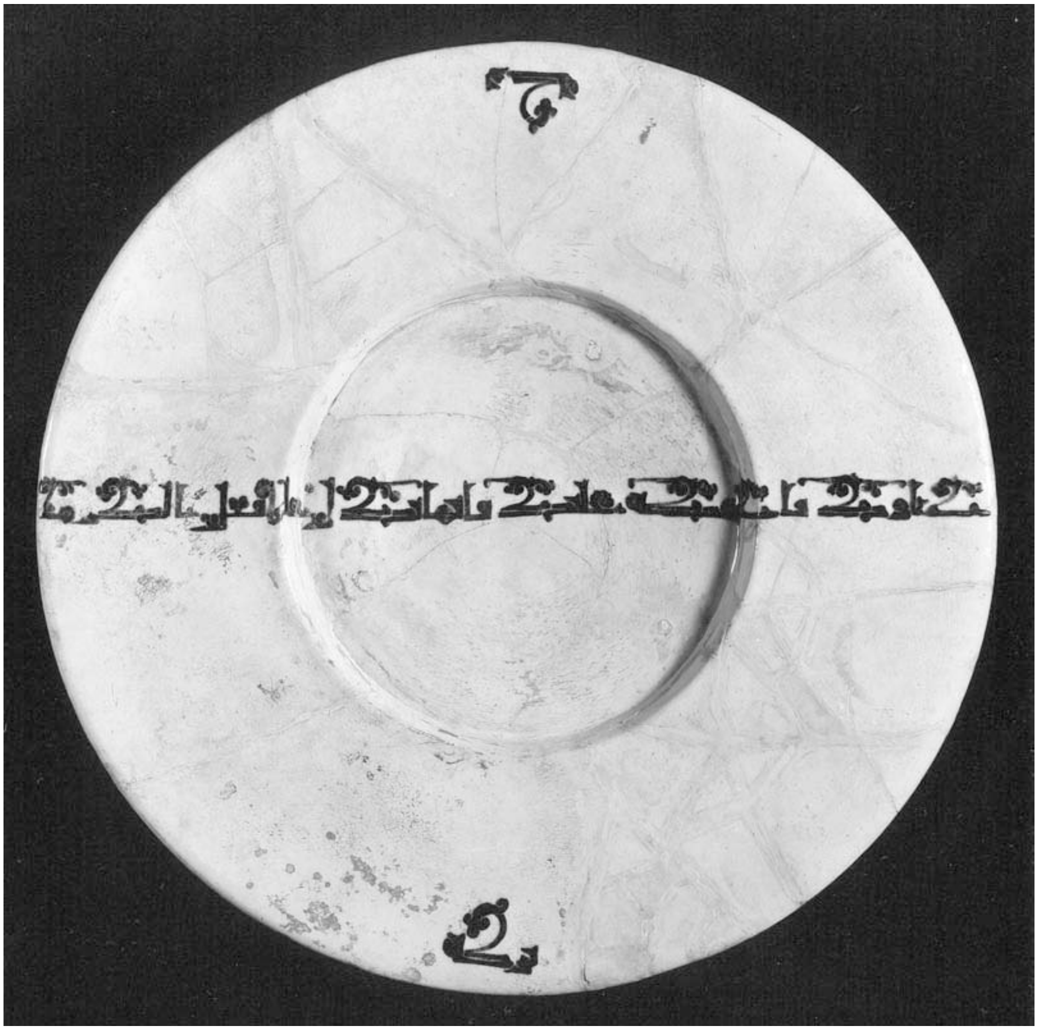

Fig. 4. Black and white before-treatment photograph, 1964 (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery)

report indicates that concealing the stained areas with overpaint was considered in 1964, but this was not done owing to a lack of time. At that time, the staining was thought to have been caused by some material that penetrated into the sherds during burial. Our most recent analyses, however, seem to indicate that the staining was more likely due to old repairs. The dish was exhibited a few times during the 1970s and early 1980s but had not gone on display since 1982 because of its disfiguring stains.

5. ANALYSES

Analyses were carried out to attempt identification of the nature and cause of the staining and accretion on the foot. Portable XRF spectroscopy was used to identify the reddish-brown accretion on the reverse of the dish. Iron, calcium, and strontium were found. After discussion with the curator, it was agreed that a historical reason for the presence of this sediment was unlikely and that it probably came from burial. It was decided to reduce the accretion as much as possible to avoid potential staining of the ceramic during subsequent stain reduction treatments.

Examination under longwave UV radiation showed no fluorescence of the stains under the glaze. Several additional analytical methods were used to identify the staining along the breaks, which were carried out during the conservation treatment once the edges of the sherds became accessible. A section of glaze loss is present directly above an area of stained slip on a small fragment of the dish, making the staining more accessible for analysis. This area was examined using SEM and qualitatively analyzed with energy dispersive x-ray spectroscopy (EDS). The image of the slip in SEM was not easily readable, which may indicate the presence of an organic stain. Although qualitative in nature, EDS showed that the stained areas contained very small amounts of iron, significantly less than would have been expected if the main cause of discoloration was an iron-based material that migrated into the sherds during burial, further supporting the possibility that an organic material may have been causing the stain. A sample was taken for analysis using pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS), microscopic reflectance infrared spectroscopy (MRIR), and microscopic transmission infrared spectroscopy (MTIR). Although the initial suspicion was that the adhesive potentially responsible for the staining was shellac, none of these analyses were able to confirm this. The results indicated the presence of organic material in the stained area but were inconclusive in terms of identifying a specific adhesive. This is probably explained by the presence of several different adhesives on the edges of the sherds from various conservation campaigns that subsequently penetrated into the porous body and slip.

6. TREATMENT

The treatment of the object started with surface cleaning, removal of paint and fill materials, and disassembly (fig. 5). This was carried out using a combined mechanical and solvent approach, with acetone and deionized water (depending on the nature of the various paints, fill materials and adhesives present) with cotton wool swabs, cotton wool poultices, and a scalpel.

The diversity of materials found in use on the object for inpainting, fills, and adhesives (particularly the two adhesives that must have been used during the second and third campaigns of restoration) confirmed the history of successive restorations. The removal of old fill material also revealed that the glaze was poorly adhered in areas, which is partly the result of manufacture, but also suggested the presence of soluble salts, although none were visible. Microchemical tests confirmed the presence of chlorides in the body of the dish. Before the central sherds could be taken apart, the iron-rich accretion inside the foot ring had to be reduced, as there was a concern that it could bleed into the unglazed body and create additional staining. It was mechanically reduced with the tip of a bamboo skewer, brushed off with a stiff brush, and cleaned with acetone on a cotton wool swab. While this did not remove the staining on the porous body and slip, it reduced the bulk of the accretion, which seemed sufficient to avoid bleeding.

6.1 Stain Reduction

Stain reduction tests started with common solvents applied on cotton wool poultices. Deionized water, ethanol, acetone, isopropanol, ethyl acetate, ShellSol 340 HT and xylene were tested and found to have no effect on the staining. Varying the type of poultice material was tested using a range of poultice materials, such as α-cellulose powder, diatomaceous earth, ion-exchanging resin Amberlite XAD, and K-dry tissues. The test poultices were left in place between 5 and 15 minutes and then removed while slightly damp, with no discernible difference in appearance. The poultices also were left in place until completely dry but, again, the stains did not react.

Fig. 5. During treatment, obverse after disassembly (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

We then consulted with Bruno Pouliot and Lauren Fair from the Winterthur/University of Delaware Program in Art Conservation before subsequent steps were taken to reduce the staining. In collaboration with Richard Wolbers, they have developed a method of stain reduction on ceramics that has proven very effective on other examples of tenacious staining (Pouliot, Fair, and Wolbers 2013). This method is based on the sequence of the action of a chelator, followed by a bleach, and then a rinse. For the application of these active agents, poultice materials are selected for their capillarity properties and the control of liquid that they provide.

On their advice, several chelating agents were tested, starting with those that have broad ranges of effectiveness and then moving on to more target-specific chelators. The abundance of small sherds provided many opportunities to test various parameters and combinations of chelators and bleaches. Sodium citrate, EDTA disodic salt (ethylenediaminetetraacetic acid disodium salt dihydrate), Tiron (4,5-dihydroxy-1,3-benzene-disulfonic acid disodium salt monohydrate), HBED (N,N´-di(2-hydroxybenzyl) ethylenediamine-N,N´-diacetic acid monohydrochloride hydrate), and acetylacetone were assessed as possible chelators. Since Tiron and HBED both target iron during chelation, these were included in the tests along with the more general chelators in case the small amount of iron detected in the stained area of slip was indeed a factor in the discoloration. As suspected based on the analysis of the stain, Tiron was not effective at reducing the darkening. Since HBED also focuses on iron, was difficult to get into solution, and is relatively expensive, it was ruled out as a possible treatment. Acetylacetone, which is a solvent and a mild chelator at the same time, did not appear to reduce the staining at all. Both sodium citrate and EDTA showed some effectiveness; however, sodium citrate was selected because it is less aggressive.[1]

Among oxidizing bleaches, hydrogen peroxide is probably the most commonly used in stain reduction. A stabilized version of hydrogen peroxide, carbamide peroxide, is made by adding to it an equal molar amount of urea. Carbamide peroxide acts more slowly than hydrogen peroxide because it takes longer to break down into hydrogen peroxide and carbamic acid, and then into hydrogen and water. This confers a more progressive and uniform action to the bleach, making it more efficient at reducing organic stains (Norquest 2008). Therefore, carbamide peroxide was chosen for the second step of the stain reduction sequence.

Several poultice materials provided different levels of flow control, absorption, and capillarity. K-dry tissue, α-cellulose powder, cotton wool, Laponite RD gel, Amberlite XAD, and agarose gel blocks were tested. Poultices were tested on the break edges and on the glazed surface directly above the staining. The latter method of application was eventually chosen, as the stains were located in the slip layer a couple of millimeters away from the break edges, requiring deeper penetration of the solution to reach the stain than if applied from the surface of the glaze. K-dry tissue did not introduce nearly enough liquid to penetrate the craquelure of the glaze and reach the slip layer and would not provide enough control if more liquid was added to overcome this limitation. α-Cellulose powder and Amberlite XAD did not offer very good adherence to the ceramic's surface and edges. Laponite RD would have been difficult to clean off the porous edges and did not provide enough contact with an interleaving layer. Agarose rigid gel blocks offered good control of the amount of liquid delivered and were easy to use, resulting in their selection as the poultice material. They were chosen as the method of application since the liquid is held closer to the surface with less penetration to the body of the ceramic than other methods. Capillarity and flow can be further controlled by variation of the concentration and thickness of the agarose gel blocks (Norquest 2008; Pouliot, Fair, and Wolbers 2013).

To prepare these blocks, agarose powder is heated on low heat with deionized water until a viscous liquid forms. The liquid is then poured into Petri dishes up to approximately 1 cm thick. Agarose cools down into a rigid gel that can be cut into blocks of the desired dimension and shape. The blocks of agarose are then soaked in the chelator or bleach solution for a couple of hours before being used. Exchanges with the liquid take place in the pores of the gel blocks; they can later deliver the solution in which they had been soaked. They could be applied specifically to the stained areas and, therefore, achieve a localized application (fig. 6).

After testing 1%, 2%, and 4% (w/w) agarose blocks, 2% (w/w) agarose was chosen because it delivered enough liquid with satisfactory flow control. Literature on stain reduction recommends a 2% (w/w) concentration for sodium citrate. For both the chelator and the bleach, the pH was adjusted to 8 with sodium hydroxide, which was a compromise between enhanced efficiency and safety of the ceramic.

Sequences of 2% (w/w) sodium citrate applications, followed by 3%, 5%, or 10% (w/w) carbamide peroxide as necessary, and rinsing in baths of deionized water were tested on some of the small sherds, with the rinse also serving as desalination treatment. The baths were changed once a day, in general for about three days, after monitoring the conductivity. The goal was to lower the conductivity to a stable

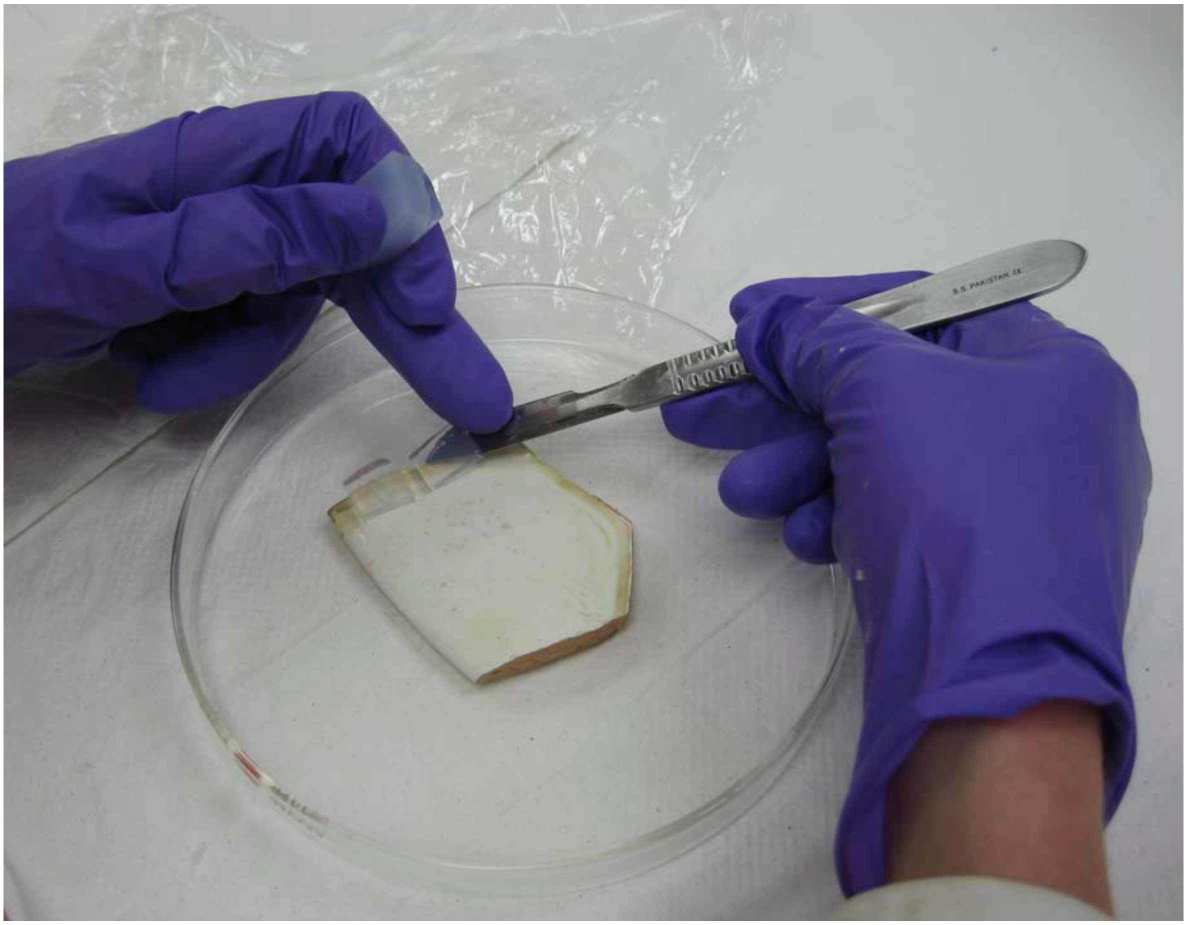

Fig. 6. During treatment, application of agarose gel block poultices for the stain reduction treatment. The application is localized and limited to the stained area. (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

level, not to entirely desalinate the sherds, which was feared could lead to leaching of certain elements from the body or glaze.

None of the sequences tested seemed to break down or move the staining, however, even when repeated one or two more times. The method described by Pouliot, Fair, and Wolbers (2013) recommends trying repeated applications at lower concentrations of bleach first but that tenacious stains may require the use of more concentrated solutions of bleach. In several case studies presented in their article, the technique is used with up to 20% (w/w) carbamide peroxide in order to reduce some staining. Initial tests of the procedure with 3% to 10% (w/w) carbamide peroxide on fragments from the dish proved to be ineffective. The concentration of carbamide peroxide was brought to 15% and then 20% (w/w), which was the only one that had an effect on this staining. The glaze and body of the ceramic were monitored under magnification during the tests and care was taken with the application of the agarose blocks to limit penetration of the solutions.

During testing, the duration of application of the agarose blocks increased progressively from 15 to about 40 minutes for the chelator applications, the same range for the bleach applications, and up to an hour for the darkest stains. Plastic wrap was placed loosely over the sherds to slow evaporation.

The most effective sequence for reducing the appearance of the staining was found to be 2% (w/w) sodium citrate and 20% (w/w) carbamide peroxide, both at pH 8 and applied through 2% (w/w) agarose gel blocks, followed by soaking in deionized water for rinse and desalination. Each 40-minute application was renewed twice, then the sherd was left to dry before the next step of the stain reduction sequence. Although this sequence was not able to remove the staining completely and the stain reduction was not homogenous among the sherds, it lightened the overall appearance significantly (fig. 7). After consultation with the curator regarding the appearance, it was decided to proceed with the overall treatment of the dish using this protocol.

6.2 Reassembly and Fills

The next step of the treatment was consolidation of the vulnerable areas of glaze along the edges of losses with 5% (w/w) Paraloid B-72 in acetone. The same solution was used to seal the porous body on sherd edges and glaze losses.

Joining the sherds back together was a challenge owing to the number of sherds—40 in total—and the condition of the edges, which had been eroded by burial and several campaigns of repair. Some joins barely had any point of contact, particularly around the bottom of the dish. Thirty-five percent (w/w) Paraloid B-72 in acetone, bulked with calcium carbonate and hydrophobic fumed silica, served as both adhesive and fill material in these areas (fig. 8).

Fig. 7. During treatment, obverse after stain reduction (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

Fig. 8. During treatment, obverse after assembly of the sherds (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

Other losses were filled with Paraloid B-72 bulked with glass microballoons (0.34–0.4 mm in diameter), and the surface of all losses, glaze losses, and cracks were filled with Modostuc spackling compound (fig. 9).

6.3 Inpainting

When inpainting the fills began (with Golden acrylic emulsion paints and Rhoplex WS-24), questions arose regarding the approach to the integration of the stains. Several options were considered, such as inpainting the joins the color of adjacent stained areas, which made the stains appear darker and more noticeable. Another option consisted of painting the joins the color of the unstained glaze, which gave the dish an appearance more in keeping with an approach commonly used in the conservation of archaeological material.

Although an archaeological approach is acceptable in many cases, the current aesthetic for the Islamic galleries at the Freer|Sackler is that of art objects rather than archaeological artifacts and the curator

Fig. 9. During treatment, obverse after filling of the losses and joins (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

prefers losses to be more integrated. The staining had been preventing the dish from being exhibited for over 30 years. Even though now reduced, the stains would still bother the curator and deter her from displaying the object.

As a result, a major treatment had been undertaken with a less than satisfactory outcome since it did not sufficiently reduce the appearance of the staining to allow for its display—the primary reason for treating the object. The treatment included a stabilization aspect, but neither the soluble salts issue nor the instability of the glaze were apparent before the removal of the old repairs and were not the impetus for taking on such a complex and long treatment.

Although all conservators who saw the dish at that point, both from the Freer|Sackler and elsewhere, found that the appearance of the dish had improved overall, the goal of the stain reduction treatment was not achieved. A few suggested covering the stained areas with paint to make them less distracting, which had already been mentioned as an option in the treatment report of 1964. This was not an intervention that had been considered during the current treatment because it meant applying paint over original surfaces. As the various experiments into ways of inpainting the losses and cracks proceeded, however, it became clear that as long as inpainting was limited to filled surfaces, it would not be possible to achieve an appearance that would meet the aesthetic requirements of the curator.

The "overpainting" option was carried out in a small area (fig. 10) to provide an idea of the visual result as well as of the amount of paint needed to mask the stains.

The tested area was chosen because it was one of the most distracting ones, with the stains creating an apparent network. The stained areas to be overpainted were first sealed with 5% (w/w) Paraloid B-72 in acetone. The overpainting was done with consecutive layers of Golden acrylic emulsion paints, applied only where necessary, with a fine brush (fig. 11).

Once the tested area was painted, each of us was dissatisfied with the result. We were uncomfortable with the principle of painting over an original surface and found the painted area more distracting than the staining, probably in part because, after working on this ceramic for so long, it was difficult to have an

Fig. 10. During treatment, obverse with losses and joins inpainted the color of unstained glaze. On the lower right corner, dark stains are partially overpainted as a test. (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

Fig. 11. During treatment, detail of area without and with overpainted stains (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

objective eye. It was decided to show the object to colleagues from various specialties in the Department of Conservation and Scientific Research, and to conservators visiting the labs. Surprisingly, the feedback received was almost unanimously positive, with most viewing the possibility of exhibiting the dish as the primary benefit since the painting could be done in a way that would not permanently affect the dish.

We decided to overpaint the stains in a larger area and to present it to the curator, who confirmed that despite the stains being lighter as a result of the treatment, she would not exhibit the object for the reopening of the Freer|Sackler Galleries if the stains were still visible. On the other hand, she was particularly happy with the appearance of the overpainted areas. The visual result was enough to make her change her mind and bring the ceramic back into the design of the Islamic Galleries for the reopening.

At that point, the pros and cons of this solution were assessed in order for us to make a final decision on the integration of the losses and stains.

The first issue was covering original surface; but not only can the overpainting be easily removed, the stained areas would also be sealed before being painted over. Additionally, the areas were overpainted during the third restoration; thus, previously unpainted areas of the glaze would not be painted in the current treatment. Furthermore, no section of the inscription would be overpainted.

Fig. 12. Obverse after treatment (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

The other main concern was whether the visual result was satisfactory. However, the goal of overpainting the stains was to allow the public to appreciate the object without being distracted by the network of stains, not for the inpainting to necessarily be invisible. The overpaint should be discernible at a close distance. Even given these concerns, the curator, as well as a number of conservators, still favored the overpainted areas instead of a stained dish.

As a result of these discussions, we decided to cover up the stained areas on the front of the dish (fig. 12). As few layers of paint as possible were applied in order to limit the issue of variation in topography of the inpainted and glazed surfaces. Dilute Rhoplex WS-24 was applied over the paint to approximate (but not quite match) the glossiness of the glaze. The difference in topography and glossiness between the overpaint and the glaze make the joins visible under certain lighting conditions (particularly in raking light) but discreet for a nontrained eye in gallery lighting.

The back of the dish was inpainted in a much more visible way to ensure that potential handlers would be aware of the level of breakage of the dish (fig. 13).

Fig. 13. Reverse after treatment (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

Fig. 14. Obverse before (left) and after (right) treatment (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

Fig. 15. Reverse before (left) and after (right) treatment (Courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery, photograph by Claire Cuyaubère)

7. CONCLUSION

In conclusion, the complex nature of this treatment and the complicated decision process it necessitated provided an opportunity to experiment with various methods of stain reduction. Although the stain reduction treatment was not as successful as had been hoped, the method did reduce the appearance of the stains significantly (figs. 14, 15). The issue of inpainting versus overpainting was a chance to reflect on the importance of accessibility of an object and whether a less than ideal but reversible outcome is preferable to another 30 years in storage.

We hope that, in the future, a more effective stain reduction method will be found for this ceramic. In the meantime, it can be exhibited and appreciated by the public and scholars.

ACKNOWLEDGMENTS

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NOTE

1. Citric acid (used in the form of sodium citrate) is a good chelator of organic materials held in ceramic-like substrate (Pouliot, Fair, and Wolbers 2013) and EDTA is a stronger chelator than citric acid (Pouliot, Fair, and Wolbers 2014), meaning that it is efficient at chelating additional elements, which seemed unnecessary for an equal apparent effectiveness on the stains discussed here.

REFERENCES

Norquest, Sharon. 2008. Preventing poultice problems: A study of ceramic stain reduction. Paper presented at the 2008 ANAGPIC student conference, New York University. Institute of Fine Arts. New York, New York. http://cool.conservation-us.org/anagpic/2008pdf/2008ANAGPIC_Norquest.pdf

Pouliot, Bruno, Lauren Fair, and Richard Wolbers. 2013. Re-thinking the approach: Techniques explored at Winterthur for the stain reduction of ceramics. *Recent advances in glass, stained-glass, and ceramics conservation 2013. Preprints of the ICOM-CC Glass and Ceramics Working Group Interim Meeting and the Forum of the International Scientific Committee for the Conservation of Stained Glass*. Amsterdam, the Netherlands. Zwolle: Spa Uitgevers. 211-223.

——. 2014. Stain reduction techniques for ceramics. *Seminar presented at the Smithsonian American Art Museum & National Portrait Gallery, Washington, DC.*

SOURCES OF MATERIALS

Rhoplex WS-24, Glass Microballoons (0.34–0.4 mm in diameter)
Conservation Resources International, LLC
5532 Port Royal Rd.
Springfield, VA 22151
800-634-6932
www.conservationresources.com

Lonza SeaKem LE Agarose
Fisher Scientific
800-766-7000
www.fishersci.com

Golden Heavy Body Artist Acrylics
Dick Blick Art Materials
P.O. Box 1267
Galesburg, IL 61402-1267
800-828-4548
www.dickblick.com

Modostuc Spackling Compound
Peregrine Brushes and Tools
267-888-6657
www.brushesandtool.com

Paraloid B-72
Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

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THE CASE FOR COLD: USING DRY ICE BLASTING TO REMOVE LACQUER COATING FROM THE *KING JAGIELLO* MONUMENT IN CENTRAL PARK

MATT REILEY

This case study provides an overview of the use of dry ice blasting as a suitable method for Incralac coating removal on a heroic-scaled equestrian bronze sculpture as part of the development of a sustainable program of protective coatings maintenance. In 2016, the Central Park Conservancy initiated a conservation project on the *King Jagiello* monument, which included the use of dry ice blasting to remove a failing coating. Dry ice blasting was selected because it is dry, nondestructive, environmentally conscious, and for its relative speed. The project, and previous methods of Incralac lacquer removal tested at two other bronze monuments provide points of comparison. This case study shares findings from the project's use of the dry ice blasting system with considerations for use in an outdoor environment and an empirical assessment of results. The rationale for replacing Incralac coating with a protective hot wax coating on *King Jagiello* is also discussed.

KEYWORDS: Bronze, Central Park Conservancy, Collections care, Dry ice blasting, Incralac, King Jagiello, Lacquer removal, Outdoor sculpture, Protective coatings

1. INTRODUCTION

1.1 History of The *King Jagiello* Monument

King Jagiello, created by sculptor Stanislaw K. Ostrowski (1879–1947) for the Polish Pavilion of the 1939–1940 New York World's Fair, has resided in Central Park since 1945 (fig. 1). The highly detailed bronze dramatically depicts Wladyslaw II Jagiello, Grand Duke of Lithuania (1377–1401) and King of Poland (1386–1434), on horseback raising two swords overhead, memorializing the political unification of east central European groups against the Teutonic Order of the Cross and commemorating their victory at the Battle of Grunwald in 1410. Following the Nazi invasion of Poland in World War II, the monument was presented to the City of New York by the exiled government and is an important symbol of Polish-Americans' independence and national identity (Nowakowska 2013).

1.2 Treatment History

King Jagiello's past treatment reports indicate a sporadic history of care since the monument's relocation to Central Park (Valera 2016). A condition assessment performed in 1984 by Washington University Technology Associates, Inc. (WUTA) found the bronze in poor condition, having suffered from vandalism and exposure to acid rain deposition (Weil 1986). The sculpture's pitted surface was encrusted in a layer of greenish corrosion products identified as copper sulfates and chlorides (Weil 1986), features were missing, and it was partially disengaged from its anchorage to the base due to "rust jack" expansion of internal steel supports (figs. 2, 3).

Conservation treatment was undertaken in 1986 under the auspices of the Central Park Conservancy (CPC) and included the removal of the corrosion crust with glass bead peening, repatination, and an application of the acrylic lacquer Incralac to the surface as a protective coating (The Daily Plant 1986). The deteriorated condition of the sculpture's anchorage and associated damage to the bronze was noted and its replacement advised, but it was not part of the scope of WUTA's work in 1986.

1.3 Incralac Application and Performance

With the inception of the CPC's cyclical program of bronze conservation in the early 1990s, the majority of the park's bronze monuments had Incralac coatings applied. Incralac's performance life is three to five

Fig. 1. S. K. Ostrowski, *King Jagiello*, 1939, bronze, 4.14 m H at crown, plus 1.9 m to top of sword. City of New York, accession number 793

years; the complete removal of aged coatings and the reapplication of new coatings is required to adequately protect outdoor bronze sculpture (Bierwagen et al. 2001). Removing and reapplying coatings on a large collection of outdoor bronze monuments on a three- to five-year cycle would require massive resources and planning. In reality, as the monuments' coatings degraded, repeated touch-ups—and, in some cases, complete overcoatings—were applied. Until recently, these patchwork coatings have rarely been removed and refurbished. As a result, the Incralac coatings on many of the park's bronze monuments have now far surpassed their performance life and are, by turns, embrittled and flaking or cross-linked and difficult to remove. Due in part to the ongoing maintenance using sacrificial, pigmented paste wax, the bronzes retain an acceptable appearance but the lacquer coatings no longer provide adequate protection from the factors causing corrosion. Additionally, the underlying surface condition and sculptural detail may be obscured by the degraded coating, and nuances of patina and light reflectance are negatively affected (Chase and Veloz 1985).

Fig. 2. Detail of corroded surface of *King Jagiello* in 1984, Courtesy of WUTA

King Jagiello was no exception. The coating was weathered and failing to adequately protect the bronze despite a complete overcoating of Incralac in 1991 (Rabinowitz 1991) and an ongoing program of applying paste wax. The coating's deterioration was accelerating, as evidenced by partial removal from pressure washing during annual maintenance (Reiley et al. 2004).

2. PROJECT BACKGROUND

2.1 Sustainability Assessment

From 2010 to 2012, the CPC devised an aspirational, multiyear plan to remove all of the Incralac coatings from the park's monuments and develop a more sustainable coatings maintenance regime. The CPC has employed other coatings removal methods prior to the *King Jagiello* project, including chemical

Fig. 3. Detail of damage from rust jack expansion of internal support

gel stripping and laser ablation. Recent conservation projects in Central Park using those removal methods are briefly detailed in the following case studies. The CPC assessed each process to determine its suitability based on various factors, such as safety, removal rate, ease of use, and cost. Findings were balanced against considerations of seasonal conditions, sculpture scale and detail, condition of the monument, setting, and accessibility.

2.2 Practical Application of Lacquer Removal Methods

2.2.1 Chemical Gel Stripper

A large bronze bust of the Italian statesman, Giuseppe Mazzini (1805–1872), by G. Turini (1841–1899) (fig. 4) was treated in 2011 as a pilot project for the development of the CPC's sustainable coatings removal and replacement plan. The aged Incralac coating originally applied in 1994 was darkening unevenly and negatively affecting the sculpture's appearance. The coating was removed by repeated applications of the methylene chloride gel stripper Rock Miracle, which was agitated with nylon bristle brushes, and subsequently cleared with a pressure washer. This process does not require specialized equipment; thus, effective coating removal was attained at low cost. The rate of removal was slow but deemed acceptable due to the bronze's relatively modest size and simple form.

The use of methylene chloride chemical gel strippers has several important drawbacks, especially when used on large statuary in an outdoor environment. The gel itself is messy and difficult to control. The efficacy of a methylene chloride gel stripper is weather and temperature dependent. Conservators applying the gel must wear personal protective equipment (PPE), such as full-face respirators with organic vapor cartridges to minimize the hazard from the inhalation of vapors and chemical-resistant garments to prevent burns (OSHA 2012).[1] Technicians, the surrounding landscapes, and adjacent structures must be protected from residue and runoff, which are safety and environmental hazards.

Fig. 4. G. Turini, *Giuseppe Mazzini*, 1878, bronze, Westerly granite, 4.3 × 1.2 × 1.2 m. City of New York, accession number 992

The uncontrolled residue, which may include mobilized corrosion products and pigments, can stain adjacent masonry and redeposit on the bronze surface, compromising the adhesion of new coatings if not done with great care (Lins 1992).

In the case of the *Mazzini* bust, a team of three technicians completed the Incralac removal over three days. The bronze was subsequently repatinated and coated with a two-part system of G. J. Nikolas lacquer RFU 11565 and a top coat of Uralac 9978 acrylic urethane which has acted as a pilot for empirical evaluation of alternative coatings. The Nikolas coating system is intact after six years; with annual maintenance of washing and applying wax, the desired aesthetics of the finish remain consistent.

2.2.2 Laser Ablation

In 2013, the cleaning and conservation of the friable surface of the Central Park Obelisk, a nearly 3500 year old Egyptian monolith also known as *Cleopatra's Needle*, left little tolerance for surface loss because of its historical significance. Laser ablation is effected by using laser parameters such as wavelength and pulse duration, which are tuned to discriminate between surface soiling and substrate. The laser energy is absorbed by the offending substance, which is excited and ejected from the surface, while harmlessly reflecting off the underlying material. The process was found to have no mechanical impact on the granite and to be environmentally responsible, whereas all other cleaning methods tested were unsuitable (Wheeler 2013). Laser ablation was also selected for lacquer removal treatment of the Obelisk's 19th century replica bronze crabs, which support each of the monolith's four corners and are in direct contact with the stone. The crabs' lacquer was flaking and the underlying surface was covered in corrosion crust. Carefully selected lasering parameters for the removal of the failing coating simultaneously altered the corroded surface to a more stable oxide, cuprite (Dajnowski, Jenkins, and Lins 2009).

The rate of coatings removal was found to be relatively slow, similar to that of gel stripping (Dajnowski, Jenkins, and Lins 2009). The cleaned crabs were patinated and a hot wax coating applied, which is regularly inspected and renewed as needed (fig. 5).

Using lasers in a public setting presents important factors to consider. Strict site controls must be established and maintained to protect technicians and the public. Special Class 4 protective eyewear must be worn to prevent accidental viewing of the harmful, 1064 nm near-infrared wavelength emitted during lasering. Hazardous vapors are created when coatings are laser ablated, requiring respirators and/or a fume extraction system (Dajnowski, Jenkins, and Lins 2009). Laser equipment is relatively fragile, weather sensitive, difficult to maintain, and expensive. Skilled technicians trained in Class 4 laser safety and use are required to achieve an effective rate and degree of removal while ensuring that operating parameters are appropriate, and to eliminate potential of damage to cultural property.[2]

Fig. 5. Replica crab during laser cleaning. Unknown artist, *Cleopatra's Needle*, 1871, bronze, 30.48 × 86.36 × 66.04 cm. City of New York, accession number 1129

3. DRY ICE BLASTING OVERVIEW

3.1 Dry Ice Blasting Mechanism

Dry ice or CO_2 blasting accelerates solid carbon dioxide pellets/particles (fig. 6) in a pressurized air stream to impact a surface to be cleaned or prepared. The process employs three distinct factors acting in concert. First, a mechanical pellet kinetic energy effect is at work, in which dry ice pellets are accelerated toward the surface at high speeds, weakening the superficial level of soiling or contamination. Then, a thermal shock effect follows as the surface is rapidly chilled to –109°F (–78.5°C), causing the soiling to contract and weaken its bond with the substrate. Lastly, the sublimation effect is imparted as the pellet media impacts the surface, instantaneously phase-changing from solid to gas and expanding roughly 800 times in volume. This creates "micro explosions" that contribute to the removal by lifting the soiling/film off of the substrate (Liu, Maruyama, and Matsusaka 2011; Continental Carbonic Products, Inc. 2016).

3.2 Rationale for Choosing Dry Ice Blasting

In 2013, as CPC conservation staff assessed the relative advantages and limitations of the methodologies of previous and concurrent lacquer removal projects, we began investigating dry ice blasting as another means of lacquer removal. Sustainability criteria for future coatings removal projects prioritized a process capable of being done in-house, adaptable to the variable conditions of an urban park setting, and nondestructive to works in the collection. The CPC required a method that successfully addressed the conservation needs of individual monuments and could surmount time constraints for completing the work while minimizing hazards to the public and to staff. The reduced environmental impact of the dry ice blasting process as compared with other abrasive cleaning processes and its potential as an in-house process for a cyclical coatings maintenance program aligned with the CPC's mission. Because the CO_2 media sublimates in the ambient environment, there is no residual blasting media to control. This is a major benefit of the process for use in Central Park. Other abrasive blasting systems can produce large

Fig. 6. Photograph of 3-mm diameter dry ice pellet media

volumes of a contaminated medium that is classified as a hazardous material, which is labor intensive and costly to control and dispose of. The only by-product produced with dry ice blasting is the removed coating itself, although potential impurities in the CO_2 should be taken into consideration (Liu, Maruyama, and Matsusaka 2011).

An effort began to research and study technical publications and contact conservation professionals who were using dry ice blasting to inquire about their research, experiences, and impressions for its use on Central Park's collection, specifically large-scale outdoor monuments. The information and feedback received supported our original hypothesis: that with proper testing and precautions, dry ice blasting is a viable approach as part of a cyclical coatings maintenance program.

3.2.1 Potential Damage Assessment of Dry Ice Blasting

Similar to traditional abrasive removal methods that have been shown to remove/damage the bronze surface, the mechanical or kinetic effect is understood to be the most important factor determining the efficacy of dry ice blasting. It also poses the greatest potential risk of alteration to surfaces or damage to the microstructure of the bronze (van der Molen et al. 2010; Chase and Veloz 1985). However, dry ice (measuring approximately 1.5 on the Mohs hardness scale) is softer than other blast media types for cleaning bronze (which measure 3.0–3.5 Mohs) (van der Molen et al. 2010; Uhlmann and Krieg 2005). In 2010, a joint study by conservators and scientists from the University of Amsterdam and the Netherlands Institute for Cultural Heritage concluded that dry ice blasting at a variety of pressure settings up to 101.5 PSI/7 bar at extended dwell times of up to one minute, gradually removes corrosion and patina but does not damage the bronze substrate (van der Molen et al. 2010). Nevertheless, selecting parameters to obtain an acceptable rate and degree of removal while minimizing risk of damage, adopting an incremental, "do no harm" approach informed by scientific test data, as well as testing and analysis of use on the specific object, are all critical for the conservator applying this treatment to bronze statuary.

3.3 Preproject Testing on the Polish King Project

A Cold Jet Aero 40FP dry ice blaster designed to operate with pellets was tested on representative but inconspicuous surfaces of the bronze prior to the start of the *King Jagiello* project. Previously, CPC conservation staff worked closely with representatives and technicians from the machine's manufacturer to establish appropriate equipment and settings. The mobile, mid-size Aero 40FP was found to be the most versatile machine for the particularities of the project and for potential future treatments of other outdoor sculptures in the collection. The pellet machine was judged to be more user-friendly than machines that shave the carbon dioxide media from a block. The full pellets maximally exploit the mechanical kinetic effect and, when used with the Mern-style nozzles (built-in shaver), media can be delivered in various particle sizes depending on the setting selected. Dry ice blasting was judged to be a rapid, effective, and appropriate means of coating removal on large-scale bronze sculpture and the best removal process available to successfully handle the time constraints imposed by the *King Jagiello* conservation project.

3.4 Existing Patina Condition

A key goal of the *King Jagiello* project was to retain as much of the existing patina as possible. CPC conservators had intended to spot patinate the bronze to visually blend any unevenness of tone following coating removal and subsequently apply a protective coating. However, as the dry ice blasting removed the layers of Incralac, it appeared that it was also aggressively and completely removing the patina, leaving a strongly contrasting, lightly toned substrate (fig. 7). Initially troubling, subsequent gel stripping tests at several locations revealed that what was being stripped was a pigmented coating rather than a traditionally applied patina (Reiley 2016) (fig. 8).

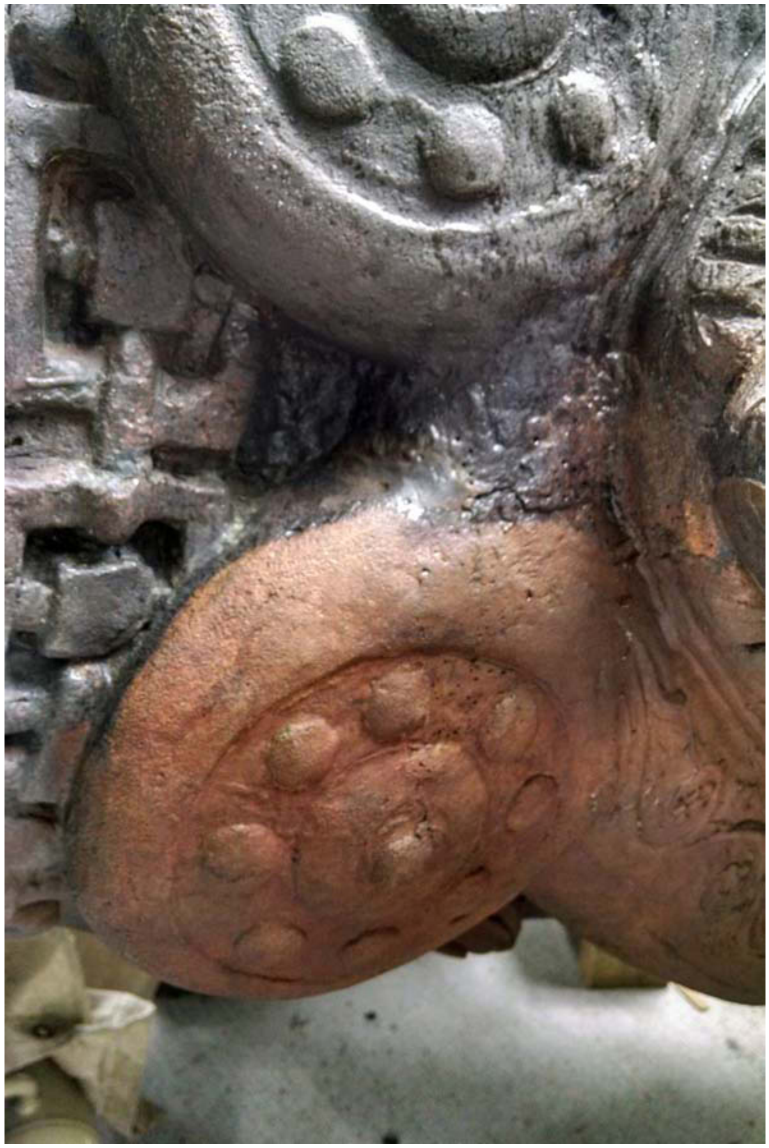

Fig. 7. Dry ice blast cleaning revealed a lightly toned substrate that contrasted with the darkly toned coating

This coating, believed to be a mixture of mineral pigments and Incralac, had been applied over the entire surface of *King Jagiello*. Incidentally, this contrast offered a helpful visual guide to gauge the rate and degree of coating removal. The bronze's surface condition was continually assessed as blasting proceeded. It was found that, although pitted and exhibiting many casting defects, the glass bead–peened bronze appeared remarkably uniform and free of corrosion 30 years after treatment (Reiley 2016).

4. *KING JAGIELLO* PROJECT BLASTING PARAMETERS

Dry ice blasting operating parameters for *King Jagiello* were optimized by determining the minimal settings needed to quickly remove the aged coating. Operating parameters were established by incrementally increasing the pressure to levels deemed safe yet still capable of achieving an acceptable removal rate and degree. Eventually, settings were optimized at or below 65 PSI (4.48 bar) and in a range of 1.0 to 2.5 lbs./0.45 to 1.1 kg per min. mass flow. Although blast pressure remained relatively constant

Fig. 8. Gel stripping test confirming that brown coloration was a pigmented coating

throughout the project, certain variables of blasting changed according to conditions, such as equipment performance, site conditions, and surface detail that required an adaptive approach to the selection of equipment, mass flow settings, nozzle types, stand-off distance, blast angle, and dwell time. In practice, the selected pressure settings and dwell time on the *King Jagiello* project were always set significantly lower than the maximal safe settings in a 2010 study executed by van der Molen, Joosten, Beentjes, and Megens (2010).

4.1 Blasting Approach

Two separate phases of blasting were undertaken to maximize the progress of work. The first phase began after the sculpture was removed from the base and laid down on its side to perform additional conservation treatment. This included forming and welding repairs, and the removal of the corroded steel internal supports which were replaced with an engineered stainless steel structure. The second phase saw the coating removal completed once the reinforced bronze sculpture was reinstalled on the base and scaffolding erected around it, providing access to previously untreated surfaces (figs. 9, 10).

4.1.1 Phase 1 Blasting

During the first phase of blasting, done while the sculpture was laid down and much of its surface readily accessible, the variable fragmenting MERN nozzles were primarily used (#323v1 and #323v2; 58.4 cm/23" length with 2.5 cm and 4.6 cm blast swath respectively) (fig. 11).

These longer nozzles feature a relatively large swath or cleaning spot for quicker cleaning and are designed to maximize the velocity of media and augment the mechanical, pellet kinetic energy effect. In general, the Incralac was very quickly removed to a near-total degree with two to three sweeping passes with 70° to 90° range of inclination to the surface at a stand-off distance ranging from 4 to 18 in. based on the conditions. Those parameters, while basically intuitive to the operator, have been demonstrated to encompass the most effective and uniform blast performance (Spur, Uhlmann, and Elbing 1999). A total

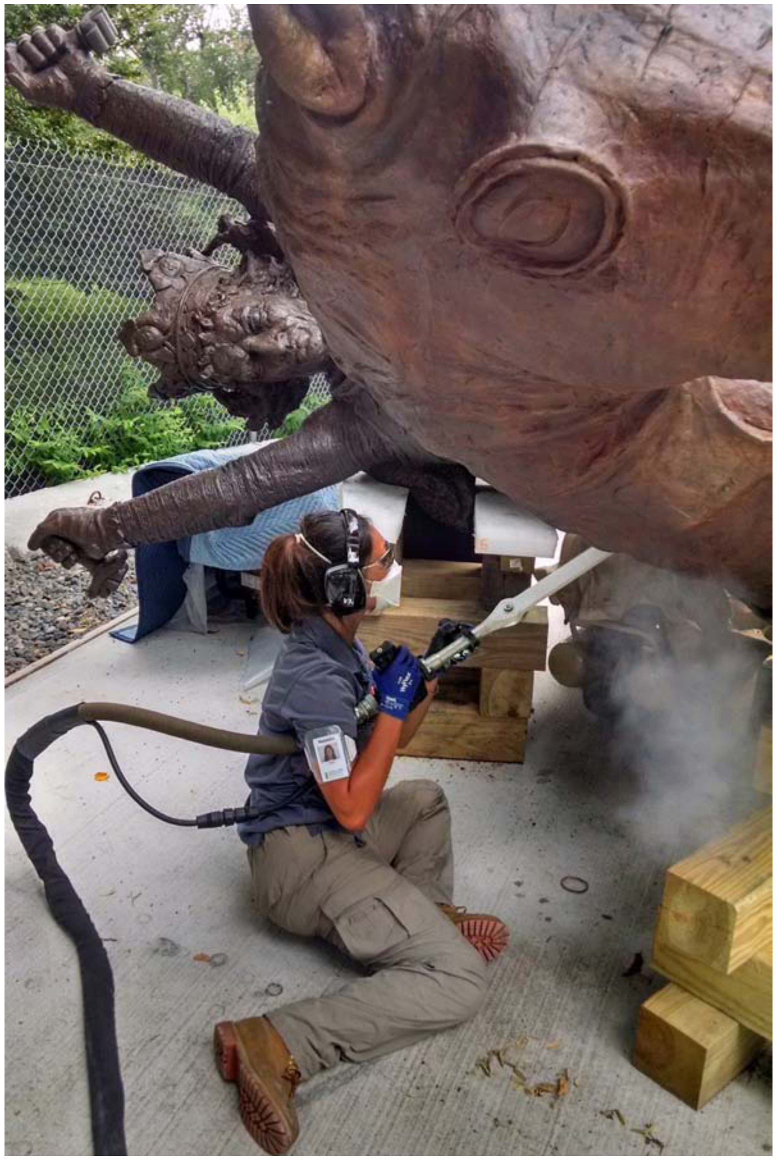

Fig. 9. Dry ice blasting while sculpture was deposed from base

dwell time at the cleaning spot was estimated at less than five seconds. Blasting was shared by up to three technicians a day to minimize fatigue and to randomize cleaning styles, thus limiting any latent tendencies in individual operators' technique.

The application of the dry ice blasting system (fig. 12) was particularly successful and rapid in this case because of the aged and embrittled condition of the Incralac (Cutulle and Kim 2015). This was coupled with another factor known to benefit the efficacy of the cleaning process—the heating of objects to exploit the thermal shock effect. Studies show evidence for improved cleaning/coatings removal depending on the increased temperature differential between the media and substrate (Spur, Uhlmann, and Elbing 1999; Cutulle and Kim 2015). A significant temperature differential existed between the dry ice media (–109°F [–78°C]) and the surface subjected to the torrid summer heat on several days during the project. Amplified by the thermal mass of *King Jagiello*, surface temperatures reached 115°F (46.1°C), a 224°F (106.6°C) temperature differential (Reiley 2016).

Fig. 10. Dry ice blasting while sculpture was deposed from base

4.1.2 Phase 2 Blasting

The MERN-type nozzles tended to be used less frequently in instances when the nozzle's large size complicated access to the surface. This was especially the case during the second phase of blasting, after the sculpture was reinstalled on the base. The shorter conical nozzle (#310S.5. 25.4 cm, 10-in. length, 1.1 cm blast swath) was favored because it offered an increased ability to adapt to site conditions, such as reduced lighting and workspaces that were restricted because of the scaffolding (fig. 13). This nozzle's smaller, more focused cleaning spot also enabled a more direct accessibility and close monitoring of removal by the operator on areas with complex surfaces.

The wider cleaning swath of MERN type nozzles is harder to monitor and it is possible that they do not always provide uniform removal. Minute amounts of coating remaining on recessed edges of surface pits was noted.

Fig. 11. Assortment of dry ice blasting nozzles with MERN-type #323v1 and #323v2 at the outer edges and the shorter conical nozzle #310S.5 at center right

In the future, an improved degree of removal may be achieved on intricate or pitted surfaces prone to more stubborn purchase of Incralac (fig. 14) by increasing pressure settings, increasing dwell time, and/or providing additional blast passes with divergent inclination to the surface (Cutulle and Kim 2015). These intuitive techniques, while likely beneficial, were not pursued comprehensively owing to project time constraints and the already adequate degree of removal. Remnants of Incralac were removed completely during subsequent patina application with a combination of torch heating and careful preparation of the sculpture surface with bronze bristle brushes. Overall, the sculpture's coating removal was very rapid, comprising a total of approximately 18 blasting hours completed in six days. Dry ice blasting conferred significant time savings on the project when compared with projected time estimates of the other coating removal methods used previously. The total bulk of dry ice pellets used for the project is estimated at 1,500 lbs.

Fig. 12. Dry ice blasting system with aftercooler in foreground

5. FINDINGS

5.1 Support Equipment

A well-used air compressor, 1987 Ingersoll-Rand generator model P 175 A-W-D, was adopted to supply air for the Aero 40 FP dry ice blast unit. The compressor was incapable of providing a full range of operating PSI (20–250 PSI) because it did not meet the specifications for air consumption. However, it did provide a range of blast pressure (maximum of 80 PSI/5.5 bar) sufficient for the rapid, near total removal of the coating in this case. The blasting system's inherently reduced capacity was initially welcomed as a built-in limiting factor, allowing for a cautious approach to the dry ice blasting process. However, future projects may require an increased range of pressure, highlighting the need to obtain an air compressor specified to support dry ice blasting.

There are clear indications that using an in-line aftercooler (Cold Jet 400P: 2M0023-G1), that removes moisture from the air supply is important when conducting blasting operations with a diesel-fueled compressor, especially in humid conditions (see fig. 12). When moisture enters the system, it can form "water ice" inside the machine and clog nozzles (Cold Jet LLC 2004). In addition, water ice is harder (Mohs 2.5) than the CO_2 media and can be propelled at the object being cleaned, increasing the potential for damage.

5.2 Logistics and Limitations

The dry ice blasting process has some drawbacks that should be considered before using it on any project. Chief among these are the noise generated and considerable logistical site challenges presented by using dry ice blasting equipment. To achieve a full range of blasting pressure, the Aero 40 FP system requires a

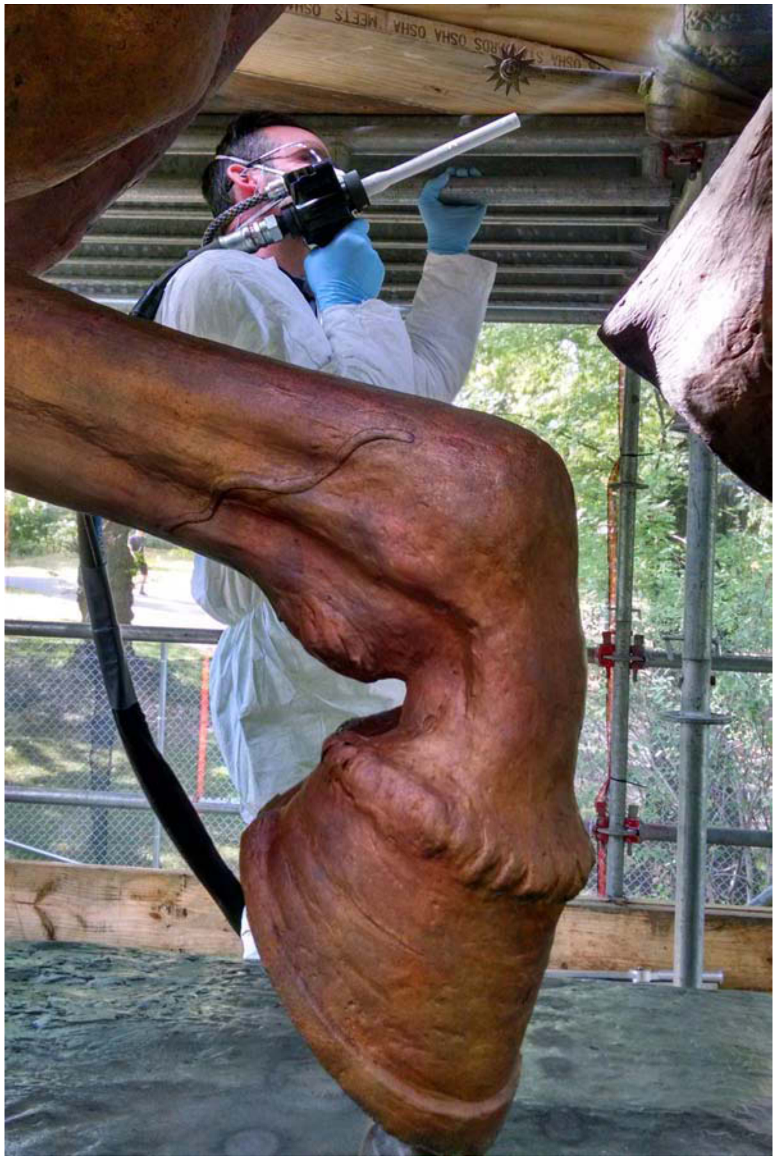

Fig. 13. Blasting with short conical nozzle in the more restricted workspace of the scaffolded monument

gas engine compressor capable of delivering 185 cfm of air, which produces noxious fumes and noise. Sufficient space should be dedicated to the compressor's placement on the project site to minimize exposure to workers and the public (Ribis 2016). This and the relatively large and cumbersome components of the system preclude it from being a viable option for use indoors, although various manufacturers do offer indoor-appropriate models.

Efficient dry ice blasting operations with the Aero 40 FP machine are best achieved as a coordinated effort among two or more technicians. Swapping duties and closely monitoring site conditions, blast parameters, media supply, and support equipment are essential for minimizing worker fatigue and maximizing blast time. Periodic replenishment of dry ice media is required throughout the process. The unit's hopper holds 40 lbs./18.14 kg of pellet media, which supplies approximately 15 to 20 minutes of blast time at 2.5 lb. (1.1 kg)/min. mass flow between refills.

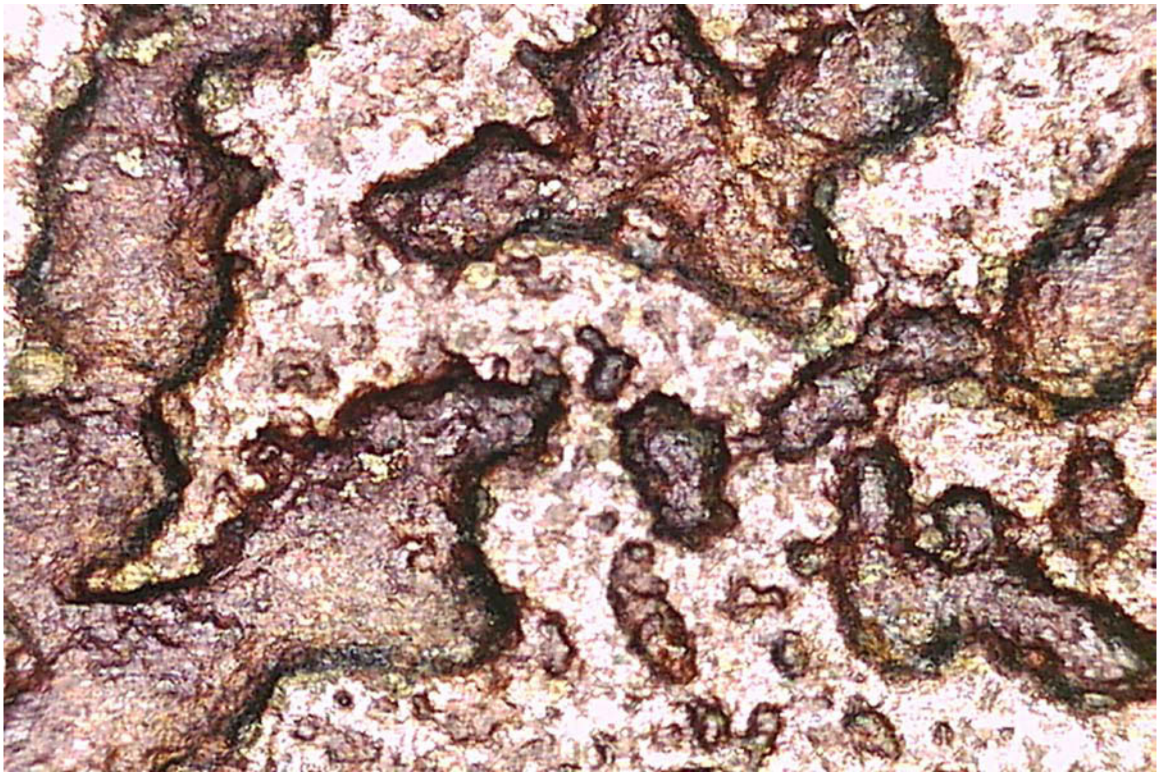

Fig. 14. Bronze surface at 150×. The undercut edges of pits provided a more stubborn adherence of Incralac

Carbon dioxide pellets are available from regional suppliers with a one- to two-day lead time and are delivered to the work site in approximately 500 lbs. of bulk. The CO_2 pellet media must be used as soon as possible to limit waste due to sublimation. Typical sublimation is approximately 2% to 10% per day depending on the climate and the container (Cold Jet LLC 2004). To arrest media sublimation during the project, technicians created an additional seal with plastic stretch wrap around the lid of imperfectly sealed containers at the end of each of work day.

Inconsistencies in the quality of the pellet media and the insulated containers have been encountered over the course of multiple deliveries. It is important to work closely with a responsive dry ice provider to communicate the medium's specific use to ensure its quality, as it seems that much end use of the product does not require optimal quality.

6. SAFETY

Dry ice blasting presents safety hazards to consider and mitigate. Personal protective equipment for ear and eye protection are required at all times when operating the machine on site. Solid CO_2 is a cryogenic material that can cause frostbite if handled without thermal gloves. The process generates considerable noise and, although it does not produce secondary waste, it does disperse dust from the ejected material into the air. To measure conservation staff's exposure levels during the *King Jagiello* project, the CPC's Environmental Health and Safety department conducted personal air sampling and sound-level measurements, providing recommendations based on Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH)/National Institute for Occupational Safety and Health (NIOSH) standards (Ribis 2016). The resulting measured air dust concentrations were below the Permissible Exposure Limit (PEL) and as such did not require a respirator, although they were used voluntarily anyway. Sound levels were measured at 112 decibels recorded at the operator's ear; noise levels are expected to increase in correspondence with increased operating pressures and blasting in hollows. To minimize exposure, both earplugs and defender muffs were required and a maximum of three blasting hours (actual time the applicator trigger is engaged) per operator per day was instituted. Recommendations were made for wearing protective garments to shield from dust and segregate the day's work clothes for storing and washing (Ribis 2016).

7. COATINGS REPLACEMENT RATIONALE

The CPC's ongoing plan of Incralac removal is based on identifying a more sustainable model for the preservation of the park's bronze monuments. Experience has shown that Incralac is difficult to apply and remove and that its useful lifetime ranges from three to five years. Thus, every three to five years, efforts must be made to remove the old coating system and reapply a new coating. Minimizing the recurrence of removing and then reapplying a new coating can be achieved by finding a better coating system to replace the Incralac and wax system. A new coating with a longer performance life would require less time, money, and energy spent on removal and reapplication, ultimately minimizing potential harm to the bronze during conservation treatments (Bierwagen et al. 2001; Weil 1980).

While assessing *King Jagiello* to select a new protective coating, lacquer was dismissed as a replacement. The bronze was found to be an assembly of very thin casts produced from both sand mold and plaster investment lost wax techniques, which exhibited many small voids and cracks in the surface (Reiley 2016) (fig. 15).

Fig. 15. Detail of voids in *King Jagiello* cast

During the welding repair phase of the project, only a selection of the worst voids—those facing skywards on horizontal surfaces where water infiltration was a constant—were welded closed. The remaining holes and cracks in the cast were seen as problematic for the longevity and performance of a replacement lacquer coating. The inability to “close the envelope” of the sculpture’s exterior made the use of a lacquer film inappropriate, as the many points of attack from the inevitable discontinuities would lead to premature failure (Reiley 2016). An object lesson learned from the former cyclical maintenance of this bronze monument was that it had effectively devolved into the conservation of the deteriorating Incralac coating.

A protective hot wax coating, on the other hand, can be readily applied and maintained on a one- to three-year cycle (Montagna 1989). Unlike the previous annual treatment, consisting of an overall application of paste wax over the failing lacquer, a hot wax coating does not require an overall application each year. Rather, it can be selectively applied in areas of wear, significantly reducing the manpower needed for coating application (Chase 2002).

Fig. 16. Detail of hot wax application that protects, darkens, and adds gloss to the bronze surface

Successive coats of a formulated blend of wax based on the National Park Service recipe (71% Victory brown microcrystalline wax, 13% Polywax 2000, 13% petronauba, and 3% Cosmolloid H-80) were applied to the heated surface of *King Jagiello* and carefully dispersed with brushes to ensure penetration, selectively infill pitted areas, and establish complete coverage of a thin film.

This process saturates and slightly darkens the surface and, once it was modulated with selective buffing, achieved a nuance of tone and gloss complementary to the artist's intent and to the spirit of the material (fig. 16). With proper maintenance, the sculpture will be protected from further deterioration (Tatti 1985). *King Jagiello* will continue to be inspected yearly as part of the CPC's cyclical conservation maintenance program and will receive treatment as required. Degraded wax coatings can be reversed with a steam pressure washer or dry ice blasting and renewed as needed (Wolfe 2015). This approach to coating maintenance has restored an intimacy with the bronze surface, which, in the case of the *King Jagiello* conservation project, helped to dispel some of our assumptions about the work's technical processes of production and its treatment history.

Fig. 17. *King Jagiello* after treatment

Fig. 18. The author testing the dry ice blaster

8. CONCLUSIONS

The use of dry ice blasting was a suitable, cost-effective, rapid, and successful method to remove an aged Incralac coating on the *King Jagiello* monument (see fig. 17). The use of the process has proved to be a versatile, nondestructive, environmentally conscious, and relatively easy-to-use component of the CPC's in-house program of cyclical coatings maintenance. As stewards of the park, we believe that dry ice blasting has shown promise to fulfill our organizational commitment and professional aspiration to employ best practices and improve sustainability. Despite some limitations—the system is restricted to use as a surface treatment—dry ice blasting is a valuable addition to outdoor sculpture conservators' tool kits. Using the process solely or in combination with additional treatment methodologies has great potential for use on a range of conservation needs across a diverse collection of cultural resources in Central Park. However, further testing that produces quantitative data to determine appropriate operating parameters and establish thresholds on a variety of materials is needed.

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NOTES

1. Alternative, nonmethylene chloride gel strippers, such as Dumond Chemicals SmartStrip and Peel Away 7, have been found to be effective in removing lacquer and are the favored aqueous method for stripping lacquer on Central Park bronzes owing to improved safety and ease of use.

2. Technological advancements, such as optimization of scan pattern, are increasing the cleaning rate of lasers, at least doubling it on flat surfaces. The purposeful design of lasers for use in cultural heritage conservation have improved its safety and ease of use (Dajnowski, B. Phone Interview with author. Personal Interview. Manhattan, August 21, 2017; and from the author's direct observation on the Obelisk conservation project, June 25, 2015).

REFERENCES

Bierwagen, Gordon, Lisa Ellingson, Tara Shedlosky, and E. Rene de la Rie. 2001. *Development and Testing of Organic Coatings for the Protection of Outdoor Bronze Sculpture from Air-Pollutant Enhanced Corrosion —Year 1, 2001–2009.* Final Report to the National Center for Preservation Center Technology and Training 1999 Grant Program, North Dakota State University. Accessed September 5, 2019. https://www.ncptt.nps.gov/download/28228/

Chase, W. Thomas. 2002. "Aesthetics, Conservation, and Maintenance of Outdoor Bronzes." In *Objects Specialty Group Postprints.* Washington, DC: AIC. 9: 41–52.

Chase, W. Thomas, and Nicolas F. Veloz. 1985. "Some Considerations in Surface Treatment of Outdoor Metal Sculptures." In *AIC preprints. American Institute for Conservation 13th Annual Meeting.* Washington, DC: AIC. 23–35.

Continental Carbonic Products Inc. 2016. *CCPI Corporate Brochure*. Accessed 2017. https://web.archive.org/web/20170117211852/https://www.continentalcarbonic.com/about-dry-ice-blasting.html

Cold Jet LLC. 2004. *Technical papers: The fundamentals of dry ice blast cleaning*. Accessed 2017. https://web.archive.org/web/20040805193034/http://www.coldjet.com/tech-fundamentals.html

Cutulle, Cassy, and Seoyoung Kim. 2015. "Dry Ice Blasting in the Conservation of Metals: A Technical Assessment as a Conservation Technique and Practical Application in the Removal of Surface Coatings." *Objects Specialty Group Postprints, Volume 22, 2015*. Washington, DC: American Institute for Conservation (AIC). 22: 77–101.

Dajnowski, Andrzej, Adam Jenkins, and Andrew Lins. 2009. "The Use of Lasers for Cleaning Large Architectural Structures." *APT Bulletin: The Journal of Preservation Technology* 40: 13–25.

Lins, Andrew. 1992. "The Cleaning of Weathered Bronze Monuments: A Review and Comparison of Current Corrosion Removal Techniques." In *Dialogue/89—The Conservation of Bronze Sculpture in the Outdoor Environment: A Dialogue Among Conservators, Curators, Environmental Scientists, and Corrosion Engineers.* Houston, Texas: National Association of Corrosion Engineers (NACE). 209–230.

Liu, Yi-Hung, Hiroyuki Maruyama, and Shuji Matsusaka. 2011. "Effect of Particle Impact on Surface Cleaning Using Dry Ice Jet." *Aerosol Science and Technology*. 45 (12): 1519–1527.

Montagna, Dennis. 1989. Conserving Outdoor Bronze Sculpture. *Preservation Tech Notes: Metals 1*. Washington, DC: National Parks Service. Accessed September 5, 2019. https://www.nps.gov/tps/how-to-preserve/tech-notes/Tech-Notes-Metals01.pdf

Nowakowska, Krystyna. 2013. *The Polish Pavilion at the New York World's Fair (1939–1940) and Its Subsequent Fate*. Warsaw, Poland: Ministry of Culture and National Heritage, Department of Cultural Heritage.

OSHA (Occupational Safety and Health Administration). 2012. Toxic and Hazardous Substances—Methylene Chloride. 1910.1052. Washington, DC: OSHA.

Rabinowitz, M., 1991. Monuments Conservation Record of Treatment. Unpublished manuscript. Central Park Conservancy, New York, NY.

Reiley, Matt, D. Gasek, R. Dardarkar, S. Singh, and S. Jackson. 2004. Monuments Conservation Record of Treatment. Unpublished manuscript. Central Park Conservancy, New York, NY.

Reiley, Matt. 2016. *King Jagiello* Conservation: Final technical treatment report, June 22–October 24, 2016. Unpublished manuscript. Central Park Conservancy, New York, NY.

Ribis, G. 2016. *King Jagiello* Dry Ice Blasting Air Sampling and Sound Level Measurement Results. Unpublished Manuscript. Central Park Conservancy, New York, NY.

Spur, G., E. Uhlmann, and F. Elbing. 1999. "Dry-Ice Blasting for Clearing: Process, Optimization, and Application." *Wear* 233–235: 402–411.

Tatti, Steve. 1985. "Bronze Conservation: Fairmount Park, 1983." In *Sculptural Monuments in an Outdoor Environment: A Conference Held at the Pennsylvania Academy of the Fine Arts, Philadelphia, November 2, 1983,* edited by Virginia Norton Naudé. Philadelphia: Pennsylvania Academy of the Fine Arts. 58–66.

The Daily Plant. 1986. "King Jagiello Statue Unveiled in Central Park After Restoration." *The Daily Plant*, November 12.

Uhlmann, E., and M. Krieg. 2005. "Shot Peening with Dry Ice." *Proceedings of the 9th International Conference on Shot Peening*. 197–201.

Valera, C. 2016. Email message to author. October 31, 2016.

van der Molen, R., I. Joosten., T. C. P. Beentjes, and L. Megens. 2010. "Dry Ice Blasting for the Conservation Cleaning of Metal." In *Metal 2010: Proceedings of the Interim Meeting of the ICOM-CC Metal Working Group*, edited by Paul Mardikian, Claudia Chemello, Christopher Watters, and P. Hull. Charleston, SC. 135–143.

Weil, P. D. 1980. "The Conservation of Outdoor Bronze Sculpture: A Review of Modern Theory and Practice." *AIC preprints*. *American Institute for Conservation 8th Annual Meeting, San Francisco.* Washington, DC: AIC. 129–140.

——. 1986. *King Jagiello* Treatment Proposal and Report. Unpublished manuscript. Central Park Conservancy, New York, NY.

Wheeler, George. 2013. Observations on Cleaning Samples from Cleopatra's Needle. Unpublished memo, New York, NY. April 23, 2013.

Wolfe, Julie. 2015. Revitalizing Barbara Hepworth's Figure for Landscape. *the iris: Behind the Scenes at the Getty*. November 24. Accessed September 5, 2019. http://blogs.getty.edu/iris/revitalizing-barbara-hepworths-figure-for-landscape/

FURTHER READING

Brostoff, Lynn. 2003. Coating Strategies for the Protection of Outdoor Bronze Art and Ornamentation. PhD diss., University of Amsterdam.

Cold Jet LLC. 2017. *Environmental facts about dry ice blasting*. Accessed 2017. http://www.coldjet.com/en/environmental/facts.php
——. 2017b. *Frequently asked questions (FAQ)*. Accessed 2017. http://www.coldjet.com/en/information/faq.php
——. 2017c. *Aero FP 40*. Accessed 2017. http://www.coldjet.com/en/products/product-catalog.php?id=20&type=machine
Gettens, R. J. 1970. "Patina: Noble and Vile." In *Art and Technology: A Symposium on Classical Bronzes*, edited by Suzannah F. Doeringer et al. Cambridge, MA: MIT Press. 57–72.
Scott, David A. 2002. *Copper and Bronze in Art: Corrosion, Colorants, Conservation.* Los Angeles, CA: Getty Publications.
Weil, P. D., P. Gaspar, L. Gulbransen, R. Lindberg, and D. Zimmerman. 1982. "The corrosive deterioration of outdoor bronze sculpture." *Preprints of the Contributions to the Washington Congress: Science and Technology in the Service of Conservation*, edited by N. S. Brommelle and G. Thomson. London, England: IIC.
Wolfe, Julie, and Rosie Grayburn. 2017. "A Review of the Development and Testing of Incralac Lacquer." *Journal of the American Institute for Conservation* 56 (3-4): 225–244.
Wolfe, Julie, Rosie Grayburn, Herant Khanjian, Arlen Heginbotham, and Alan Phenix. 2017. "Deconstructing Incralac: A formulation study of acrylic coatings for the protection of outdoor bronze sculpture." In *ICOM-CC 18th Triennial Conference Preprints: "Linking Past and Future," Copenhagen 4–8 September 2017*, edited by J. Bridgland, art. 0808. Paris: International Council of Museums.

SOURCES OF MATERIALS

1987 Ingersoll-Rand Generator Model P175 A-W-D
Ingersoll Rand
170/175 Lakeview Dr.
Dublin, Ireland
https://company.ingersollrand.com/

Cold Jet Aero 40 FP
Cold Jet
455 Wards Corner
Loveland, OH 45140
http://www.coldjet.com/en/index.php

CleanLASER 100W
Dornkaulstr. 6-8
52134 Herzogenrath
Germany
info@cleanlaser.de

CO_2 Pellets
Continental Carbonics
https://www.continentalcarbonic.com/

Replacement Coating System
G J Nikolas & Co., Inc.
2800 Washington Blvd.
Bellwood, IL 60104
http://www.finish1.com/page_home.htm

Strippers
Rock Miracle
Samax Enterprises
29-75 Riverside Ave., Bldg #2
Newark, NJ 07104

Dumond Chemicals, Inc.
1475 Phoenixville Pike, Suite 18
West Chester, PA 19380
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Victory Brown Microcrystalline Wax (Hot Wax Formula)
Freeman Manufacturing and Supply Company
1101 Moore Rd.
Avon, OH 44011

Polywax 2000 and Petronauba Waxes
Baker Hughes
12645 West Airport Rd.
PO Box 5050
Sugar Land, TX 77487-5050

Cosmoloid H-80 Wax
Picreator Enterprises Ltd.
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TREATMENT OF TWO BADLY DAMAGED EGYPTIAN MUMMIES AND ASSOCIATED COFFINS

J. P. BROWN, MIMI LEVEQUE, AND MORGAN NAU

The Field Museum has one of the larger collections of Egyptian mummies in the United States. In this article we discuss the analysis and treatment of Egyptian mummies in preparation for a traveling exhibit, with particular focus on two mummies with coffins, both quite fragile. Such a situation combines the ethical questions of restoration and respect for human remains and ancient religious practice. In particular, we look at the problems of stabilizing and restoring human remains; inverting large, fragile, nonrigid objects for examination and treatment; stabilizing and restoring painted wooden coffins; reconstructing cartonnage; and using laser, computed tomography, and photogrammetric three-dimensional imaging to design and fabricate display and travel mounts for the treated objects.

KEYWORDS: Human remains, Ethics, Treatment, Mummies, Cartonnage, Coffins, Mounts, X-radiography, CT scanning, 3D imaging, CNC cutting

1. INTRODUCTION

Mummies are enigmatic objects—sealed in coffins, wrapped for eternity, hiding their secrets under many layers of fabric. The temptation to unwrap them to see what is inside is very strong, but one which has been largely resisted at The Field Museum—a museum with one of the larger collections of Egyptian and Peruvian mummies in the United States.

In 2011 and 2012, mummies not on display were scanned using a mobile medical computed tomography (CT) scanner. The results prompted a temporary in-house exhibit on mummies, followed by a traveling exhibit.

In this article we will talk about the examination and treatment of two of the Egyptian mummies and their associated coffins in preparation for travel to multiple venues in the context of a deadline-driven exhibit conservation schedule:

- "Minirdis son of Inaros": A Ptolemaic mummy of an adolescent boy in a reused Late Period coffin, acquired by transfer from the Chicago Historical Society in 1925 (fig. 1a). This mummy has a wood coffin with clay fills, painted inside and out, containing a damaged, but otherwise unwrapped, mummy. From outer layers to inner, the mummy assemblage comprised the following:
  - A gilded cartonnage mask, and cartonnage panels on the chest, legs, and feet
  - A linen shroud
  - Linen wrappings, the outer spiral-wrapped layer having some resin applied to the front portion of the wrappings
  - The mummified body
- "Penptah": A partially unwrapped adult male in a 26th Dynasty coffin, acquired by purchase in Egypt in 1894 (fig. 1b). This mummy assemblage comprised the following:
  - A wooden coffin with clay fills, painted on the outside
  - The mummified body, partially unwrapped, with some inner wrappings still in place, lying on a modern painted wooden board inside the coffin

A glossary of technical terms relating to Egyptian mummies is provided at the end of the text.

Fig. 1. Mummies in their coffins before treatment. (a) "Minirdis son of Inaros," Ptolemaic mummy (ca. 330–20 BCE) in reused Late Period coffin (ca. 670–330 BCE). Wood, human remains, linen, cartonnage, clay, gesso, paint, gilding, resin; 166 × 46 × 38 cm. Field Museum 111517.1-12. (b) "Penptah," 26th Dynasty mummy and coffin, ca. 670–520 BCE. Wood, human remains, linen, clay, gesso, paint, resin; 173 × 43 × 30 cm. Field Museum 30023.2-5.

2. ETHICAL FRAMEWORK

Over the 30 plus years that author Leveque has worked with mummies, she has developed the following series of guidelines for ethical treatment (Leveque 1987, 239).[1] We know how important the preservation of their bodies and perpetuation of their names was to the ancient Egyptians; thus, returning dignity and respect to their mummies is paramount (Ikram and Dodson 1998).

Guidelines:

- Thoroughly document all aspects of the mummy.
- Restore dignity to the mummy by:
    - Cleaning to remove nonoriginal material (especially storage dust and grime)
    - Reattaching detached pieces
    - Rearticulating bones where possible
    - Replacing missing bones where possible (as discussed in Lacovara et al. 2015)
    - Reintegrating linens and trappings
    - Maintaining all original material with the mummy
- Stabilize the mummy, limiting further damage.
- Avoid damage due to treatment methods and materials, as well as to permit future research and intervention.
- Avoid altering or obscuring details of wrapping and mummification.
- Ensure that all additions can be completely removed.
- Treat the mummy as an individual—not as an object.

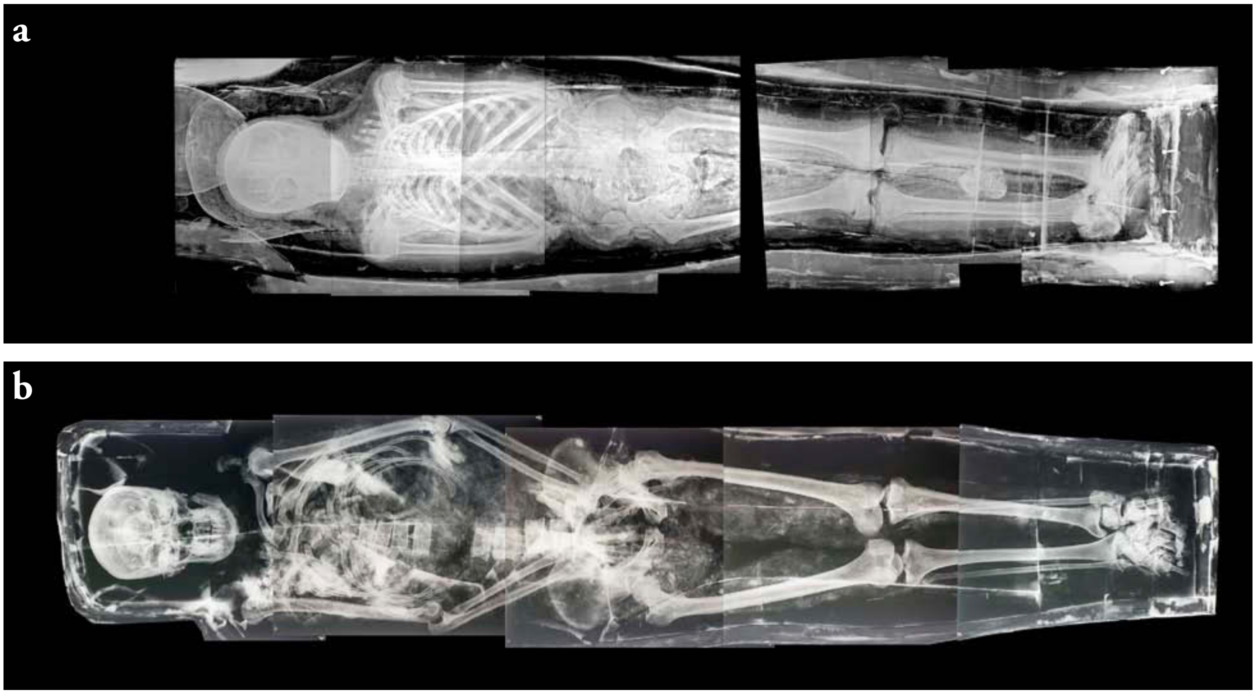

Fig. 2. Composite x-ray radiographs of the mummies. (a) Minirdis in his coffin. (b) Penptah in his coffin.

The treatment of the mummies of Minirdis and Penptah at The Field Museum serve as examples of this approach. As with all conservation projects, treatment decisions were also guided by curatorial intentions for the exhibition and there were frequent discussions about the final appearance of the mummies, especially since these mummies were being treated for inclusion in a traveling exhibition. The treatment of the mummies and coffins was carried out in the Regenstein Laboratory, which is a publicly viewable conservation lab. The public was able to observe and appreciate the care and respect with which the mummies were handled during treatment.

3. EXAMINATION

Unusually for museum collections, it appears that the Minirdis mummy had never been removed from the coffin. Every effort was made to keep the coffin and mummy in association during the initial examination. X-ray radiography of Minirdis in the coffin showed that the mummy was shorter than we would expect from the length of the coffin, that the mummy was of an adolescent, that the arms were crossed over the chest, and that the legs were damaged at the hips and disarticulated at the knees and ankles (fig. 2). On the basis of these x-radiographs—in particular, the relative gracility of the skull—it was hypothesized that the mummy was of an adolescent girl.

A subsequent CT scan of the mummy in the coffin showed definitively that the mummy was an adolescent boy and gave a better estimate of the extent of the damage to the mummy, cartonnage elements, and wrappings. The legs were disarticulated at the knees, the feet were disarticulated from the legs, one of the heel bones was displaced, and there was rotation and tearing of the wrappings and cartonnage elements. We could see from the scans that the cartonnage mask had rotated and torn, and that the cartonnage leg cover was now below the mummy. All of the damage was consistent with the mummy sliding and striking the foot of the coffin with the outer shroud catching on the coffin bottom,

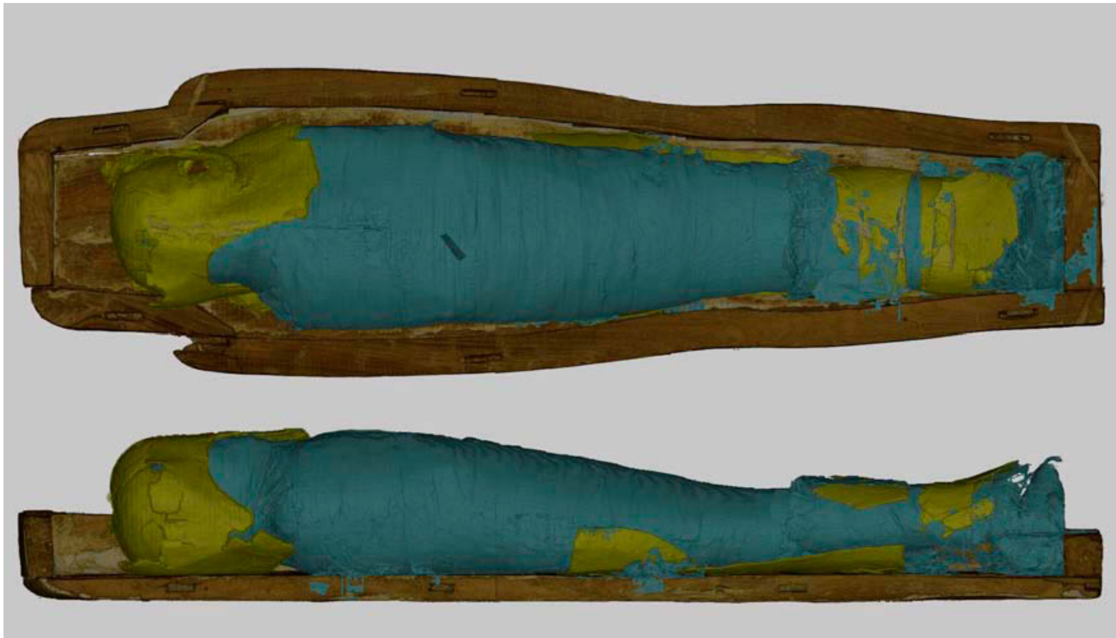

Fig. 3. Volumetric renderings from the CT scan of Minirdis showing wrappings (blue) and cartonnage elements (yellow)

displacing, crushing, and tearing the cartonnage elements in the process (fig. 3). The CT scan also revealed the construction of the coffin: each side of the coffin was split from a single piece of wood; there were numerous breaks in the dowels securing the wood pieces; there were clay fills between wood pieces; and there were flat, rectangular biscuit dowels securing the planks that form the back of the coffin (fig. 4).

Opening the coffin was complicated by the poor state of the joins between the coffin elements. In the end, plastic wedges were worked into the gap between the front and back halves of the coffin to open a gap of about 3/8 in. Steel plates (3/16 in. thick) were then slid into the top and bottom of the gap and clamped to aluminum C-section beams running down each of the long sides. Additional short steel plates were clamped to the aluminum beams to help support the long edges of the coffin. Finally, Tyvek-covered padded slings were tied over the top of the coffin to help hold elements together, as illustrated in figures 5 and 6. The support was then raised straight up, lifting the front half of the coffin with it, carried to a low table, and put down on polyethylene foam blocks.

Once the top was removed, it became apparent that the wood section forming the proper right side of the lower half of the coffin was no longer attached to the back of the coffin. We removed this side panel, which allowed us to pick up the mummy and move it to a transparent acrylic-topped table for further inspection. A quantity of cartonnage fragments, linen wrapping fragments, and old packing material remained in the coffin, which were carefully removed and sorted. A shroud—originally a single length of linen that stretched under the mummy from the feet to the head, around the top of the head, and then back down the front to the feet, below all the cartonnage elements but above the wrappings—was found to have broken at the head and to have separated into several pieces where the mummy had been lying on it. The crisscross linen bands that would have secured the cartonnage panels over the chest (pectoral) and waist and legs (abdominal), and the cartonnage foot covering, were broken and these panels were displaced. The mask, remaining cartonnage, and shroud were carefully removed for later examination and treatment.

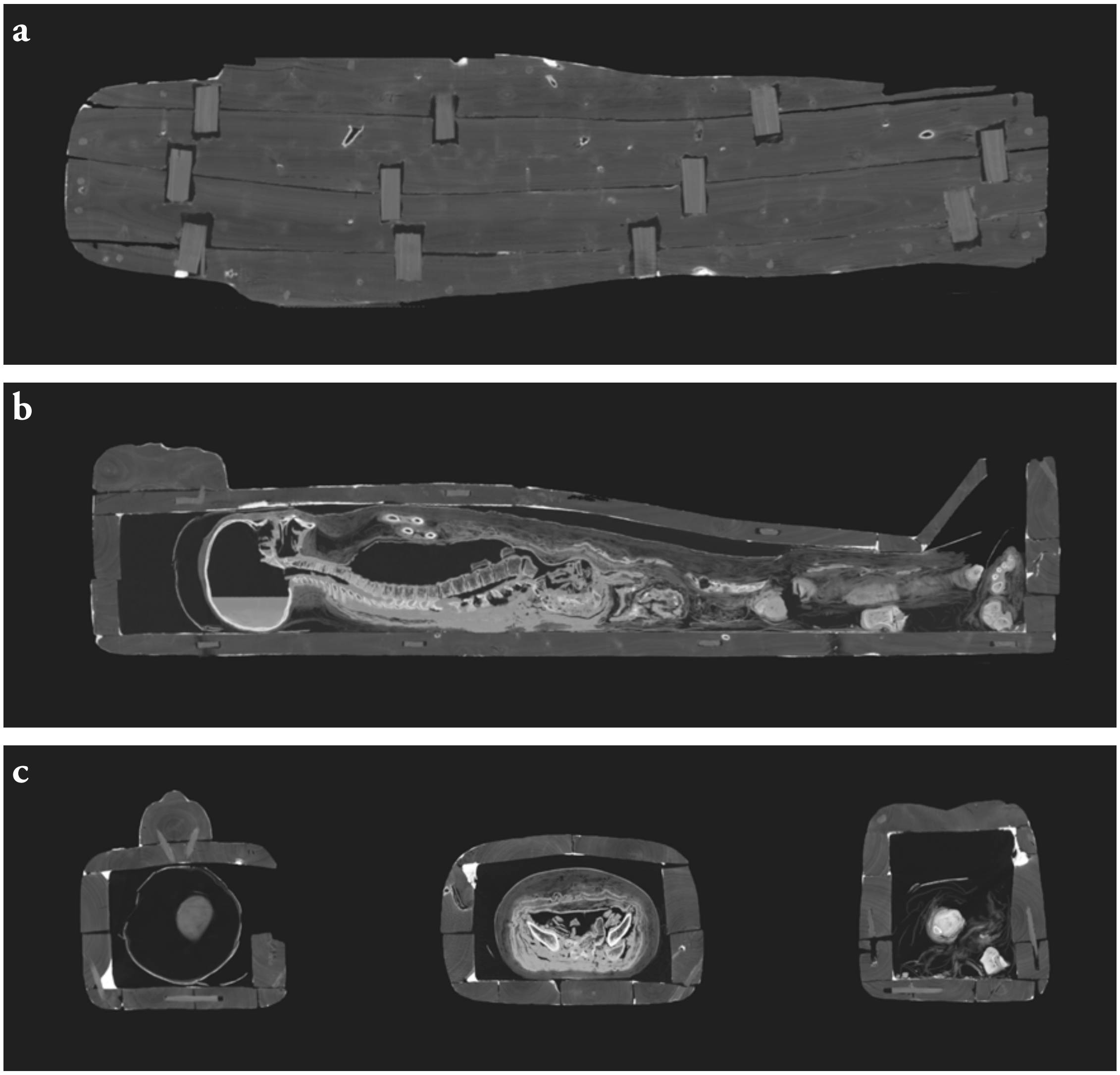

Fig. 4. Multiplanar reformatting of the CT scans of Minirdis. (a) Biscuit dowels joining wood pieces of the base. (b) Breaks in continuity of wrappings and disarticulation of skeleton. (c) Construction of face panel, broken dowel at lower right, broken dowel at right; note high-attenuation clay fills (white areas) and continuity of wood grain on side panels.

The front of the Penptah coffin was removed using the same method as described earlier. It was evident that the mummy had previously been removed from his coffin: the mummy had been partially unwrapped, exposing the inner wrappings and head, and then put on a modern painted wood board and placed back in the coffin on the board. The exact date at which the mummy was placed on the board is unknown, but the form of the painted board is consistent with other support boards found under mummies at The Field Museum. It therefore probably dates to the initial acquisition of the mummy by the museum in the late 19th century.

X-ray radiography of Penptah showed some disarrangement of the skeleton under the wrappings, with disarticulation of the cervical vertebrae, ribs, lumbar vertebrae, and knees, and several modern metal pins holding wrappings together (fig. 2b).

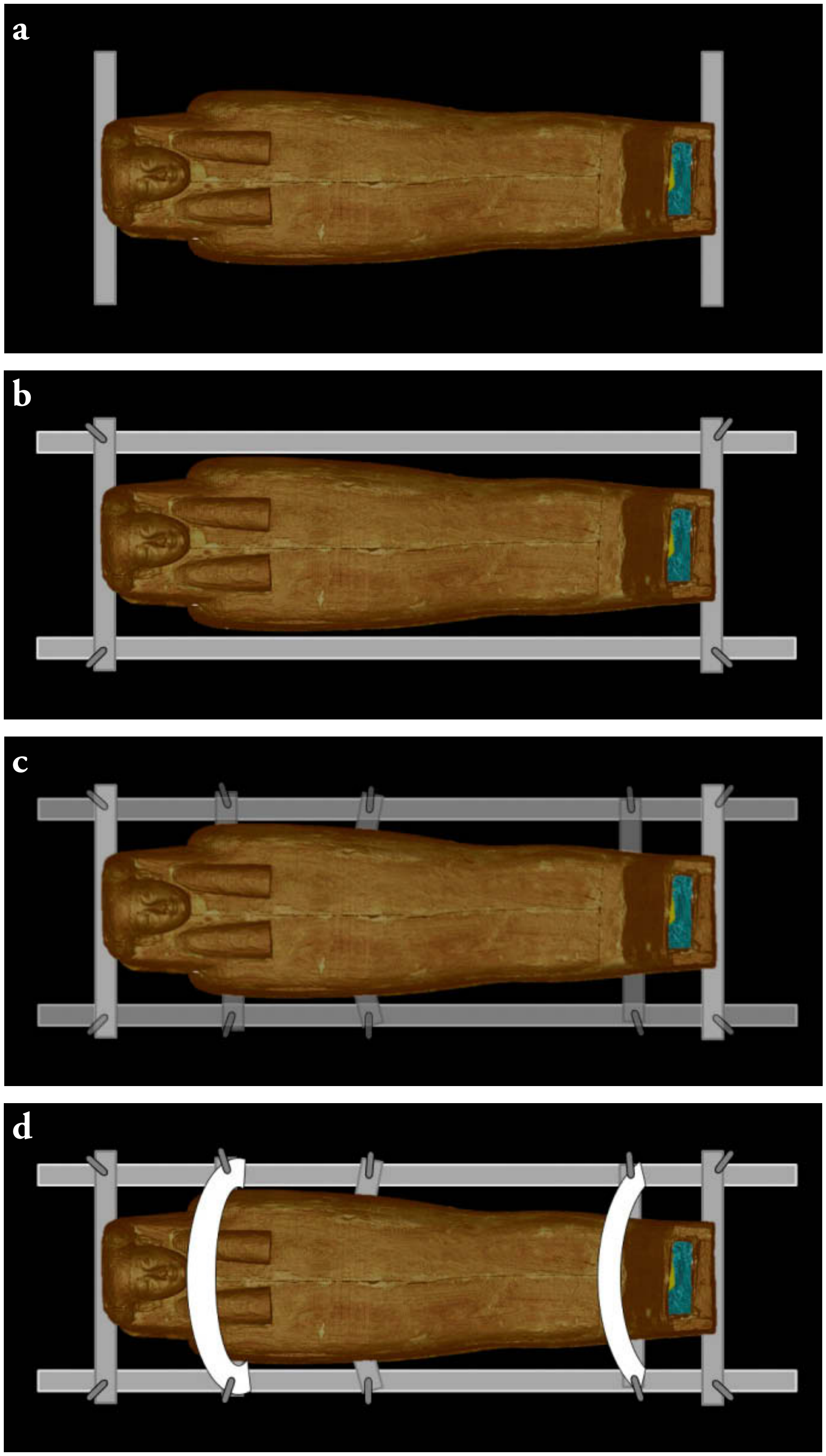

Fig. 5. Sequence of assembly for lid lifting support. Note that wood is shown brown and the mummy wrappings are shown blue-green. There is a missing panel at the top of the foot of the coffin where the blue-green wrappings show through. (a) 36 × 3 × 3/16-in. steel plates slipped under the top and bottom back edges of the front of the coffin. (b) 3 × 1-in. aluminum C-section beams attached to steel plates with 2-in. C-clamps. (c) Additional 6 × 3 × 3/16-in. steel plates slipped under the left and right bottom edges of the coffin top and clamped to an aluminum C-section beam. (d) Padded Tyvek slings stretched over the top and attached to C-clamps.

Fig. 6. The front of Minirdis's coffin on its lifting support, prior to lifting

4. TREATMENT OF MUMMIES

Prior to treatment of any mummy, it is important to try to understand and document the wrapping sequences, as the preparation of mummies in ancient Egypt changed over time. It is also essential to do a technical analysis of all the textiles to which there is access: recording thread counts, weave patterns, and any other features. Thorough documentation is key to accurate reconstruction of any mummy.

The overall approach to the treatments of the mummies (and of their coffins) was twofold. The first goal was to stabilize them to withstand the logistics of traveling to four different venues from coast to coast via truck and being on display in an earthquake zone. The second goal was to create a more accurate and visually integrated overall appearance.

During cleaning, we used variable speed high-efficiency particle air (HEPA) vacuums set on low with a fresh bag to be able to recapture any material that might be lost. We often used micro-vacuum tools and brush attachments directly so that we could see exactly where we were cleaning. This seemed to give better control than a separate brush and vacuum; we have found that covering the brush attachment with an open-weave fabric can sometimes abrade fragile ancient linens.

4.1 Treatment of Minirdis

In the case of Minirdis, his feet needed to be rotated and the heel bone replaced before the linens could be rearranged and secured; then the break at the knees needed to be realigned. One of the difficulties was that the upper half of the linen wrappings had been uniformly covered in a rigid black resin that held the wrappings together, but the lower half of the wrappings were not coated. Furthermore, the lower wrappings had been saturated with oils and resins seeping from the body; thus, they were weak, brittle, and unable to support the weight of the bones at the knees and ankles.

In order to stabilize breaks and weak areas, we have found that using a combination of paper, adhesive, and linen, somewhat like cartonnage, makes strong and safe supports for the ancient materials (Lacovara et al. 2015). Sections of this material can be made away from the object and then attached with strips of modern linen, sewn to themselves, allowing them to be removed easily if needed. Stiffer paper, archival cardboard, or other inert rigid materials can be incorporated as reinforcement. Since Minirdis was going to be traveling to multiple venues, we decided that the extent of the damage required his lower body to be completely stabilized. In addition to supports at the knees and feet, the lower body and the original wrappings covering the lower body were wrapped with modern linen strips dyed to match the original linens and cut to the same width as the outer linen strips on the mummy. The upper part of the new linen was painted with acrylic paint to match the black resin on the original wrappings. All the added material can be removed without any damage to the original (fig. 7).

For the cartonnage panels, the mask and foot covering had to be cleaned and stabilized—both were badly torn and had numerous losses. Fortunately, the pectoral and abdominal panels were in better condition, mostly needing cleaning and minor repairs.

Dry polyurethane cosmetic sponges were ideal for cleaning dusty, sooty cartonnage. Once clean, the cartonnage was humidified and realigned. Form-fitting inner and outer supports for the mask and foot covering were cut from pink polystyrene insulating foam employing models derived from the CT scan using a computer numeric control (CNC) machine, essentially a three-axis computer-controlled cutting head. The polystyrene worked well as a support: pins or bamboo sticks could be placed in it to hold sections in place. The cartonnage was slowly humidified by applying squares of damp 100% cotton fiber blotting paper with Hollytex and Gore-Tex as a barrier. Squares were held in place by metal hair curling clips padded with thin pieces of Volara polyethylene foam. Larger sections were realigned with strips of stretch wrap pinned to adjacent blocks of foam with bamboo sticks or pins. Tears and losses in the cartonnage were mended from behind with a variety of weights of Japanese kozo tissue using various viscosities of methyl cellulose or methyl cellulose mixed with wheat starch paste if the break needed stronger support. Fragments of the eye from the mask, along with other pieces of the trappings, had been found below the body and could be reattached using Japanese tissue supports. The linen fabric that formed the nose was found folded inside the mask, but the gilded gesso surface was gone. The linen was humidified and reshaped, then covered with gold painted kozo tissue to provide aesthetic reintegration (fig. 8).

The foot covering was more complicated, as it had been torn into two pieces, flattened, and parts of the sides and all of the underside were missing. Since the feet of the mummy had been realigned, we had to modify the support that had been made for them to be sure that the angle was correct. After cleaning, the pieces were humidified and shaped to the mount. Then, the missing sections were replaced using Japanese tissues of differing weights, attached using 4% methyl cellulose in distilled water. The paper fills were covered with a slurry of Paraloid B-72 (15%–20% w/v in acetone) bulked with glass microballoons and tinted with dry pigments to match the painted surface (smaller fills on the mask were also made using this method). Additional features, such as the gilded toenails on the cartonnage foot cover, were added using Japanese tissue painted with acrylic paints attached with 4% methyl cellulose. Once the cartonnage panels were conserved, they were secured with bands of modern linen folded to the size of the original linen straps and placed in their original locations (fig. 9). We decided not to replace the original shroud below the trappings, as it was too fragile to travel.

4.2 Treatment of Penptah

This mummy was even dustier than Minirdis. There was thick, sooty grime all over the linens; therefore, cleaning was the first priority. Once the original locations of the disturbed linen wrappings were determined, they were rearranged. In order to secure them in place, modern linen bands were added where it was clear there had originally been linen bands due to indentations and the lighter color of the linen in those areas. Where the toe bones were exposed, they were covered and secured with modern linen; then, the original ancient linen was replaced over the feet. The chest was more problematic, as there was no evidence of bands other than at the shoulders; it was clear that many of the upper layers of linen on the chest were missing. Consequently, that area was covered with a piece of brown silk crepeline tucked below and held in place by the previously added modern linen bands (fig. 10).

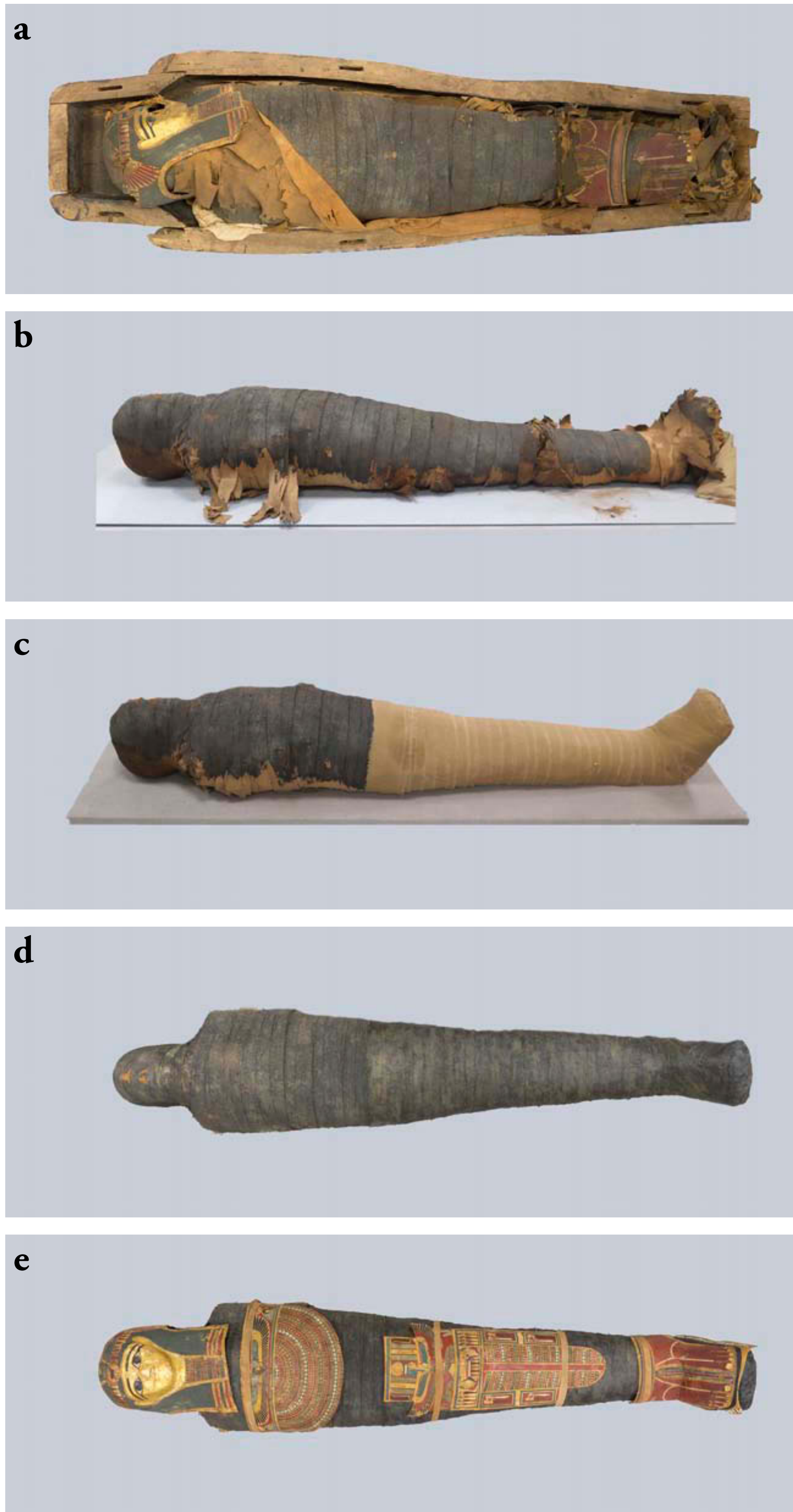

Fig. 7. Treatment sequence for the Minirdis mummy. (a) As found in the coffin. (b) Moved to the table, wrappings arranged. (c) Bottom section overwrapped in modern linen. (d) Modern linen painted. (e) Cartonnage panels replaced, tied with modern linen bands.

a

b

c

Fig. 8. Treatment sequence for the Minirdis cartonnage mask. (a) Before treatment. (b) During treatment. (c) After treatment.

On examination, the head was found to be detached from the body and adhered by the skin of the back of the head to a painted wooden block nailed to the painted wood board. The skin had separated from the back of the skull and the skull was, effectively, resting in a shallow cup of stiffened skin adhered to the painted wood block. FTIR analysis of the adhesive showed similarity with plant resin; it was suspected to be a late 19th century heat-activated "mastic" adhesive (Thornton 1988). Only a small amount of skin remained on the head. Initially, we believed this lack of flesh to be the result of poor unwrapping technique. X-ray radiography of the skull showed that the skull had contents and that the jaw had been attached to the cranium using lengths of twisted copper wire, attached to the inside surfaces of the left and right sides of the jaw with an adhesive that was very similar to that used to adhere the head to the painted mount. On further examination we found the contents of the

a

b

c

Fig. 9. Treatment sequence for the Minirdis cartonnage foot cover. (a) Before treatment. (b) During treatment. (c) After treatment.

cranium to be crumbly dried matter (possibly the remains of the brain) and the corpses of flesh-eating insects that had also been found inside the wrappings: *Dermestes frischii*, *Cleridae* (*Necrobia* spp.), and *Chrysomya* spp. (the latter blow fly type was subsequently identified as an Old World species specifically from North Africa). It is now believed that the body was either poorly mummified or in the process of decomposition when it was mummified. The material was carefully bagged to be replaced with the body.

The skull was lifted out of the skin "cup," and the wood block with the skin fragment still adhered was removed from the board and treated in an atmosphere of amyl acetate to loosen the adhesive and allow the skin to be separated from the wood. The detached skin was reattached with Paraloid B-72 (40% w/v in acetone). Lifting areas of skin on the skull were secured with tabs of sausage casing using the B-72.

a
b
c

Fig. 10. Treatment of Penptah. (a) Before treatment. (b) After vacuuming, with wrappings laid out (and skull removed for photo). (c) After treatment.

Since the wires attaching the lower jaw to the rest of the skull were broken in places and likely to cause damage, they were clipped and removed. The jaw was reconnected to the skull with pieces of Japanese tissue using methyl cellulose (4% w/v in distilled water). Areas where the tissue would be visible were toned with acrylic paint (fig. 11).

The repaired skull was still too fragile to travel attached to the mummy during the exhibit tour; thus, we decided not to permanently rejoin the head to the neck. Instead, the open neck at the top of the body was closed with a pad made from a nylon stocking filled with polyester batting to prevent loss of cervical vertebrae and mitigate damage to the linen opening. We decided to create a reversible support for the skull that would bring the head back into correct alignment with the body while the mummy was on display but would allow the removal of the skull for separate crating during transport.

5. TREATMENT OF COFFINS

Overall, the coffins were dirty with museum dust and black carbonaceous soiling, imparting a grayish tone. There was abrasion and loss to the painted decoration on both the interior and exterior surfaces. Both coffins had splits, cracks, and separations at nearly all of their joins. Along most of the joins and seams of both coffins, the plaster fill material was friable, loose, and actively coming away or already missing in many areas. There were minor losses on the front side to the gesso and paint layers, as well as

a

b

c

d

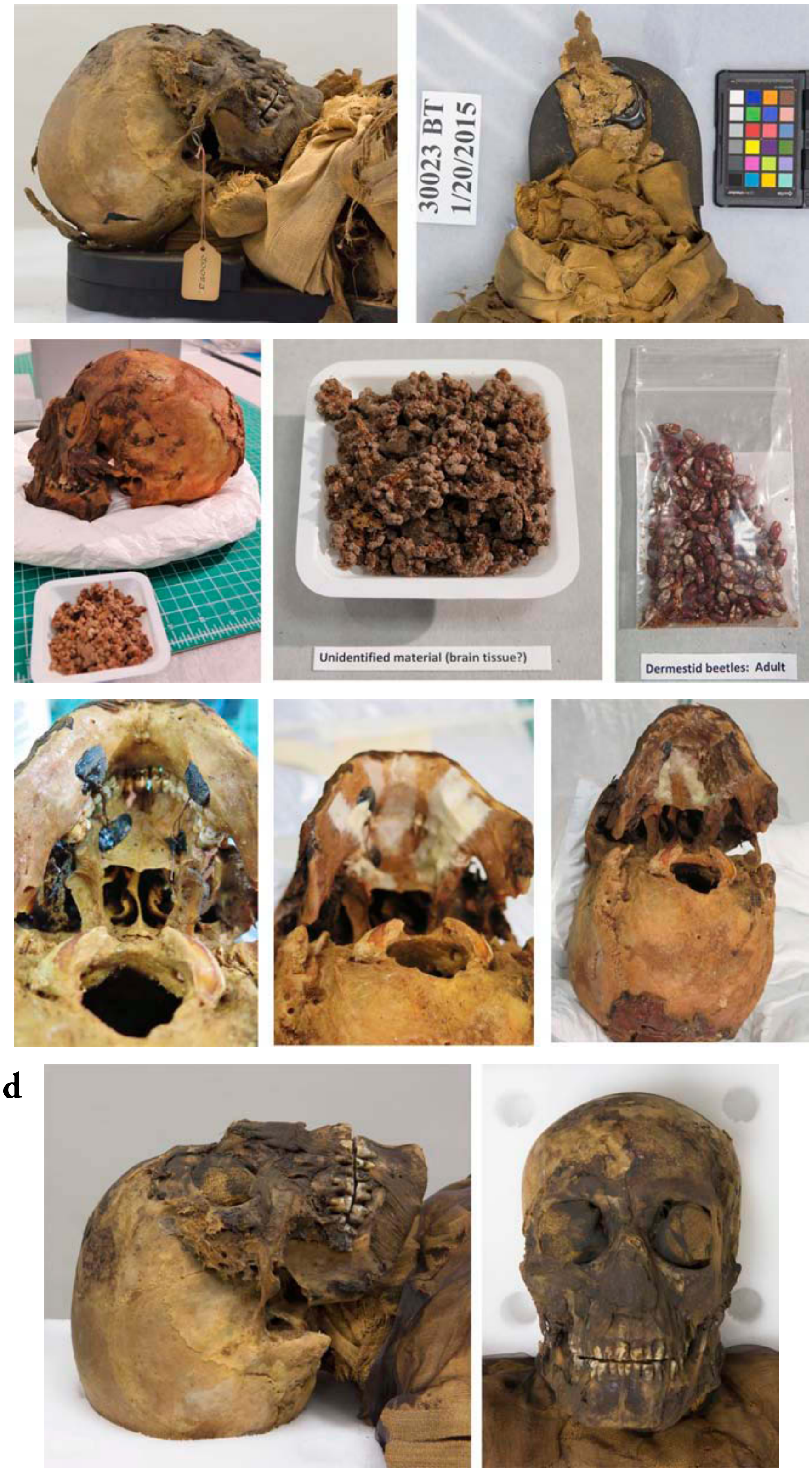

Fig. 11. Treatment of Penptah's skull. (a) As found: skull cupped in skin adhered to board and skin adhered to board. (b) Skull with skin re-adhered and contents; unidentified contents, possibly dried brain tissue; dermestid beetle carcasses. (c) Twisted copper wire attaching jaw; wire removed and replaced with Japanese tissue paper; toning of Japanese tissue. (d) Skull re-associated with mummy after treatment.

other gouges and losses. On the coffin of Minirdis these voids were significantly more distracting, as they caused interruptions to the dark, black surface and painted decorations. However, the paint and gesso losses on the coffin of Penptah were far more extensive, with the paint cupping and actively flaking off across the entire exterior surface.

Minirdis's coffin also had minor structural issues in the form of a lost footboard and a missing section of wood along the side of the head. Also, one of the exterior planks of the bottom of the coffin was loose, causing the whole lower side to detach. On the top of the coffin, the nose had been lost; there was damage and loss to the left eye and eyebrow with surrounding lifting paint.

In contrast to the essentially untouched coffin of Minirdis, Penptah's coffin had been previously treated. Gray adhesive residues and drips were found scattered over the surface, indicating that the lifting and flaking paint was not a new problem. Solubility testing suggested that the previous adhesive may have been a poly(vinyl alcohol) emulsion.

It was also decided early on, regarding the treatment of Minirdis's coffin, not to reattach the loose bottom side of the coffin or reconstruct any of the missing elements, but instead offer any additional structural stability through the mount. This is because the construction was found to be such a fascinating component of the coffin and was featured as part of the display.

The coffins were first brush-vacuumed and then cleaned with dry polyurethane cosmetic sponges. The visual appearance was significantly improved, and a previously unsuspected painting of the goddess Nut was fully revealed on the inside surface of the back of half of the coffin.

5.1 Stabilizing the Clay Fills

The most pressing problem was stabilizing the clay that had been used in original manufacture to fill the gaps between the wood elements. These clay fills had hydrated, swelling and cracking, pushing off paint, and the exposed surfaces were so friable that they could not tolerate brushing. We solved this problem by misting 10% weight/volume Paraloid B-72 in acetone onto the surface to create a hardened surface crust. Once the B-72 was set, higher solids B-72 was injected through the crust with hypodermic syringes to consolidate the clay below. This treatment was successful in consolidating the clay but led to an increase in color saturation at the clay surface. It is possible that the clay could continue to be a problem if relative humidity is not maintained in fairly narrow boundaries. The intended humidity range for storage, transport, and display of the coffins is 40% to 60% RH going forward. We expect that this will prevent further changes in volume of the clay fills.

5.2 Turning Coffins

The remaining problem was how to turn the coffin elements over for treatment of the undersides.

We found a very flexible system from CIVCO Radiotherapy called Vac-Lok positioning cushions, nylon bags filled with tiny polystyrene beads. When you blow air into the bag it becomes somewhat floppy and conformal, rather like a stiff beanbag chair. When you suck the air out of the bag, it locks in place and becomes rigid. The bags are designed for holding patients still while they are undergoing radiation therapy and come in various sizes. The bags are not perfectly airtight, and we found that the bags start to lose rigidity after about 10 days. Therefore, they can be used as a temporary support for only about a week. If the bag is needed in position longer, the air needs to be sucked out again after each week.

Our method of using the cushions was as follows: first, blow air into the Vac-Lok cushion to make it floppy. The coffin was then prepared by draping a 0.5-mL Mylar sheet over the coffin and then covering it with pads made of polyester batting covered with washed Tyvek. The expanded Vac-Lok cushion was draped over the batting pads; then, the top of the cushion was flattened to provide a level surface for when the assembly is turned over. We then sucked the air out to make the cushion rigid and wrapped 4-in.-wide bands of stretch-wrap film around at three or four locations to secure the coffin element to the Vac-Lok cushion. The whole assembly was then turned over, chocked in position, and the stretch wrap was removed. This method worked well, even for particularly fragile coffin elements.

It is notable that CIVCO offers two versions of electrical pump for this system: the one shown in figure 12, which is cheaper but only sucks air out of the cushions, and a substantially more expensive one that both sucks air out and blows air in. If we were doing this again, we would get the more expensive one—it is surprisingly tricky to return the evacuated cushion to its floppy state by hand (fig. 12).

5.3 Treatment of the Minirdis Coffin

To start, sections of loose or detached paint and gesso were stabilized or re-adhered with 20% weight/volume Paraloid B-72 in acetone. This adhesive was chosen because the lifting paint and gesso had detached in bulky chunks and needed the strength it would provide. In addition, it was the same adhesive that had already been used to consolidate and strengthen the gesso and clay in many areas.

Loss compensation and visual reintegration were performed at the voids and gaps where the planks of the coffin had separated or there had been damage. A barrier layer created from Japanese tissue coated with Aquazol 200 was placed over all the loss edges and reactivated with ethanol and allowed to dry. For larger voids, balsa wood was carved to fit the loss, following the grains of both the balsa and the wood of the coffin to allow for the expansion and contraction of both in reaction to fluctuating environments. The balsa fills were lightly pressure fit into place and adhered with Aquazol 200 15% weight/volume in ethanol. The adhesion with Aquazol 200 ensured that they would stay in place but also allowed them to be easily removable in the future. Another layer of Aquazol-coated Japanese tissue would then be applied over the balsa fill. All losses were further filled using microballoons in Paraloid B-72 20% weight/volume in acetone. Texture was carved into the fills using dental tools as it hardened. Japanese tissue, toned black using acrylic paints, was wet torn to the shape of the fills and applied using methyl cellulose 4% weight/volume in water. Following this, any areas where the yellow decoration followed an obvious pattern were inpainted on the tissue fills using acrylic paint (fig. 13).

The losses to the left eye and eyebrow were rebuilt using Flügger acrylic putty and reintegrated with Japanese tissue fills using the same method as described earlier—the tissue was toned to match, impregnated with Aquazol 200, wet torn to shape and laid in place, and then reactivated with ethanol (fig. 14).

5.4 Treatment of the Penptah Coffin

The active extensive cupping and flaking paint was stabilized using Lascaux Medium for Consolidation, chosen for its low viscosity and penetrating ability, and reversibility and reworking properties. The exposed wood surface around the flaking paint was first protected with a barrier layer of 1% methyl cellulose in 1:1 water:ethanol to prevent the Lascaux from staining the wood. The adhesive was applied to the break edges of cracked and lifting paint and was left for several minutes to begin to set. A tacking iron

a

b

c

Fig. 12. Vac-Lok cushion being used to turn the front half of Minirdis's coffin. (a) 0.5-mL Mylar, Tyvek-covered padding, Vac-Lok cushion in place. (b) Air being pumped out of bag; note pump at lower right and plywood board on top to help form a flat surface for when the piece is inverted. (c) Coffin inverted.

Fig. 13. Treatment sequence for the top portion of the front half of Minirdis's coffin. (a) Voids filled with balsa wood or folded Japanese tissue. (b) Carved fills of Paraloid B-72 with microballoons. (c) Painted Japanese tissue paper adhered over carved fill.

on low heat, with a silicone release Mylar barrier between the object and the iron, was then used to set down and adhere the paint flake.

It was decided not to perform fills or inpainting for two reasons: first, the vast amount of small losses across the surface would be very time-consuming to fill individually; second, due to the color palette and overall busyness of the decoration, the losses were not visually distracting.

The finished coffins can be seen on their mounts in figure 15.

6. PRODUCTION OF MOUNTS

The first venue for the traveling exhibition was Los Angeles, which meant that everything needed seismic mounts to provide protection in the event of an earthquake.

We decided that we would make combined travel and display mounts so that the objects and mummies would not be handled directly during the tour. Everything would stay on its mount throughout the tour and the mount would cleat to the case deck for display or clamp to the floor of the crate for travel, as necessary. Each coffin and mummy got its own mount.

Fig. 14. Aesthetic compensation of the left eye and eyebrow on the Minirdis coffin. (a) Before treatment. (b) Painted tissue being added to Flugger acrylic putty fill. (c) After treatment.

The core of each mount was a plywood panel, cut to size. The top and sides of the plywood were covered with aluminized polyethylene as a barrier against migration of harmful by-products from the plywood. The top surface was then covered with polyester batting, tacked in place with hot-melt adhesive, and the top and sides were covered with fabric that was stapled to the bottom of the plywood. For the mummies, we used undyed linen fabric to provide a surface similar to the linen mummy wrappings. For the coffins, we used undyed cotton since it was cheaper than linen and linen provided no advantage over cotton for the coffins.

The plywood panels acted as a base for shaped supports. We manufactured these supports by taking three-dimensional (3D) models of objects, subtracting them from computer models of the foam blocks, and CNC-cutting the result of the subtraction from 6-lb. Ethafoam.

Fig. 15. Coffins on mounts after treatment. (a) Front half of the Minirdis coffin. (b) Back half of the Minirdis coffin. (c) Penptah coffin.

For the Minirdis coffin, we were able to use the CT scan to derive 3D models of the various components by segmenting the CT scans using Volume Graphics VGStudio Max CT analysis software. For the remaining objects, we derived 3D models from photogrammetry using a Nikon D7100 DSLR with Nikon prime 24-mm and 50-mm lenses. During photography, we took care to include scale bars so that correct dimensions could be inferred. The digital images were processed as JPEGs and fed into Agisoft PhotoScan Pro photogrammetry software; usable models were produced quite quickly and cheaply. The overall process is illustrated in figure 16.

The foam parts for a particular mummy or coffin mount were made in at least four pieces: one section each for the head, feet, and left and right sides. Countersunk holes were added to the model to allow the foam pieces to be screwed to the plywood mount core.

Two things that we found during the manufacturing process are notable. First, the rotary cutting head of a CNC machine produces a raised, velvety “chew” on the surface of the foam. This extra material adds about 1 mm to the thickness of the cut part. Thus, for a good fit between the object and the foam, it is necessary to increase the dimensions of the 3D model of the object by at least 1 mm. When the enlarged

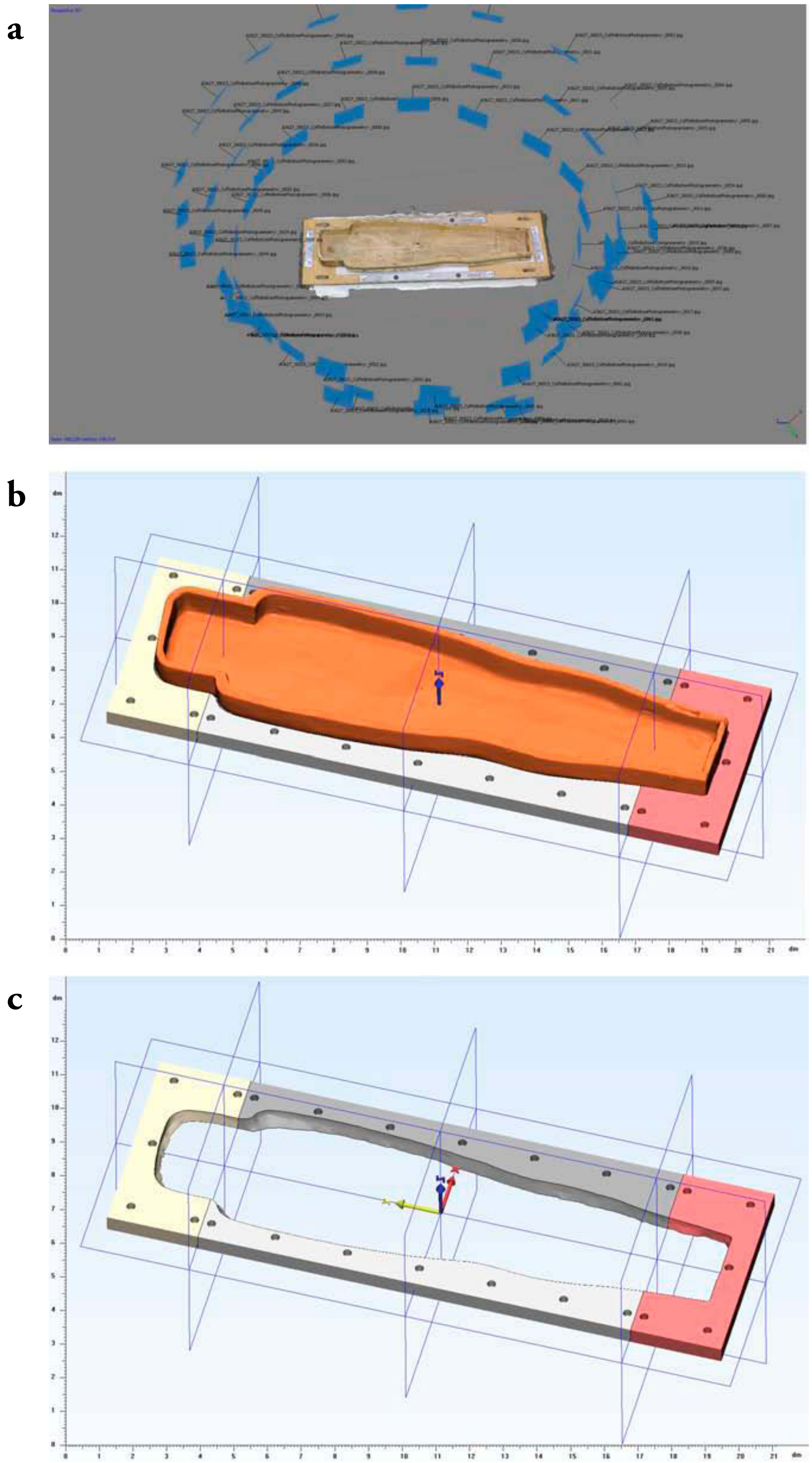

Fig. 16. Design of travel/display mounts. (a) Photogrammetry of the back half of the Penptah coffin in Agisoft PhotoScan (note scale bars). (b) 3D model of coffin back, slightly enlarged to allow for "chew," in position on 3D models of foam mount pieces in Materialise 3-matic. (c) 3D model of foam mount pieces once coffin model has been subtracted in Materialise 3-matic.

a
b
c

Fig. 17. Construction of combination travel and display mounts. (a) Padded board with foam pieces clamped in place for pilot holes to be drilled; details of hardware for attaching foam. (b) Locating the coffin in the mount: first the top and bottom foam pieces are secured, then the coffin is placed on the board. (c) CNC-cut foam pieces on plywood spine to support the inside of the coffin.

a

b

c

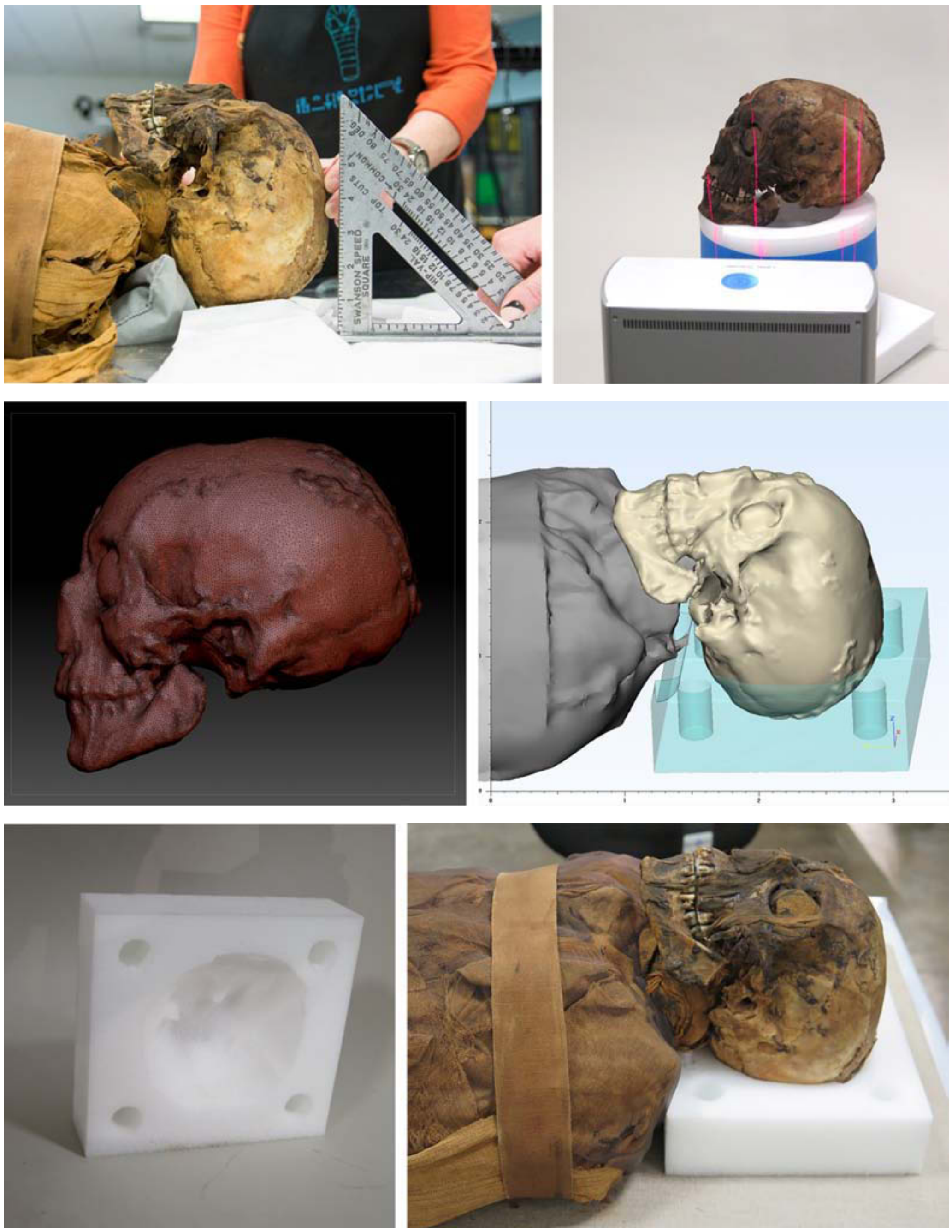

Fig. 18. Sequence of construction of the head mount for Penptah. (a) Determining the correct angle for the head, and laser scanning. (b) The 3D model of the head and designing the support. (c) The CNC-cut foam support and the articulation of the head in the support with the mummy.

object model is subtracted, the additional space for the chew is built into the result. This velvety finish produced a slight cushioning and had similar surface roughness to washed Tyvek. Therefore, we did not cover the contact surfaces of the CNC-cut elements with Tyvek. Second, the foam blocks that we received from the manufacturer were not perfectly flat: the top surface tended to undulate slightly and some of the undulations rose above the nominal surface thickness (2-1/4 in. in this case). The effect of this unevenness was that the CNC machine would try to cut the foam surface above the nominal surface thickness, leaving the cut portions of the surface with the distinctive chewed-looking surface resulting from the rotary cutting head. Once we realized the source of the problem, we increased the height of the top surface in the models of the foam blocks so that the nominal upper surface was above the true surface in all cases.

The CNC-cut foam pieces were clamped into position on an isolated, padded plywood board, pilot holes were drilled, and the pieces were secured with wide-area hardware to prevent the foam tearing if it was stressed. We then left the top and bottom foam pieces as references, placed the object on the mount, and secured the side pieces, as shown in figure 17.

A similar process of photogrammetric modeling and software subtraction gave us CNC-cut shapes to support the interior of the coffins. In this case, the foam pieces were threaded onto a central “spine” cut from plywood, tested for fit, and then secured with hot melt glue and steel bolts (fig. 17c).

We followed a similar construction method with the Minirdis coffin and the mummies. The only slight variation was the dissociated skull for Penptah. We determined a plausible relationship between the skull and the body and then used a NextEngine laser scanner to get a model of the skull. We refined and aligned its position in Pixologic ZBrush and then brought the model into Materialise 3-matic, enlarging it by 1 mm to allow for CNC chew on the surface of the polyethylene foam, as previously discussed, and then subtracting it from a rectangular prism to make a machinable model that was CNC-cut from 6-lb. Ethafoam. This resulted in an extremely satisfactory but reversible fit between the back of the skull and the mount.

7. CONCLUSION

In the end, the ancient Egyptians wanted to be remembered—to be present with the living in order to live forever. We think that the work that we have done enables that wish.

The overall treatment of the mummies, particularly the repair of damage and reintegration of separated elements into an aesthetically coherent whole, fulfills both curatorial needs and is consistent with what we know of Egyptian religious belief. The 3D scanning and CNC cutting used to produce the mounts was extremely successful, allowing these mummies and coffins to move over 8,000 miles by road to four different US museums with no damage.

One of the best parts of this project is being able to do the treatments in an open lab where the public can observe the work, passing along our enthusiasm to the next generation as well as exhibiting the respect we show and care we take with these mummies. We think the interaction with the public has been incredibly valuable—as seen by this lovely letter from a child who was visiting in another museum where Leveque was working in the gallery on a mummy:

> *Dear Ms. Mimi Leveque*
> *Thank you so very much for all the concern you showed regarding the mummies. I saw you working with so much care so that other people could see not only the Egyptian mummification but the other kind. The room smelled a lot but it was OK. Being a conservator must be hard but us females do great. Ever since I saw you I might want to be a conservator if I get an opening at a museum. Sincerely,*
> *Helen Richardson.*

ACKNOWLEDGMENTS

CT scanning services for this project were provided by Genesis Mobile Imaging. Segmentation of some of the CT scans was performed by Katarina Kaspari. Conservation Assistant Lauren Fahey assisted with the radiography of the Minirdis mummy. Portions of the conservation treatment described here, especially cleaning the coffins and toning the rewrapped portion of the Minirdis mummy, were performed by Conservation Assistant Sophie Hammond-Hagman. Identification of insect carcasses removed from the Penptah mummy was performed by Insects Collections Manager Crystal Maier.

GLOSSARY

Cartonnage: A rigid material created from layers of linen or papyrus adhered with glue. It can be formed over a mold to create masks, panels, or even complete coffins. The outer surface or both inner and outer surfaces are covered with a ground, like gesso, painted and frequently gilded.
Coffin: The coffin is the container into which the mummy is placed. The number of containers surrounding a mummy and the forms that coffins took changed throughout Egyptian history. There can be single-coffin burials or sequences of coffins, each inside the next, from a large outer coffin, generally called a sarcophagus, to smaller inner coffins. The coffins for both Minirdis and Penptah are made of wood, gessoed and painted, and are shaped like a mummified human, termed "anthropoid."
Shroud: Following the wrapping of a body with linen, the mummy is frequently covered by a large linen fabric. Depending on the period of Egyptian history or the status of the individual, shrouds could be plain linen, dyed red or pink, or painted.
Trappings: Ornamental elements added to the outer wrappings of a mummy. Trappings can be simple or elaborate and can include cartonnage or plaster elements (such as a mask), decorated panels or plaques for the chest, and leg and foot coverings. Bead network body coverings and portrait panels are also seen in certain periods.
Wrappings: The mummified body was wrapped in layers of linen fabric. The length and width of the strips of linen depended on where they were being placed on the body. The source of most of the fabric seems to have been from used garments or other textiles, such as sheets or shawls. There is a tremendous variability of weave types and fabric thicknesses, even in a single mummy.

NOTE

1. This ethical framework was developed by Mimi Leveque in association with Renée Stein (Michael C. Carlos Museum, Emory University), with whom Leveque has worked on numerous mummies.

REFERENCES

Ikram, S. and A. Dodson. 1998. *The Mummy in Ancient Egypt: Equipping the Dead for Eternity*. London: Thames and Hudson.

Lacovara, Peter, Salima Ikram, Bob Brier, Margaret Leveque, and Renée Stein. 2015. "An Egyptian Mummy of the Late Old Kingdom in the Michael C. Carlos Museum, Emory University." *Journal of the American Research Center in Egypt* 51: 65–74.

Leveque, Mimi. 1987. "An Approach to the Conservation of Egyptian Mummies: The Mummy of Lady Nesmutaatneru." In *Recent Advances in the Conservation and Analysis of Artifacts*, ed. J. Black. London: Summer Schools Press, University of London: 239–41.

Thornton, Jonathan. 1988. "A Brief History and Review of the Early Practice and Materials of Gap-filling in the West." *Journal for the American Institute for Conservation* 37 (1): 3–22.

SOURCES OF MATERIALS

3-D modeling software
3-matic
www.materialise.com
ZBrush
www.pixologic.com

Aquazol 200
Talas
https://www.talasonline.com/Aquazol

CT segmentation software
VGStudio Max
www.volumegraphics.com/

Coffin lid lifting supplies: non-marring ABS wedges, aluminum U-section beams, 3/16-in. steel plates, 2-in. C-clamps
www.mcmaster.com

Ethafoam (6lb density)
Northern Products
https://www.northernproducts.net/

Lascaux Medium for Consolidation 4176
Kremer Pigmente
https://shop.kremerpigments.com/

Makeup sponges
Qosmedix
www.qosmedix.com

NextEngine laser scanner
www.nextengine.com

Photogrammetry software
Agisoft Photoscan
www.agisoft.com/

Scale bars for Agisoft Photoscan
Cultural Heritage Imaging
culturalheritageimaging.org/

Vac-Lok cushions and pump
Civco Radiotherapy
civcort.com

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SITTING PRETTY: COLLABORATIVE TREATMENT OF AN EARLY YAYOI KUSAMA SOFT-SCULPTURE CHAIR

FRAN BAAS AND LAURA EVA HARTMAN

This article discusses the collaborative treatment undertaken on an early Yayoi Kusama (born 1929) soft-sculpture chair by both objects and paintings conservators at the Dallas Museum of Art. The chair is one part of *Accumulation* (1962–1964), a body of work characterized by accumulations of phallic-like fabric protuberances that would eventually evolve to full sensory environments. This body of work represents Kusama's early artistic career during the period when she first moved to New York City in 1958 and was developing in the avant-garde.

Accumulation, a co-owned work between the Rachofsky Collection and the Dallas Museum of Art, was requested for loan for a retrospective on Kusama; this article details a project during which its condition, treatment needs, and travel logistics were evaluated. The chair is encased in a network of soft, stuffed fabric bundles that are painted white with a thick, rigid paint. Safely packing the object was the primary concern owing to its complex surface—soft, yet brittle simultaneously. Structural treatment of the individual fabric bundles had to be addressed, as several had been crushed and damaged in the past. Networks of large unstable cracks had formed throughout the paint layer, which had also become embedded with grime and needed to be cleaned and consolidated. Owing to the complex nature of the object, both paintings and objects conservators collaborated to develop and enact a specialized treatment plan for this complicated and fantastic object.

1. INTRODUCTION

Treatment was undertaken during the fall of 2016 on a Yayoi Kusama (born 1929) *Accumulation* chair co-owned by the Dallas Museum of Art (DMA) and the Rachofsky Collection. Kusama's *Accumulations* are complex, multi-faceted environments that incorporate many "soft" objects, like the DMA/Rachofsky chair (fig. 1). This chair had originally been incorporated into one of these conceptual spaces and would once again join other soft sculpture objects as it was planned to travel with a retrospective of the artist's work.

In order to prepare the chair for travel for this loan, the piece required collaboration between both objects and paintings conservation specialties. The soft painted elements applied onto the underlying chair required cleaning and stabilization. The piece as a whole also had to fit within the broader context of other white monochrome *Accumulations*. The collaboration between objects and painting conservators resulted in the development of a cleaning system involving gels and emulsions—specifically for cleaning complex painted surfaces—and the creation of a specialty crating system for an unusual and fragile three-dimensional object.

The conservation of contemporary art can become a complex web. Essential is the delicate balance between any number of often competing influences that can affect treatment decisions. Included in this balance are factors such as materials and techniques, artist's intent, aesthetics, conservation ethics, urgency, technical limitations, and economic aspects. Decisions develop from collaborative discussion between conservators, curators, artists, and other colleagues from any number of specialized industries. This project allowed the team to work collaboratively toward stabilizing and preparing this object for travel and, importantly, showing it within its original context among a larger *Accumulation*.

Fig. 1. Yayoi Kusama, *Accumulation*, 1962–1964, sewn stuffed fabric with paint on wooden chair frame, 87.63 × 96.52 × 83.82 cm. The Rachofsky Collection and the Dallas Museum of Art through the TWO × TWO for AIDS and Art Fund, 2008.41 (Courtesy of Dallas Museum of Art, photograph by Brad Flowers)

2. RESEARCH: ARTIST, CONTEXT, INTERVIEWS, AND CONSULTATIONS

Yayoi Kusama was born in 1929 in Matsumoto, Japan and grew up near her family's plant nursery. She describes a rough childhood as dark and hopeless, leading her to create art. Polka dots and nets were early repetitive motifs evoked by the young Kusama at around age ten. By this age, she was already suffering from visual and aural hallucinations. Self-obliteration, as she refers to it, became a coping mechanism for Kusama, a process in which her life and her art became one—in which she would lose herself in the imagery. This repetition would become a recurring theme throughout her life and artistic career (Turner 1999).

As a teenager during World War II, Kusama worked in a parachute factory. This familiarity with sewing factors into her later use of fabric in the development of what became known as her soft sculptures. At 19, following World War II, she went to Kyoto to study the traditional Japanese style of painting known as *Nihonga*, an experience she has discussed as having hated (Kusama 2011). During this time, she began experimenting with abstraction. She contacted Georgia O'Keefe, whose address she had found in a book at the Embassy, to ask for advice (Kusama 2011). O'Keefe encouraged her to move from Japan to the United States in 1957, and Kusama's career took off almost immediately after her arrival.

Living in New York from 1958 to 1973, Kusama moved in avant-garde circles with such figures as Andy Warhol, Claes Oldenburg, Donald Judd, and Eva Hesse. She began to refine her signature dot and net motifs while developing her soft sculpture installations. This was a time of experimentation, marked also by Kusama's infamous naked polka-dot painting *Happenings* in the late 1960s. The soft sculpture installations began by taking furniture and other everyday objects and covering them with handmade fabric penises—covering and consuming well-known objects such as stepladders, chairs, and a rowboat, to name a few. She eventually created entire environments out of these formations, initially in all white. In many references, she mentions her motivation at the time as being reactionary to not only a sexist art environment and her womanizing philandering father but also her fear of sex (Kusama 2011).

The DMA/Rachofsky *Accumulation* was created between 1962 and 1964, most likely in a downtown loft located in the same building as the studio of her friend, the artist Claes Oldenburg. Other artists—such as Donald Judd, who lived in her building—helped in the preparation and stuffing of the protrusions (Takasugi 2017). Kusama comments on the creation of her soft sculptures as follows: "At that time, I was really poor. So, I took my sheets and sewed together numerous phalluses on a second-hand sewing machine, filled them with the stuffing from the armchair I found in the junkyard, and attached them to various things in my room—burying the room under those luxuriating protrusions." (Matsui 1998).

After reviewing old interviews, diving into Kusama's writings, contacting other custodians of white stuffed Kusama objects, and even receiving a few responses from Kusama herself (via her studio assistant Megumi Takasugi), three things emerged that drove the conservation treatment decisions:

(1) Her use of white paint on the soft sculptures was short lived owing to issues of stability. In an interview in 1999 by Grady Turner in *Bomb* magazine Kusama stated, "Initially, I used white paint, but began to use silver and gold sprays around 1963 as I found them to be more durable."
(2) The surface of the white accumulation sculptures was meant to be regular, unified, and matte. This was directly communicated in an e-mail exchange with Kusama's current studio assistant Megumi Takasugi (Takasugi 2016).
(3) Visual evidence gathered from other similar soft sculptures from the Museum of Modern Art (MoMA) in New York, the Whitney Museum of American Art in New York, the Hood Museum in Hanover, New Hampshire, the Akron Art Museum in Akron, Ohio, and the Des Moines Art Center in Des Moines, Iowa provided a survey of current condition issues and general understanding of the intended original surfaces. This survey was essential in deconstructing the various layers of restoration piled on our chair. All of the original surfaces were matte and thin as opposed to the current surface of the DMA/Rachofsky chair, which was layered and stiff with a glossy finish.

Archival photographs helped to shed light on not only the original context of the *Accumulations* but also the original structure and tactile qualities of the soft sculptures. In several photographs, Kusama can be seen leaning and sitting on her white *Accumulation* furniture, giving insight into the likely original soft texture of the fabric phallic protrusions.

3. CONDITION AND TREAMENT HISTORY

The DMA/Rachofsky *Accumulation* is a stripped chair, with hundreds of stuffed fabric bundles (protrusions) hand sewn to a base layer of fabric. The network of soft, stuffed fabric bundles, bottom fringe, and legs are painted white with a thick, rigid paint (top layer). The fabric used to create the protrusions differs in texture and thickness, originating from different sources (including color and pattern). It was obvious both visually and when examined with UV radiation that there had been several campaigns of restoration, as evidenced by a variety of patchy layers of different tones and sheens of white-colored paint, each exhibiting a discrete induced fluorescence. In raking light, a rough and fragile underlayer was observed, lying fragmented beneath layers of overpaint and varnish/adhesive. The extensive flaking of this underlying paint layer visible in raking light was likely the reason for the multiple restoration campaigns (figs. 2, 3). All of this inconsistency and variance prompted a more in-depth investigation.

Structural treatment of the individual fabric bundles had to be addressed, as several had been crushed and deformed in the past. Networks of large unstable cracks had formed throughout the paint layers, which had also become embedded with grime and needed to be cleaned and consolidated. Additionally, this piece was quite dusty; the numerous protrusions created difficult areas to dust coupled with a lot of surface area to collect dust (fig. 4).

Provenance records show that *Accumulation* had been through at least five previous owners before it was acquired by the DMA and the Rachofsky Collection in 2008. The only conservation treatment record

Fig. 2. This figure shows the differences in color and uneven applications of different restoration paints along the back of the chair. (Courtesy of Dallas Museum of Art, photograph by Brad Flowers)

Fig. 3. Detail of fractured underlying paint layer overpainted during multiple campaigns of restoration.

that exists for *Accumulation* is from 2006, and describes how Beva 371 was used to consolidate a few localized areas of loose paint.

Examining various white *Accumulations* in other collections, it became clear that the states of preservation varied greatly. MoMA's *Accumulation* No.1, a similar white chair, has the most direct lineage from artist to museum and became the benchmark for the intended original paint surface. The surface paint of the MoMA chair is relatively thin, and many of the protrusions remain relatively soft to the touch. The MoMA chair also has an overall cooler tonality than the overlying paint layer of the DMA/Rachofsky chair. Within crevices and underneath protrusions, there is visual evidence that the DMA/Rachofsky chair had, at one point, a similar appearance to the MoMA *Accumulation* (fig. 5). The MoMA chair also exhibits similar flaking to what is likely underlying the restoration layers on the DMA/Rachofsky chair.

4. ANALYSIS

FTIR analysis was undertaken by Dr. Corina Rogge, Andrew W. Mellon Research Scientist at the Museum of Fine Arts, Houston and the Menil Collection, to better understand the stratigraphy of the paint and restoration layers. There were three distinct layers, identifiable by slight shifts in color and sheen, throughout the chair's surface. The bottom-most more matte and thin (likely original) paint layer was characterized as likely a white oil paint. The secondary paint layer, seemingly applied throughout as an attempt to stabilize the flaky and insecure original layer, had a discolored peachy tone. Analysis suggested that this layer was an alkyd-based paint. Finally, analysis suggests that the upper clear but grayish shiny layer was acrylic based.

Fig. 4. Details of before-treatment condition. From left to right: dust, dents, discoloration, loss, and grime.

5. TREATMENT

In consultation with curatorial colleagues, the goal of treatment became twofold: to stabilize areas of flaking paint and to unify the uneven surface both in gloss and color, bringing the chair closer to Kusama's desired intention. The latter goal was especially important, as the chair would sit alongside other white *Accumulations*. To complicate matters, there was a tight turnaround between the deinstallation from the DMA galleries and the packing/crating date for the outgoing loan, meaning the Conservation Department had only about two months to complete the entire project. This factor had an important influence on the treatment developed and undertaken.

Removing all of the previous restorations was out of the question for the time being. As described, there was a tight treatment period before exhibition, but visual evidence suggested that extensive loss of original paint was present underneath the layers of thick overpaint and likely the reason for them. However, time allowed for a deeper understanding of the DMA/Rachofsky chair and for a preliminary exhibition treatment compromise until the chair could undergo a more extensive treatment upon return. The decision was made to reduce the most discolored and glossy overlying layers, but to retain the bottom-most restoration layer that was serving a consolidating function and was more even than the overlying layers. Treatment started with vacuuming years of accumulated dust. The vast number of

Fig. 5. Deep within the protrusions, where previous restoration attempts did not reach, a cool white paint layer still can be seen.

protrusions created a difficult landscape to dust and a large amount of surface area. The chair also had been touched frequently, as evidenced by surface grime and damaged and indented areas from handling.

Localized cleaning tests were conducted to reduce the embedded grime. An unpacking approach was initially taken to understand each layer individually and better outline the complicated and uneven stratigraphy currently present on the chair. Testing using the Modular Cleaning System concluded that the embedded grime could be reduced with an aqueous preparation of 0.5% w/v citric acid solution in water at a pH of 7.5, adjusted with a 1 M NaOH solution and using boric acid to create a buffer at the desired pH between 7.5 and 8.0 (Stavroudis, Doherty, and Wolbers 2005). Due to the complicated three-dimensional structure of the chair, gelling the cleaning solution was desirable to retain the solution on the surface and avoid dripping into crevices.

Various types of gels were made and trialed, including Xanthan gum, Pemulen TR2, and Agarose[1]. Xanthan gum and Pemulen TR2 provide a liquid gelled solution with a texture similar to honey or hair gel, while agarose produces a stiff, gummy gel. It became clear that we would need to manipulate the gel with a brush to effectively reduce the thick layers of grime and overpaint. Therefore, we focused on testing with the liquid gels.

The citric acid solution found initially promising was then gelled in each xanthan gum and Pemulen TR2. Both successfully cleaned the grime off the surface, reducing years of fingerprints and grime, as seen in figures 6 and 7. The gels were made using the Modular Cleaning System and with information provided in various publications (Stavroudis 2010). As Xanthan gum remains structurally more stable as a gel over a broader range of pH and conductively parameters, it was therefore chosen over the use of

Fig. 6. The embedded grime could be reduced with an aqueous preparation of 0.5% w/v citric acid solution in water at a pH of 7.5, adjusted with a 1-M NaOH solution, and using boric acid to create a buffer at the desired pH between 7.5 and 8.0.

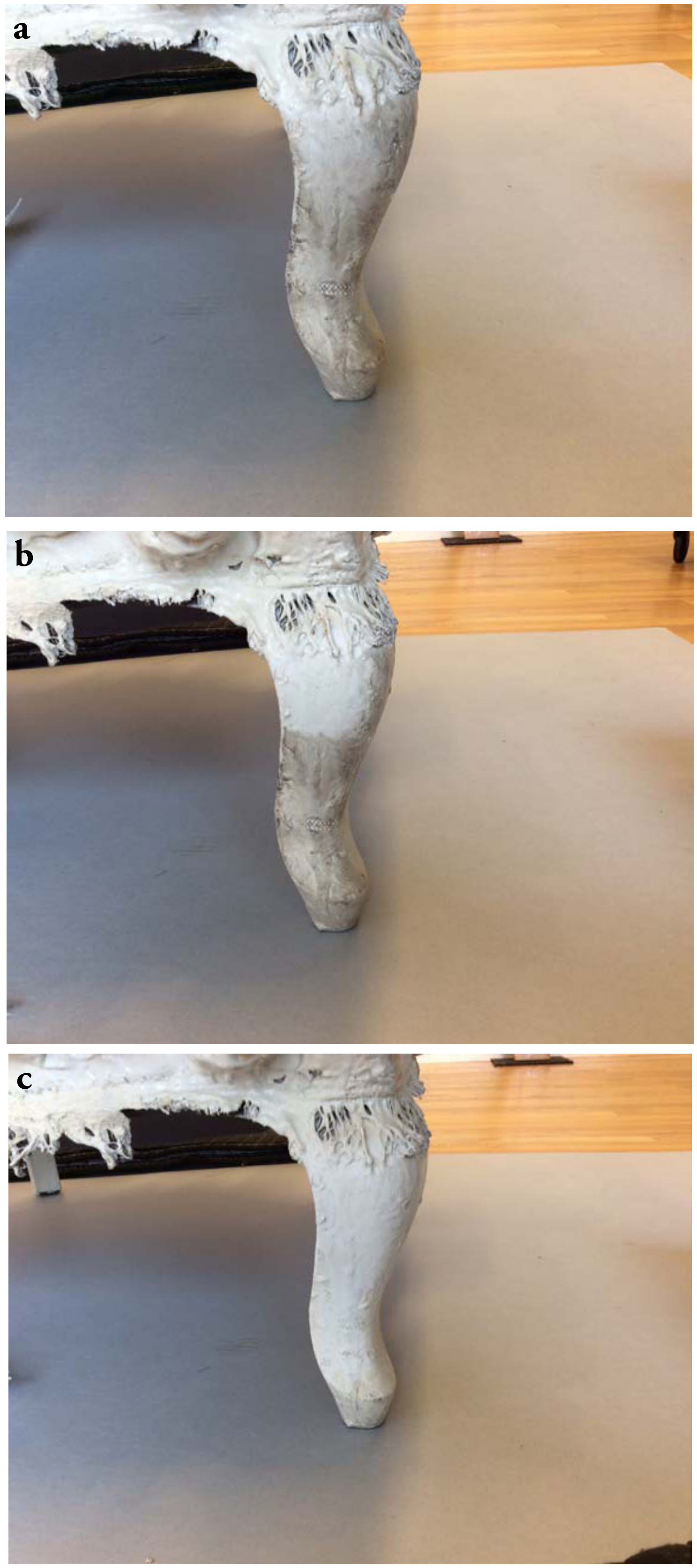

Fig. 7. Embedded grime before, during, and after treatment.

Pemulen TR2, as the surface of the chair varied greatly and the added stability was desired (Passeri, Finne, and Bezur 2017; Wolbers 2017).

However, in order to address the yellowed restoration layer, a solvent emulsion gel was necessary. Owing to the vast surface area, testing was also undertaken to see if a gel could be used to address both the surface grime and the yellowed restoration layer in a single step for areas where both layers were present. To that end, various gels were made using the Modular Cleaning System as a guide and experience from similar projects as a starting point (Wolbers 2000; Stavroudis, Doherty, and Wolbers 2005; Stavroudis 2012). Solvent emulsion gels were then tested using the same aqueous gels initially proven successful to produce an effective gel that would reduce the yellowed coating while retaining the underlying white, first restoration paint. The benzyl alcohol was added into each gel in increments and emulsified by shaking to effectively reduce the yellow restoration layer (figs. 8, 9). The benzyl alcohol proved effective as the solvent component in the gel. Benzyl alcohol was added up to 5% (v/v) into the gel and shaken vigorously to emulsify it within the gel structure. Adding more than 5% benzyl alcohol rendered the gel too strong for the underlying overpaint that needed to be preserved. For the thinnest areas, as low as 2% addition of benzyl alcohol proved effective. Multiple gels were used for each area, including a gel with no solvent for areas with just grime. The gel was first cleared with a dry swab and then with ShellSol D38.

The uneven, gray, shiny coating had to be addressed first where it was present, as it created a shield for the underlying yellowed layer. Fortunately, this layer was very uneven and only present in some areas of the chair. This layer easily swelled in the aqueous gel preparation and was easy to peel once swollen.

After the grime removal and reducing the yellowed overpaint and shiny surface coating, the surface was more unified and even. Areas of insecure paint were consolidated with BEVA 371 throughout. Small but

Fig. 8. Pemulen TR2 solvent emulsion gel reducing the yellow restoration paint layer along top of protrusion

Fig. 9. Various gels were made using the same aqueous solution and emulsifying solvent into the system to produce an effective gel to reduce the yellowed coating while retaining the underlying white, first restoration paint. Varying amounts of benzyl alcohol were added depending on need.

obvious losses were then filled with BEVA "cakes"—a meltable fill material made with varying proportions of BEVA 371, calcium carbonate, pigment, and kaolin.

The broken/cracked fringe along the bottom of the chair was backed with Japanese tissue coated with an equal mixture of Lascaux 360 HV and 498 HV (fig. 10).

Although the cleaning treatment produced a more even surface, there were still some discolored patches that had to be addressed. In order to render a more even, harmonious surface for exhibition, an ultrathin

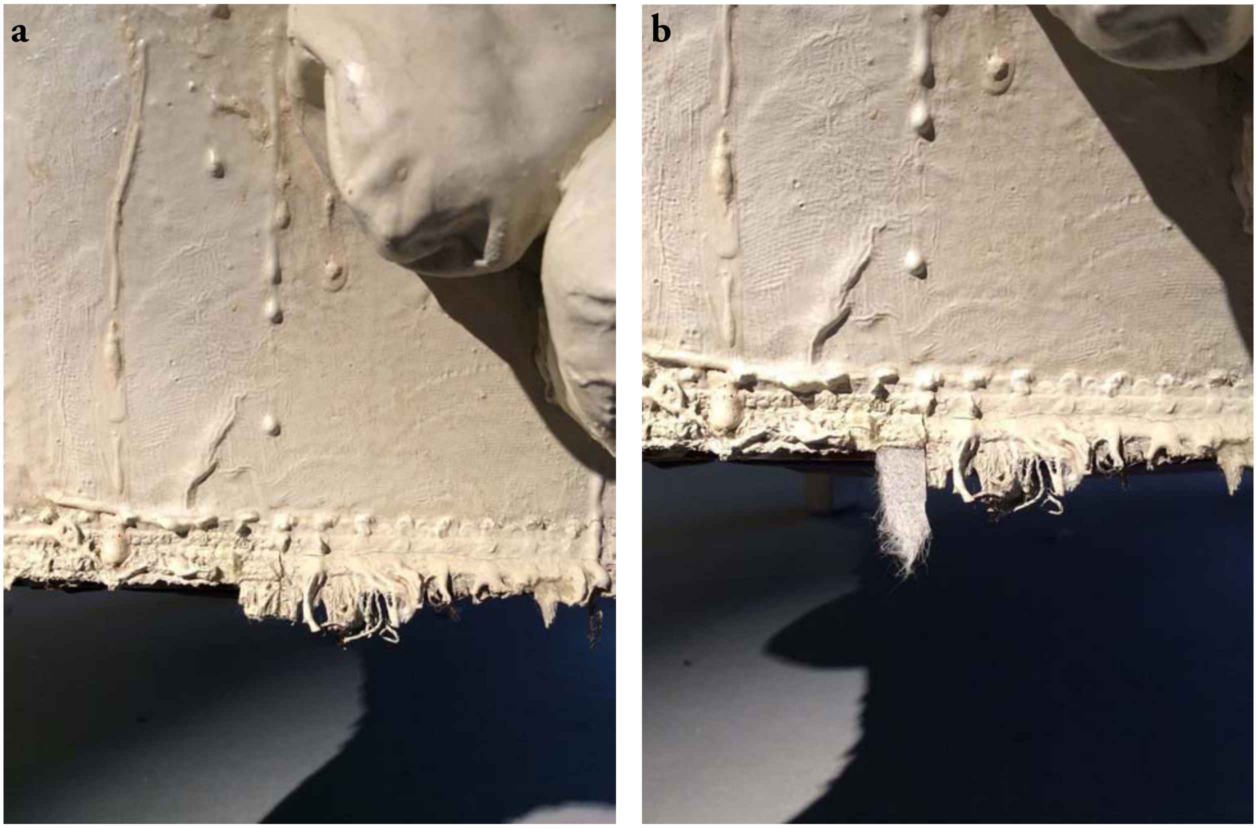

Fig. 10. Left to right: The broken/cracked fringe along the bottom of the chair was backed with layers of Japanese tissue with an adhesive a mix of Lascaux 360 HV and 498 HV.

layer of Gamblin Conservation colors in titanium white was airbrushed over any remaining discolored patchy areas. This restoration material is easily removable from the overpaint layer retained and still allows for a final presentation surface that is closer visually to the intended appearance (fig. 11).

6. CRATING SOLUTION

The chair was traveling to multiple venues coast to coast; thus, a crating system needed to be designed that was sturdy, durable, and easily repeatable. The crating system also needed to dampen any vibrations so as not to shake the already fragile protrusions. Complicating this was the fact that there were limited places to brace. A local fine art shipper developed a rather simple but effective solution utilizing the understructure frame.

As seen in figure 12, the strong, thick, wood framework on the underside proved to be an ideal location to attach three D-ring hangers (hidden from the casual viewer and not to be removed). These D-rings can be flipped up out of view when on exhibition (fig. 13). There is a corresponding D-ring underneath each of those D-rings on the transport tray and a D-ring placed in the center of the tray. Twill tape connecting the D-rings on the chair to those on the tray secures the chair in place and is ratcheted down, preventing the chair from moving at all without contacting the fragile protrusions. Soft Volara lining the transport tray created friction, which also kept the chair from shifting (figs. 14, 15). The crate was a "crate within a crate," with thick 2-in. foam surrounding the inner crate.

Fig. 11. An ultrathin layer of Gamblin Conservation colors in titanium white was airbrushed over any remaining discolored patchy areas.

Fig. 12. Note, on the underside of the chair, the wooden framework along the edge—an ideal location for the D-rings used for the crating/shipping solution. (Courtesy of Dallas Museum of Art, photograph by Brad Flowers)

Fig. 13. One of three D-rings being installed to the wooden framework. The D-ring is used in transit and flipped up for exhibition.

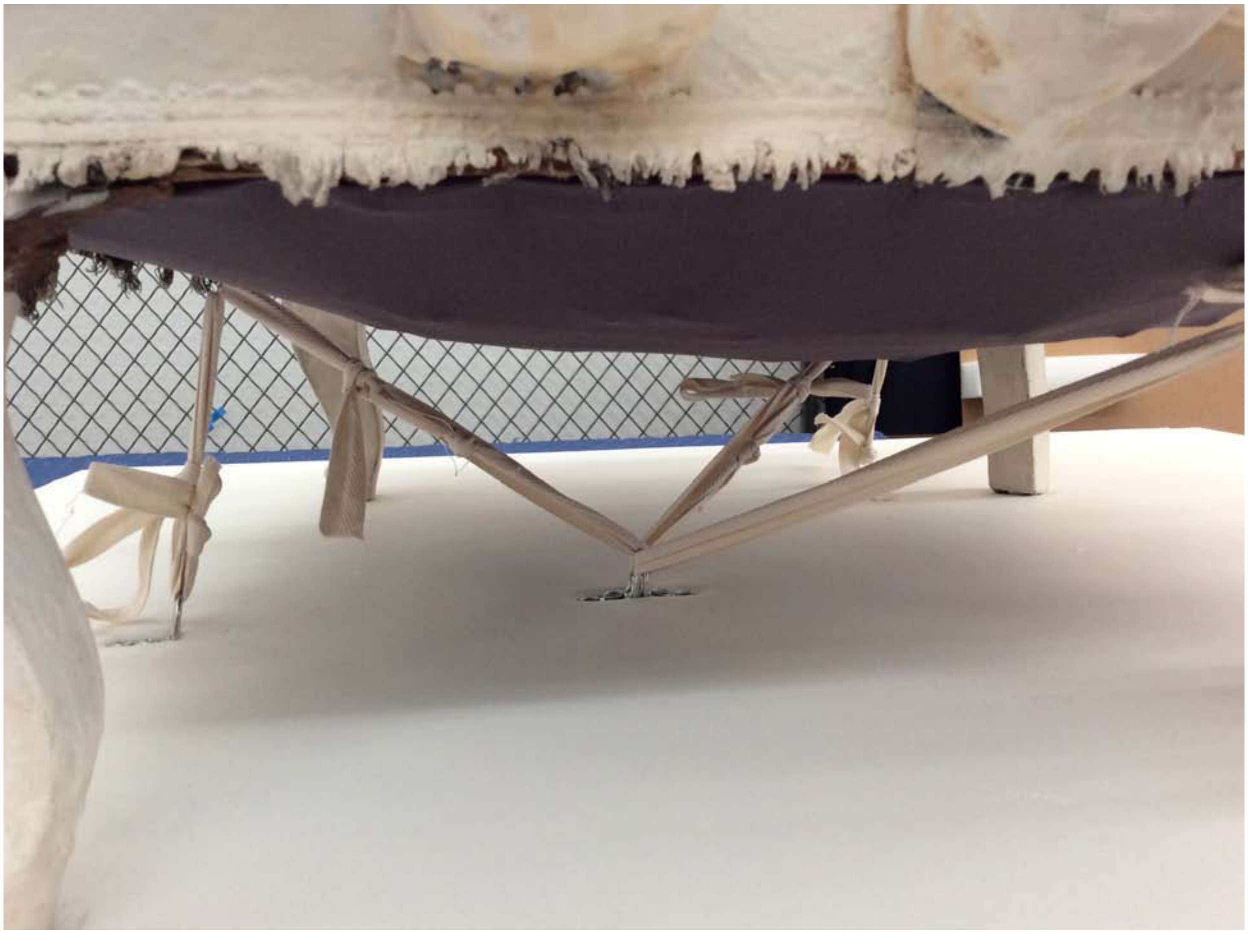

Fig. 14. D-rings on chair and those attached to crating tray are secured together and ratcheted down. Also note the Volara lining underneath the chair, adding to reduction of shifting.

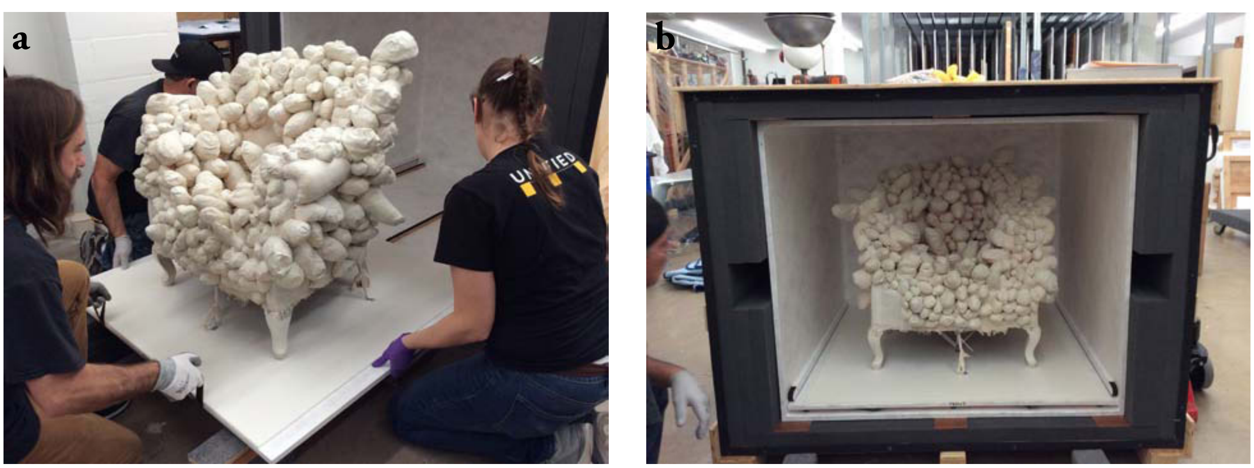

Fig. 15. The "crate within a crate" design, with ample foam surrounding the inner crate. The chair is ratcheted down with twill tape onto the Volara-lined tray that can be inserted/slid into the inner crate.

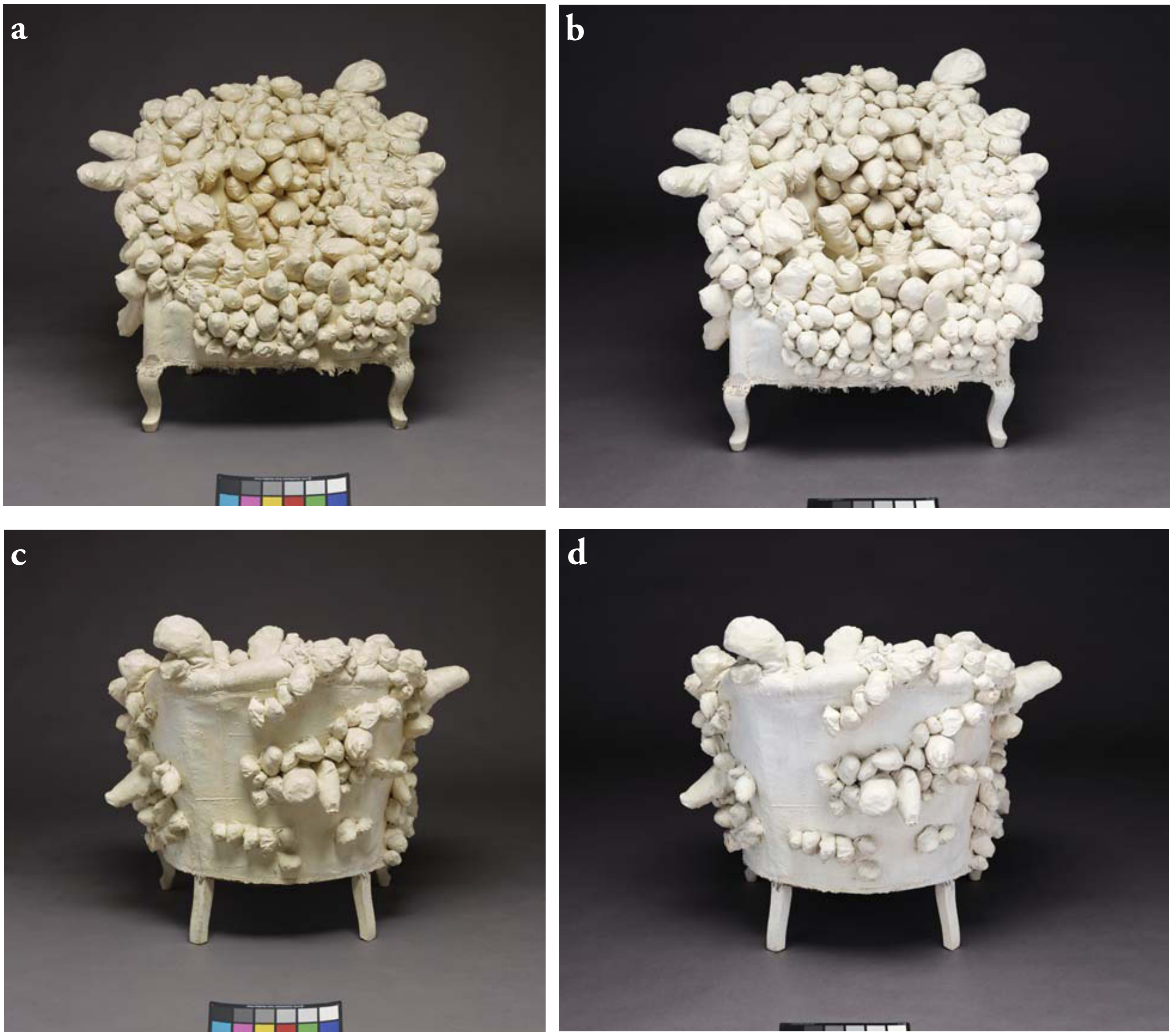

Fig. 16. Yayoi Kusama, *Accumulation*, 1962–1964. From left to right: front before treatment, front after treatment, back before treatment, back after treatment. (Courtesy of Dallas Museum of Art, photograph by Brad Flowers)

To date, this system has been successful: not one flake of paint has been dislodged nor have any particulates loosened after travel.

7. CONCLUSION

This project has allowed for communication between colleagues working on other similar soft sculptures. As work continues on each soft sculpture, future collaborations will lead to a larger body of knowledge concerning Kusama's technique and the *Accumulations*' individual histories. Connecting to a broader conversation about the treatment of this chair created the necessary mindfulness to maintain the object's physical and aesthetic integrity and return the piece as close as possible to what the artist intended (fig. 16).

ACKNOWLEDGMENTS

The following colleagues and institutions are warmly thanked for their help, advice, and contributions to this project: Mark Leonard, Kimberly Crozier-Mitsche, Gavin Delahunty, The Rachofsky Collection, Anthony Meier, Des Moines Art Center, Hood Museum of Art, San Francisco Museum of Modern Art, Museum of Modern Art, Whitney Museum of American Art, Linda Nieuwenhuizen, and Dr. Corina Rogge.

NOTE

1. For a more in depth description and characterization of each type of gel, see Wolbers 2017.

REFERENCES

Kaprow, Allan. 1966. *Assemblage, Environments & Happenings*. New York: H. N. Abrams.

Kusama, Yayoi. 2011. *Infinity Net: The Autobiography of Yayoi Kusama.* Translated by Ralph F. McCarthy. London: Tate Publishing.

Matsui, Midori. 1998. "Yayoi Kusama." *Index Magazine*. Accessed July 4, 2018. http://www.indexmagazine.com/interviews/yayoi_kusama.shtml

Passeri, Irma, Annika Finne, and Anikó Bezur. 2017. "Gel Formulations Coupled with Mechanical Cleaning Techniques to Remove Old Overpaint Coatings on a Large Alterpiece by Piero di Cosimo." In *Gels in the Conservation of Art,* edited by Lora V. Angelova, Bronwyn Ormsby, Joyce H. Townsend, and Richard Wolbers. London: Archetype Publications. 306–315.

Stavroudis, Chris. 2010. "Using Pemulen with the MCP," *WAAC Newsletter* 32 (3): 16.

——. 2012. "Pemulen TR2 – The Once and Future King (of Conservation)," *WAAC Newsletter* 36 (2): 10–11.

Stavroudis, Chris, Tiarna Doherty, and Richard Wolbers. 2005. "A New Approach to Cleaning: Using Mixtures of Concentrated Stock Solutions and a Database to Arrive at an Optimal Aqueous Cleaning System." *WAAC Newsletter* 27 (2): 17–28.

Takasugi, Megumi. 2016-2017. Personal communication.

Turner, Grady T. 1999. Yayoi Kusama. *Bomb Magazine*, January 1. https://bombmagazine.org/articles/yayoi-kusama/

Wolbers, Richard. 2000. *Cleaning Painted Surfaces: Aqueous Methods.* London: Archetype Publications.

——. 2017. "Terminology and Properties of Selected Gels." In *Gels in the Conservation of Art,* edited by Lora V. Angelova, Bronwyn Ormsby, Joyce H. Townsend, and Richard Wolbers. London: Archetype Publications. 381–394.

FURTHER READING

Crook, Jo, and Tom Learner. 2000. *The Impact of Modern Paints*. New York: Watson-Guptill Publications.

Jørgensen, Lærke Rydal, Marie Laurberg, and Michael Juul Holm, eds. 2016. *Yayoi Kusama: In Infinity*. Louisana Museum of Modern Art and the contributors. Denmark: Rosendahls.

SOURCES OF MATERIALS

BEVA 371
Conservator's Products Company
5 Corey Rd.
Flanders, NJ 07836

Gamblin Conservation Colors
2734 SE Raymond St.
Portland, OR 97202

Lascaux Acrylic Adhesives, Volara Foam
Talas
330 Morgan Ave.
Brooklyn, NY 11211

Pemulen TR2
The Lubrizol Corporation
29400 Lakeland Blvd.
Wickliffe, OH 44092

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NEW TECHNOLOGIES APPLIED TO RESTORE A NINETEENTH-CENTURY WAX MEDARDO ROSSO SCULPTURE

LLUÏSA SÀRRIES ZGONC

Using a number of cutting-edge technologies, I restored *Bambino ebreo*, a damaged 19th century wax sculpture by Italian modernist Medardo Rosso (1858–1928) and structurally reinforced it to prevent future damage. The sculpture was dubbed the "McArthur" cast for this project.

Scientists took detailed three-dimensional scans of ten casts of this same subject from various collections in order to learn more about how each serial sculpture varies from its peers. On my initial consideration of the restoration, I realized we could use these scans to determine the likely original character of the McArthur cast. I considered the question of whether to interfere with the sculpture at all given the fragility of the wax and extent of the loss; it became clear that using this 3D technology was the best way to reconstruct the sculpture's missing parts as faithfully as possible to the original, with minimal intervention.

KEYWORDS: Wax sculpture, Serial sculpture, Medardo Rosso, 3D scanning, Wax composition testing, Casting, Reintegration, Surface retouching

1. INTRODUCTION

The artist Medardo Rosso gave one of his *Bambino ebreo* casts to Erna Brünauer (1884–1971) sometime between 1895 and 1905. Mrs. Brünauer had met Rosso while he was travelling in her native city of Vienna. Mrs. Brünauer married the architect Albert Chase McArthur around 1910 and the couple immigrated to the United States, first living in Chicago. This photograph of the *Bambino* was taken around 1912 in their Chicago home (fig. 1). Between 1924 and 1925, the family moved to Phoenix and later to Hollywood, bringing the Rosso *Bambino* with them. After his mother's death, their son Manfred McArthur inherited the work. Therefore, this version of the sculpture is referred to as the "McArthur" cast.

The Rosso sculpture came to my attention in the context of a 2014 New York exhibition, *Medardo Rosso*: *Bambino ebreo* at Peter Freeman, Inc. The show included 11 casts all titled *Bambino ebreo*: one original plaster, two bronzes, and eight wax castings (fig. 2). Prior to the opening of the exhibition, curated by art historian Sharon Hecker, a team of scholars was organized to meet and examine the casts side by side at the gallery. In order to compare and contrast the different characteristics of each sculpture invisible to the naked eye, we worked with Ronald Street, Manager of the 3D Imaging and Modeling Department at The Metropolitan Museum of Art, who scanned each head for us.

2. BACKGROUND

The McArthur *Bambino ebreo* is a wax cast made from a plaster mold in two pieces with a fused seam. In some areas, portions of the seam are visible to the naked eye. The thickness of the wax is variable across the different parts of the head; for example, in the back there are sections that are less than 1 mm in thickness and others that are almost 1 cm thick. Only a few of the heads have their original wood pedestal—the McArthur *Bambino ebreo* is one of them. We can also see the same style of pedestal in historical photographs of a different *Bambino ebreo* formerly owned by Rosso's friend and supporter, Etha Fles, a Dutch collector.

Fig. 1. Medardo Rosso (Italian, 1858–1928), *Bambino ebreo*, wax over plaster, 22.9 × 15.2 × 20.3 cm. The McArthur cast, seen here in its 2014 damaged condition and in the background in a photograph taken between 1905 and 1912 in the McArthur family home in Chicago. (Courtesy of the author and the McArthur family)

The McArthur *Bambino ebreo* was in very bad condition when it arrived at the gallery. Nevertheless, it was interesting to have it in the exhibition, because the public was able to see part of the plaster infrastructure of the piece revealed underneath the areas where the wax was damaged (figs. 3, 4).

After studying the work, it was clear that it had suffered under heat. I saw that the contour of the head was not as sharp as in other *Bambino ebreo*s, and dirt was embedded in the wax. When I asked where the sculpture had been displayed in the home of Mr. McArthur, I was told that it had been on a shelf behind a sun-exposed window for several years. There was also hair embedded into the surface, probably from the family's cat, which I chose not to analyze; thus, it was not removed.

Fig. 2. Nine casts of Medardo Rosso's *Bambino ebreo*, gathered before an exhibition at Peter Freeman, Inc., New York in 2014. The damaged cast is the first one on the right.


Fig. 3. Visible damage to the back
Fig. 4. Front of the McArthur cast (Courtesy of Nick Knight)

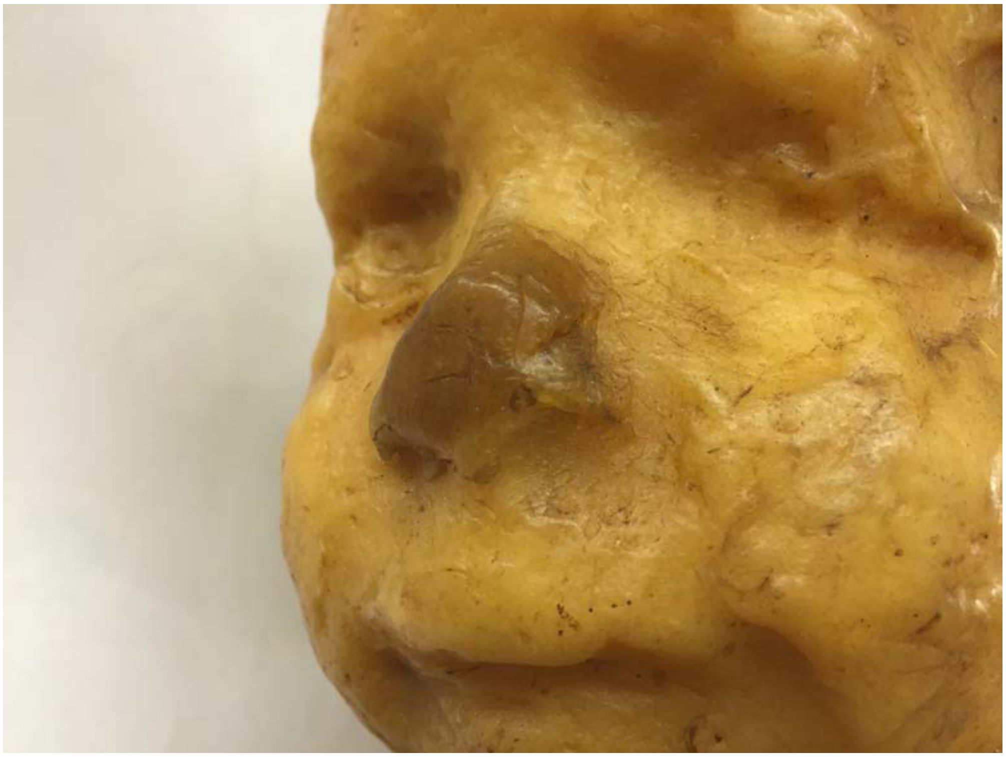

Fig. 5. A detail of the damaged earlier restoration of the McArthur cast

The most disturbing damage was an earlier restoration. The wax used to conserve the nose had probably changed color over time, becoming dark and brown so that the face looked like that of a clown (fig. 5).

In addition, the angle of the head was wrong. The metal axis or rod on which the head was mounted was bent forward (figs. 6, 7). The head had most likely fallen at some point, crushing the nose and upper lip.

The back of the head had several missing areas of wax. The bottom front left (as viewed) part of the head had a loss. Several areas were also deformed and detached from the plaster: the left part of the neck and the right edge on the backside of the head. My question was: “How will I approach this restoration?”

3. RESTORATION

The first step was to analyze the wax to gain a better understanding of the material. We learned that it was mostly a mix of beeswax and paraffin. The testing was carried out at the Università Ca’ Foscari Venezia Dipartimento Scienze Ambientali, Informatiche e Statistiche (the Department of Environmental Science, Information Technology and Statistics at the University of Venice).

The damaged parts were so big and important to the interpretation of the work that I decided that the only way to approach this restoration was to make molds of the parts of the head that were damaged, using the undamaged casts of the work.

Part of the aim of organizing the 2014 exhibition was to be able to compare these serial casts, which are, though of the same original subject, each unique due to the artist’s idiosyncratic casting methods and

Fig. 6. The original pedestal, showing the tilted metal axis
Fig. 7. The cast on the original pedestal

choice of materials. Three-dimensional scans were done to enable comparisons that are much more precise than those made with the naked eye.[1] Although all of the *Bambino ebreo*s are unique, some are more similar than others. Ronald Street, senior manager of The Metropolitan Museum of Art's 3D Imaging and Modeling Department, and I compared all of the 3D scans to find the one most similar to the damaged McArthur *Bambino ebreo* (figs. 8, 9).

I also compared all the photographs I had of all of the heads exhibited at Peter Freeman, Inc. I understood from observation that Rosso used at least two different molds to make the casts. Occasionally, he used the back of one mold and the front of another in the same cast. After deciding which cast was the most similar, we commissioned a specialist company to make a 3D print of that head in resin (fig. 10).

From this resin print we made a silicone mold; using that mold, we made a plaster cast. From the resultant plaster cast we took molds of the damaged parts: the nose, neck, and back of the head (fig. 11).

The first real work on the sculpture was to consolidate the wax on the back of the head. In some areas, this wax was very thin and flaking. The consolidation was done with a dilute (approximately 5% w/v) solution of Klucel G dissolved in water.

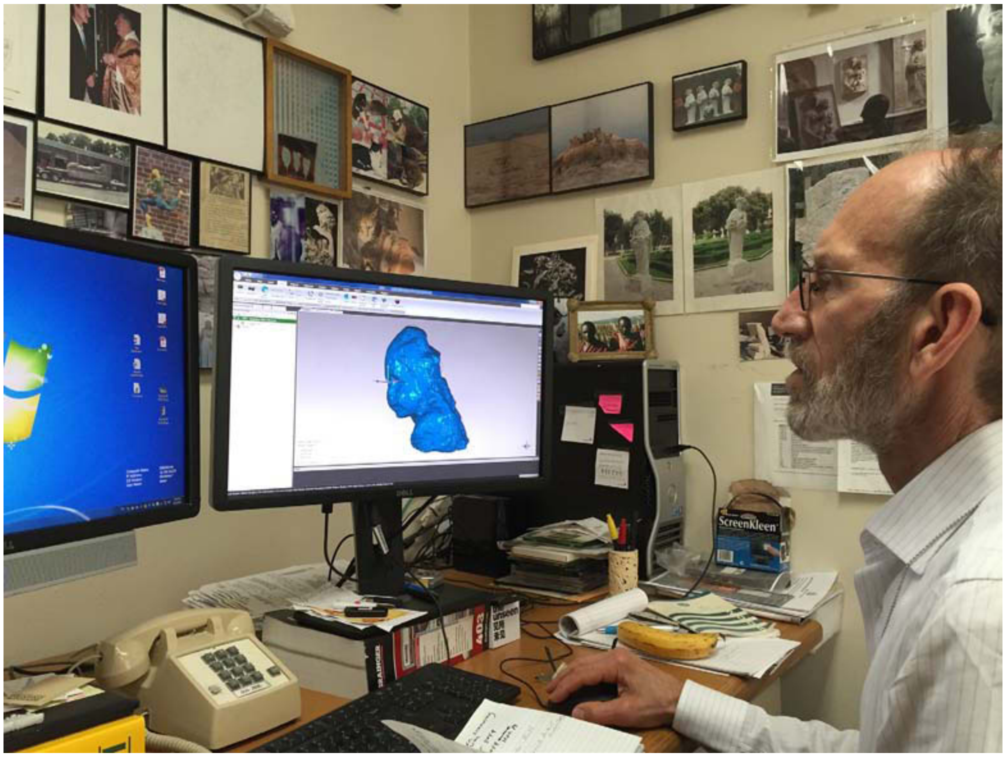

Fig. 8. Ron Street, senior manager of The Metropolitan Museum of Art's 3D Imaging and Modeling department, at work analyzing scans of multiple casts of *Bambino ebreo*

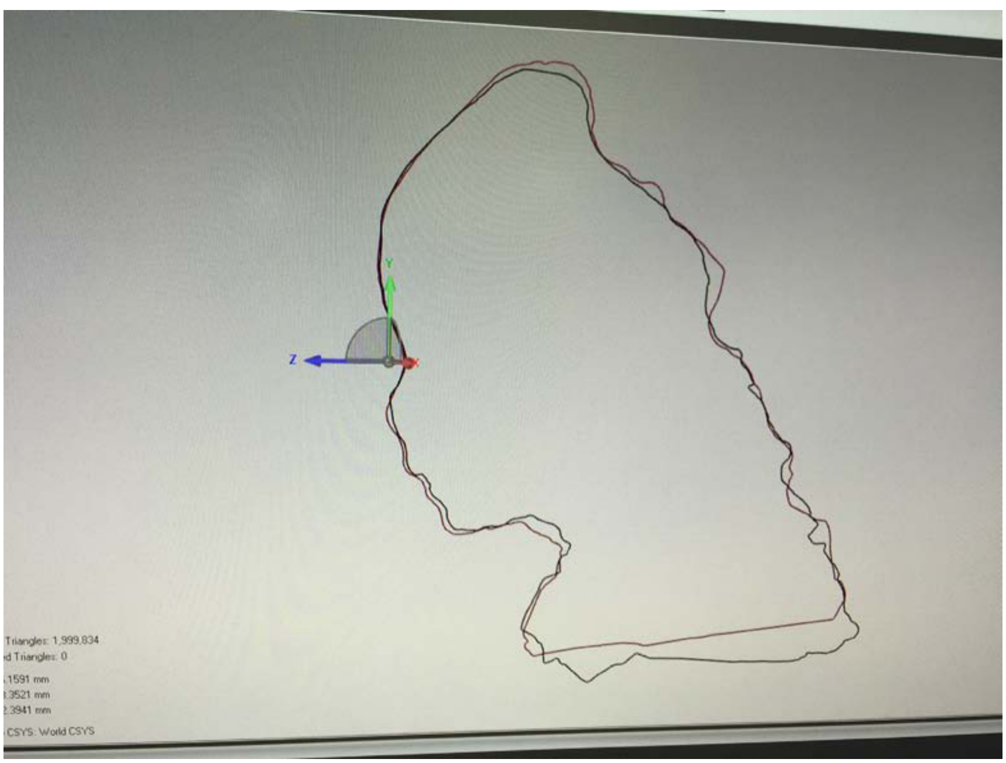

Fig. 9. Superimposition of slices of scans of two heads

Fig. 10. A 3D print in resin (Courtesy of Nick Knight)

Fig. 11. The three steps to get to the individual molds for each damaged area: (left to right) silicone mold to make plaster cast, plaster cast with areas of damage traced for mold making, final molds to cast wax fills. (Courtesy of Nick Knight)

Fig. 12. Before the repositioning and cleaning of the metal axis, and the cleaning of the pedestal
Fig. 13. After the repositioning and cleaning of the metal axis, and the cleaning of the pedestal

The next step was to correct the angle of the metal rod or axis (fig. 12). I did this by referencing the ca. 1912 Chicago picture of the damaged head, when it was presumably in its original condition. The metal was very rusted; thus, I also treated it with rust converter (fig. 13). After I repositioned the head on the pedestal, I started to consolidate the plaster and cleaned the inside of the wax.

The cleaning of the plaster was done with a small vacuum cleaner and brushes. The consolidation of the plaster was also done using dilute Klucel G dissolved in water (as described previously), inserted with a syringe. The cleaning of the wax on the interior was done with saliva and cotton swabs.

Different levels of dirt were on the surface of the wax. I was able to remove a thin layer of dirt with a small brush and saliva on cotton swabs. It was impossible to remove or reduce more of the dirt on the dark areas, because the dirt was embedded in the wax. This was due to the sun's heat to which the sculpture had been exposed at the McArthur residence. I removed the wax that had been added to the sculpture in earlier restorations, as identified through examination under UV light. These areas were on the back, a small area on the top of the left (as viewed) ear and the brown nose. In order not to remove any original wax, I observed the areas under longwave UV radiation. The added wax fluoresced differently than the original wax (fig. 14).

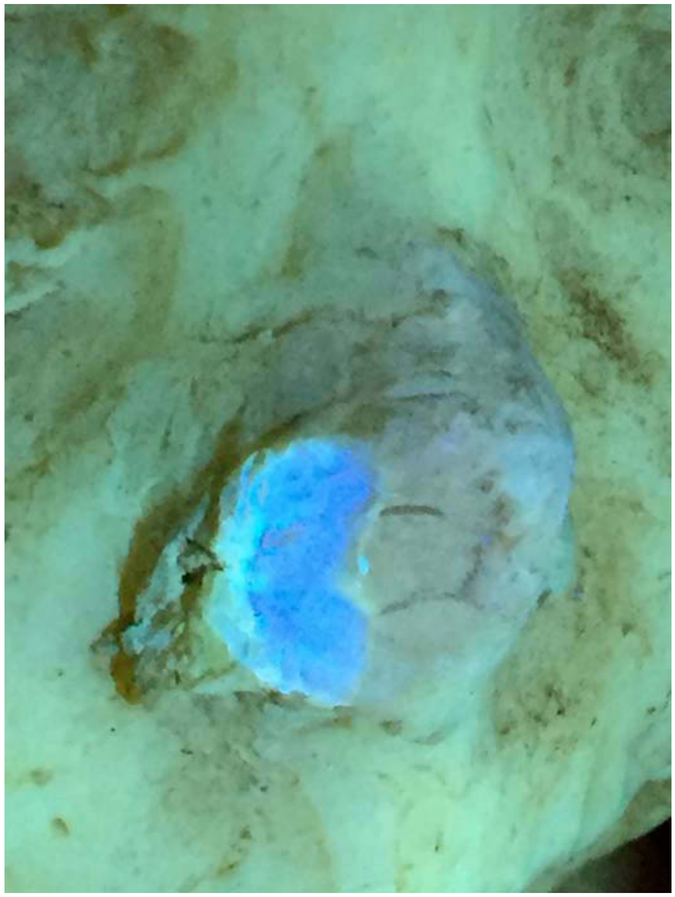

Fig. 14. UV examination of the sculpture’s nose area reveals the wax that was applied during an earlier restoration

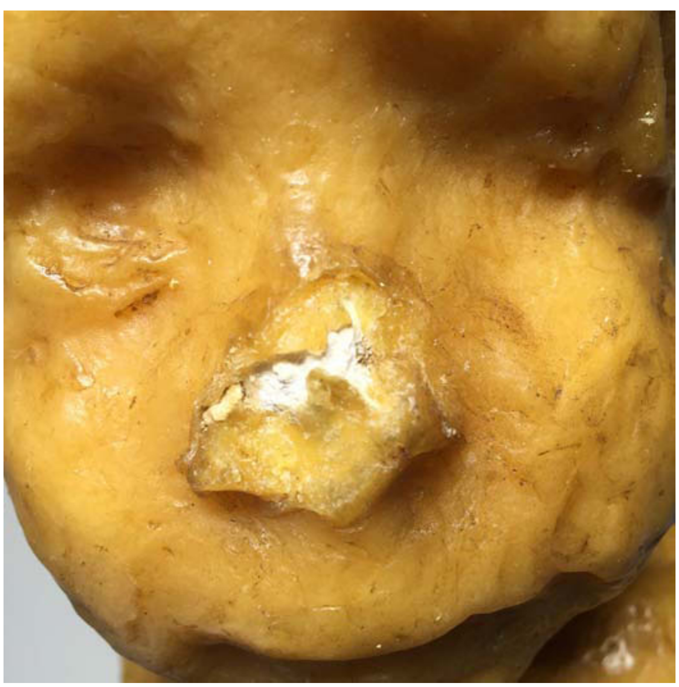

Fig. 15. The nose area after the wax of the earlier restoration had been removed

Fig. 16. Reforming the neck area using an original mold

The next step was to restore the deformed part of the neck to the original position. This was achieved by slightly warming the defined area and pushing it back with the help of the customized mold (fig. 16). By using this neck mold, the detached right edge of the back of the head was also slightly pushed into its original position. The damaged upper lip was also repositioned by using gentle heat and a mold of that area.

It was necessary to fill the gap in the back area where the plaster was lost to avoid future damages. To achieve the needed volume, I filled this area with soft pillows made of Klucel G and Arbocel dissolved in water (fig. 17).

To make the wax for the missing areas I mixed Cosmoloid microcrystalline wax and a caramel-colored sticky wax, typically used in orthodontistry, in a 1:1 ratio. Mixing these two products resulted in wax of a similar color to that of the original. Interestingly, warming the mixture longer resulted in different shades without having to add any pigment to the wax mixture to get the right colors. This mixture was used to reintegrate all of the missing areas. To reintegrate the back, I cast small areas from the silicone molds and then applied them step by step with a hot needle and hot mini-spatula (fig. 18). The decision to close this area in steps rather than using one cast for the whole area had to do with the area's large size. A large cast would have been more visible and difficult to integrate.

The nose was also reintegrated with small quantities of different shades of this same wax mixture, added little by little with a hot spatula (fig. 19). As I was shaping it, I frequently referenced the original plaster head. In some areas I did not replace missing wax. In the original condition of some sculptures, Rosso intentionally left areas waxless.

The nose did not need any inpainting to visually integrate it to the surrounding area. The back and bottom front was retouched with Gamblin Conservation Colors (fig. 20).

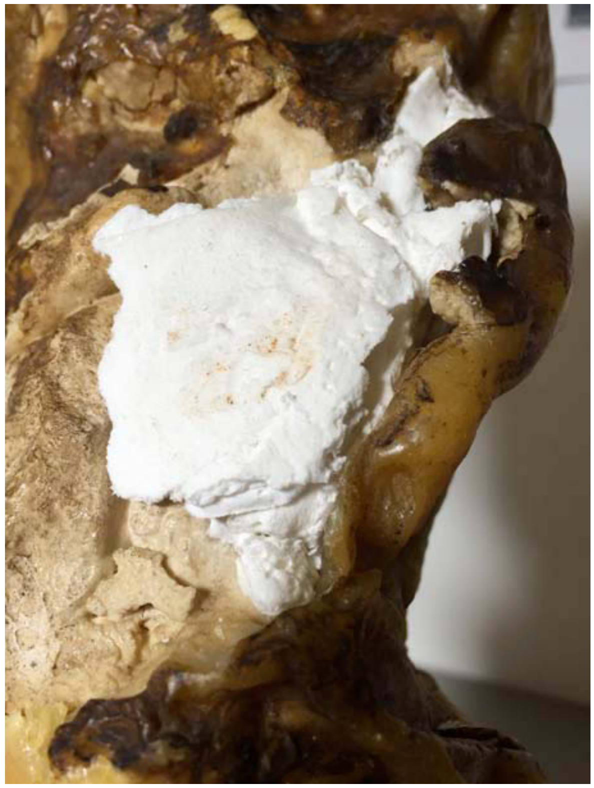

Fig. 17. Applying pillows of Klucel G and Arbocel dissolved in water to fill in the areas of lost plaster

Fig. 18. Wax reintegration, midway through retouching

Fig. 19. Front view of the restored sculpture

Fig. 20. Back view of the restored sculpture

I was hesitant to do this restoration. I consulted several colleagues, who said not to touch it. It was only thanks to the 3D scans that I felt I could approach the McArthur *Bambino ebreo* conservation. It involved researching methods and materials used by other Medardo Rosso wax conservators (see Further Reading).

ACKNOWLEDGMENTS

I need to thank Shirin Afra and Maria Grazia Cordua, two wonderful conservators from Opificio delle Pietre Dure, Florence who have been enormously generous with their experience and knowledge. Their help and motivation made this conservation treatment possible. I also want to thank Ron Street, who passed away last December. He was an important part of this treatment, and without him it would not have been possible. We miss him. I especially want to thank Peter Freeman for his trust and support through the whole process.

NOTE

1. The scanner used was a Breuckman smartScan. Scans were closed surface mesh, also known as a surface model.

FURTHER READING

Afra, Shirin, Laura Speranza, and Filippo Tattini. 2013. "Il Grande Scheletro di Clemente Susini. Restauro e montaggio di una scultura monumentale in cera del Museo della Specola di Firenze." *OPD Restauro* 25: 297–303.

Andreoni, A., F. Kumar, and L. Speranza. 2007. "I rilievi in cera di Giambologna raffiguranti gli atti di Francesci I dè Medici: restauro e studio della tecnica esecutiva, confronto con le matrici bronzee ed i rilievi in lamina d'orata." *OPD Restauro* 19.

Cooper, Harry, and Sharon Hecker. 2003. *Medardo Rosso: Second Impressions*. New Haven and Cambridge: Yale University Press and Harvard University Art Museums.

Cordua, M. G., F. Kumar, and L. Speranza. 2014. "Il restauro del *Book Maker* di Medardo Rosso." *OPD Restauro* 2.

Cordua, Maria Grazia, Giancarlo Lanterna, Lisa Lombardi, Rosanna Moradei, Mario Scalini, and Laura Speranza. 2009. "Mirabili orrori. Cere inedite di Gaetano Zumbo dopo il restauro." *OPD Restauro* 21: 71–87.

Gabbriellini, Chiara, Gabriella Nesi, Francesca Rossi, Raffaella Santi, and Laura Speranza. 2009. "La collezione di cere del Museo di Anatomia Patologica di Firenze. Note sulle vicende storiche, sulla tecnica esecutiva e sui restauri." *OPD Restauro* 21: 51–70.

Hecker, Sharon. 2008. *Medardo Rosso*. New York: Peter Freeman, Inc.

Mola, Paola, and Fabio Vittucci. 2009. *Medardo Rosso: Catalogo ragionato della scultura*. Milan: Skira editore.

SOURCES OF MATERIALS

Cosmoloid H 80 micro-crystalline wax; Klucel G
Kremer Pigmente GmbH & Co. KG
Barerstr. 46
80799 Munich
Germany
0049 89 285 488
www.kremer-pigmente.com

Gamblin Conservation Colors
Gamblin Artist's Colors
2734 SE Raymond St.
Portland, OR 97202
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RON STREET (who passed away in December 2016) was manager of 3D imaging and modeling in the Imaging Department of The Metropolitan Museum of Art. He had an extraordinary career at the museum for over 30 years that also included long-term supervision of the modeling studio, and he was called upon for advice and collaborations by institutions around the world. He was a trained sculptor, studio glass artist, and ceramicist who taught glass-blowing in Australia, Canada, and the United States; studied traditional crafts in Iran; and worked at archaeological sites in Egypt, Tanzania, and Guatemala.

THE CASE OF THE HYDRATING HYDRA: EXAMINATION AND TREATMENT OF A BLASCHKA GLASS INVERTEBRATE MODEL

N. ASTRID R. VAN GIFFEN

Leopold and Rudolf Blaschka were a father and son team of master glassworkers active in and around Dresden in the 19th and early 20th centuries. They made realistic and accurate models of hundreds of invertebrate species that they sold to schools and museums all over the world. In preparation for an exhibition about the Blaschkas at The Corning Museum of Glass, the museum's conservation team carefully examined, cleaned, and, in some cases, reconstructed about 75 of these delicate and unique models.

Although the models are primarily made of glass, other materials—such as metal wires, shells, paper, glues, resins, and paints were also used. Time and fluctuating environments have caused the structurally fragile models to suffer from deterioration of many of the components, including the glass. The extremely thin glass and the sensitive surfaces of the models necessitated the development of innovative new treatments for minimally invasive cleaning, stabilization, and reconstruction.

The microscopic and UV examination of one model provided interesting information about the deterioration and fabrication of Blaschka models. Treatment of this model included surface consolidation, dry brush and solvent cleaning, reassembly, and loss compensation with cast Paraloid B-72 film.

KEYWORDS: Blaschka, Glass, Model, Casting Paraloid B-72

1. INTRODUCTION

In the last half of the 19th century, a father and son team of master glassworkers, Leopold and Rudolf Blaschka, ran a successful business creating and selling realistic and accurate glass teaching models of invertebrate animals. The unique and delicate models were shipped all over the world from their studio in Dresden, Germany to universities, schools, and museums, including to Cornell University in Ithaca, New York. In 1885, Cornell purchased 570 models through Ward's Natural Science Establishment in Rochester, New York, the Blaschkas' sole agent in North America.

A selection of just over 70 of these incredible models from the Cornell collection was recently on display in the special exhibition *Fragile Legacy: The Marine Invertebrate Glass Models of Leopold and Rudolf Blaschka* at The Corning Museum of Glass. All of these models came through the museum's conservation laboratory for careful examination, cleaning, and treatment when necessary. About 30 to 40 needed only cleaning, some needed minor repairs, and a few needed extensive treatment. This article will focus on the examination and treatment of one of the more damaged models. It was the only model that needed a fill, which was done with cast Paraloid B-72.

Casting Paraloid B-72 into clear, bubble-free sheets for filling losses in glass was developed at The Corning Museum of Glass conservation laboratory. Since first presenting the method at a CCI symposium in 2011, new tricks and tips to improve the technique have been realized that will be explained in this article.

2. THE BLASCHKAS AND THEIR MODELS

Leopold and his son Rudolf came from a long line of glass workers. Leopold started his career in the family business making costume jewelry out of metal and glass. He later started his own business and began making glass teaching models of invertebrates in 1863. Rudolf joined the business in 1876. The Blaschkas sold their teaching models through printed catalogs and agents to museums, schools, and universities all over the world. As their expertise grew, they added new models to their catalogs. By 1888, the Blaschkas offered 700 models that, according to Leopold, were "universally acknowledged as being perfectly true to nature."

The reason they were so successful was, in part, because they were offering something no one else could provide at that time. Unlike other animals, invertebrates cannot be satisfactorily preserved. They are not candidates for taxidermy and preserved specimens lose their shape and color to the point of becoming unrecognizable. The accurate and precise replicas made by the Blaschkas were a wonderful alternative, and glass was an ideal material with which to convey the transparency, translucency, and vivid colors of these soft-bodied animals.

Although the models are usually described as glass, they include a lot of other materials as well. The models are assembled largely with animal glues, and most of the glass is coated with plant gums, waxes, or paints. Metals, mostly copper alloys, were used as armatures and attachment points for the glass. Paper was used in a variety of ways, including to strengthen extremely thin glass and as a cover for bases made up of shells. In areas such as the webbing between the arms of squids and octopuses, paper or a proteinacious material was used.

2.1 Blaschka Collections Around the World

The Blaschkas' production was prolific, especially when you consider that there were only two of them producing the glass specimens. Based on the sizes of known collections, an estimated 10,000 to 15,000 invertebrate models would have been manufactured by the Blaschkas from 1863 to 1890. That means that they probably made, on average, more than one invertebrate model every day for 27 years.

Research by the curatorial department based on documenting museums, schools, and individuals that purchased the Blaschkas' models in the 19th century, and the dispersal of those models in current collections around the world led to the creation of a digital interactive map, which is available on the museum's website at https://dm.cmog.org/blaschka/blaschka_web.html. The map provides geographic references for original and current locations of Blaschka models with the name of the institution or individual owner, location, an accompanying image, a short description of the history of the collection, and its current status. To date, the map documents 179 discrete collections, 68 of which survive in the holdings of museums, schools, and individuals. A more detailed account of the research was published in the 2017 volume of the *Journal of Glass Studies* (Larson and Ruggiero 2017).

As the only digital collated list of every known Blaschka invertebrate collection, the interactive map will be regularly updated, providing open and mobile access to those interested around the world. The Corning Museum of Glass continues to research the extraordinary work of Leopold and Rudolf Blaschka. We expect that the map will continue to grow and encourage anyone who has information about additional Blaschka collections or questions regarding the identification or the care and conservation of Blaschka models to contact us.

2.2 Production of the Models

The Blaschkas were fairly secretive about their working methods. Close examination and analysis of the models and materials from their studio and archives has been crucial in determining the production process.

Fig. 1. A small selection of glass models made by Leopold and Rudolf Blaschka (Courtesy of The Corning Museum of Glass)

Drawings and sketches, such as the one in figure 2, were made for most of their invertebrate models. They were based on several sources, including illustrations in scientific publications, preserved specimens, and, later, live specimens kept in an aquarium. Both Leopold and Rudolf also went on expeditions to observe the creatures in their natural environments.

The Blaschkas were lampworkers. All the glass elements used in the invertebrate models were made from purchased glass rods and tubes shaped in the flame of an oil or paraffin lamp using the typical glassmaker tools and techniques of the time. The models are usually made of a number of different glass elements that are glued together. The Blaschkas prefabricated many of these glass parts and only assembled the models once they received an order. Some of these prefabricated parts survive and are now in The Corning Museum of Glass collection. These materials from the Blaschkas' studio include 42 matchboxes containing smaller glass parts, such as the tentacles of anemones or the polyps found on hydra models, and about 80 larger glass parts, such as jellyfish domes, hydra stalks, and anemone bodies (fig. 3).

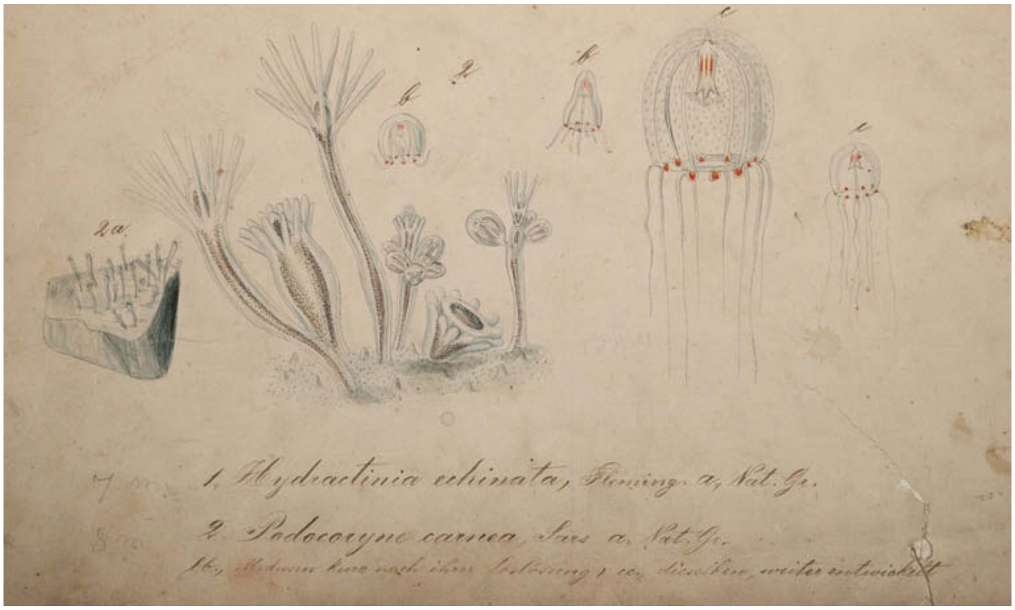

Fig. 2. Drawing of *Podocoryne carnea*. Detail from Leopold and Rudolf Blaschka, *Hydractinia echinata/Podocoryne carnea*, 1863–1890, ink, watercolor on paper; 32 × 41 cm. The Corning Museum of Glass, Rakow Research Library, CMGL 122416. (Courtesy of The Corning Museum of Glass)

Fig. 3. A selection of materials from the Blaschkas' studio in the collection of The Corning Museum of Glass (Courtesy of The Corning Museum of Glass)

The ability to simultaneously examine the prefabricated materials and assembled models led to the identification of some glass elements as well as a greater understanding of how models were made.

A variety of materials were used to finish the models and make them as realistic as possible, including pigmented waxes, paints, enamels, paper, and natural materials. The assembled models were then attached to a base. Many of the earliest models were attached to painted plaster bases. Others were mounted on a flat piece of composite material, painted wood, or a stiff paper card. The models were either glued onto their base or attached with thin metal wires in a few places. Each model also has a label with its catalog number, the name of the species represented, and a reference to the publication on which the model is based. Just like the glass parts of the models, the Blaschkas made their labels ahead of time. Stacks of labels were found in their archives carefully sorted by model number and stored in handmade envelopes. The bases provide identifying information, in some cases with handwritten notes, but they were also the main reason that these fragile objects were able to be shipped across the world without breaking.

Clearly, the bases are an important part of the original objects, but they were not always treated that way, especially the paper card bases. Many of the cards are in very poor condition with tears, warping, losses, and staining, sometimes to the point of being unsuitable for display. Some cards appear to have been cut down in the past and many models have been removed from their bases, leaving them more vulnerable during handling and transport. In some cases, the bases, and therefore the model's identifying information, has been lost.

2.3 Types of Common Damage

Since the models were all made in a similar way, the damage that they exhibit is also similar. In addition to the expected glass breakages and adhesive failures, there are a few common types of damage related to the construction of the models that were found on many of the models treated for the exhibition. Other common types of damage to Blaschka models that were not seen on the models for this exhibition have been previously published (van Giffen et al. 2010).

Many Blaschka models have metal wires, usually copper, thinly coated with glass, like the tentacles of jellyfish. In many of these types of construction, bluish-green copper corrosion was present where the surrounding glass is cracked or broken (fig. 4). In some cases, the metal corrosion caused the wires to break. The metal corrosion might be exacerbated by the slightly unstable glass.

Many of the octopuses and squids have cracks in the glass or lifting surfaces where the arms attach to the head. These types of damage likely occurred because the materials used to attach the arms and create the webbing between them reacts differently to changes in relative humidity and temperature than to the underlying glass.

Finally, flaking paint and overcleaning of the painted or coated surfaces is a common occurrence (fig. 5). Many of the materials used by the Blaschkas are water soluble and therefore easily removed. Many models are not painted with colors but have only a coating to make the glass matte. Unfortunately, dirt has often migrated into these coatings, making it impossible to remove without disrupting the original material. It is easy to imagine how not knowing about the surface coatings can lead to overcleaning. Sadly, this has already happened in many Blaschka collections.

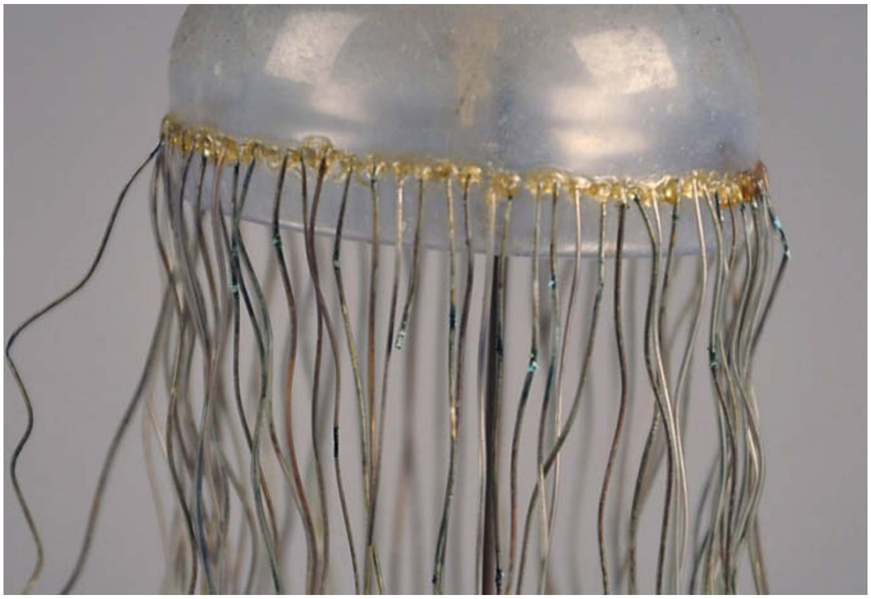

Fig. 4. Detail of a jellyfish model showing tentacles made of copper wire coated in glass, with corrosion where the glass is cracked or broken. Leopold and Rudolf Blaschka, Nr. 157 *Lafoea calcarata*, about 1885, glass, metals, wood, paints, and resins, 17.5 × 7.8 cm. Collection of Cornell University, Department of Ecology and Evolutionary Biology; Managed Loan, The Corning Museum of Glass, L.17.3.63-475. (Courtesy of The Corning Museum of Glass)

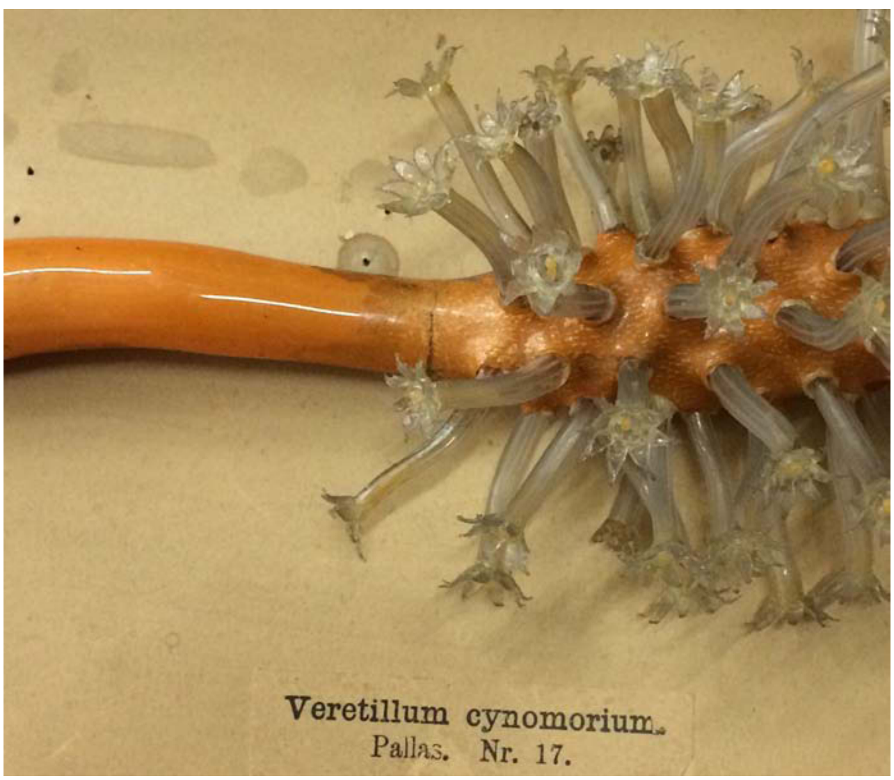

Fig. 5. Detail of a model that has been partially overcleaned. Note the shiny surface on the stem (left) compared with the delicately painted surface under the tentacles (right). Leopold and Rudolf Blaschka, Nr. 17 *Veretillum cynomorium*, about 1885, glass, paper, paints, and resins, 7.0 × 25.7 × 15.0 cm. Collection of Cornell University, Department of Ecology and Evolutionary Biology; Managed Loan, The Corning Museum of Glass, L.17.3.63-14. (Courtesy of The Corning Museum of Glass)

Fig. 6. Detail of polyps on Nr. 173 *Podocoryne carnea* showing droplets of hydration inside the glass bubbles. (Courtesy of The Corning Museum of Glass)

2.4 Glass Deterioration

Figure 6 shows droplets inside the glass polyps of model Nr. 173, the model that this article focuses on. Hydration like this is an early sign of glass deterioration. While many models exhibited signs of unstable glass in the form of droplets, crystals, or both, in most cases, like the droplets in model Nr. 173, it was left untreated because there was no way to access the inside. The closed glass forms that are used in many of the models easily trap moisture, which creates microclimates that promote glass deterioration. Removing surface alkalis is one way to slow down the process, but that is often impossible in these models. Therefore, climate control is especially important to keep the glass in good condition.

For a few models, it was possible to access the inside of the hydrated glass forms. The alkalis on the interior surface were carefully rinsed out with deionized water using a pipette and removing the water with thin strips of paper towel. Although the adhesive construction and often water-soluble surface coatings make using water fairly risky with Blaschka models in general, the affected glass elements on these particular models did not have any surface coatings and their interiors could be accessed without contacting the water-sensitive adhesive.

3. MODEL NUMBER 173: *PODOCORYNE CARNEA*

One of the more damaged models that was to appear in the exhibition was model Nr. 173 in the Blaschkas' catalog, representing a tiny creature known as *Podocoryne carnea* (figs. 7, 8). This is a type of

Fig. 7. Before treatment. Leopold and Rudolf Blaschka, Nr. 173 *Podocoryne carnea*, about 1885, glass, metal, paper, paints, and resins, 8.2 × 17.8 × 14.9 cm. Collection of Cornell University, Department of Ecology and Evolutionary Biology; Managed Loan, The Corning Museum of Glass, L.17.3.63-267. (Courtesy of The Corning Museum of Glass)

Fig. 8. After treatment. Nr. 173 *Podocoryne carnea* (Courtesy of The Corning Museum of Glass)

Fig. 9. These parts from the Blaschkas' studio materials are similar to the polyps on Nr. 173 *Podocoryne carnea*. They are made of two bubbles of glass inside one another. (Courtesy of The Corning Museum of Glass)

hydra with polyps that release to form tiny jellyfish, which later grow into larger jellyfish, as illustrated in the matching preparatory drawing (fig. 2). The adult medusa (i.e., the jellyfish) was offered as a separate model (Nr. 173a). The hydra model has two distinct parts: the life-size version and the enlargement, the latter of which needed treatment.

3.1 Description

The enlargement is made up of five hollow stalks glued to an extremely thin glass base. Each stalk is supported on the inside with a piece of metal wire bent into an L shape. There are two long and skinny stalks, one short and squat stalk, and two shorter stalks with balloon-like polyps. The polyps are made of two bubbles of glass inside one another (fig. 9). Each inner bubble has four streaks of pink-and-white glass. Other than these streaks, all of the glass in the model is colorless.

A flower-like glass element is also glued to the base with the same type of metal support. In addition, four smaller conical glass elements are glued directly to the glass base. The base itself is slightly domed and roughly oval, with irregular edges. The entire glass base and the lower parts of the glass elements attached to the base are covered with tiny glass beads. Unlike many Blaschka models, the surface of much of the glass is uncoated. Instead, the stalks are colored with pigment on the interior surface. The underside of the base is painted.

The glass base of the enlargement is attached to a stiff paper card base with two thin metal wires. The life-sized model, which is made of only glass, was glued to the same card with “Nat. size” (natural size) handwritten directly below it. The card also has a printed paper label.

3.2 Ultraviolet Examination

UV examination of this model revealed some interesting things about how it was constructed. Under shortwave UV (fig. 10) certain glass parts, such as the spikes to which the polyps are attached and the

Fig. 10. Two sections of Nr. 173 *Podocoryne carnea* under shortwave UV (Courtesy of The Corning Museum of Glass)

spikes at the tops of the stalks with polyps, fluoresced an icy blue color, which is typical for glass containing lead. The tiny glass beads on the base are also lead glass, but their fluorescence is mostly obscured by the adhesive used to attach them to the base.

When the areas with lead glass spikes were viewed under longwave UV, which causes the adhesive to fluoresce most brightly (fig. 11), it became clear that the leaded glass parts were not glued but rather were hot fused to the stalks. Interestingly, the spikes on the larger stalks, which are larger but similar, were glued on instead of hot fused.

Fig. 11. Two sections of Nr. 173 *Podocoryne carnea* under longwave UV (Courtesy of The Corning Museum of Glass)

There are at least four different adhesive materials found on the model, some of which may be later additions from previous conservation campaigns. The adhesive mentioned earlier used to attach some of the spikes to the stalks appears to be the same material that was used to attach the polyps and seems to be covering the base. This is likely an animal glue.

Under both longwave and shortwave UV, dark-orange streaks are visible on the lower parts of the stalks. They can also be seen in visible light but were more apparent under UV. The streaks contrast with the rest of the stalks, which were not painted with a coating, as is often the case in Blaschka models. This is possibly a natural wax.

Another material with a bluish fluorescence under longwave UV is found on the lower ends of a few of the stalks, along the edges of the loss, and as a smear on the paper card base. This is probably from a previous restoration and is possibly polyvinyl acetate.

The life-sized version of the model was glued to the paper card base with an adhesive that fluoresces orange, typical of shellac. This is likely not the original adhesive. Although shellac was available at the time that the Blaschkas were active, it is not often found on the models. When it is found, the application is usually not consistent with the rest of the model.

Finally, the dull-yellow fluorescence of the nonlead glass under longwave UV indicates that it has manganese, which was often used to decolorize soda-lime or mixed alkali glasses.

3.3 Comparison

The Blaschkas, of course, made many examples of model Nr. 173 *Podocoryne carnea*. Another example (fig. 12) was purchased by the University of Wisconsin, Madison in 1890. That makes it a few years later than the model from the Cornell University collection, which was purchased in 1885.

When comparing the two models, there are some interesting differences in how they were constructed. In the earlier model, the glass base, which is extremely thin, slightly domed, and has irregular edges, was flattened over the flame. In the later model, a piece of plate glass was used instead. The size, shape, and number of stalks is different. In the later model, all of the spikes on top of the stalks are hot fused; in the earlier model, the large spikes are glued on. Considering that the Blaschkas made many versions of each invertebrate model over the course of 27 years, it is not surprising that some of their materials changed and their techniques evolved over time.

3.4 Condition Before Treatment

The enlargement was badly damaged before treatment (see fig. 7). The glass base was broken into four pieces and was missing an area roughly the size of a quarter. There were also some smaller losses along the outside edge of the base. The two larger sections of the glass base were still attached to the paper card base with the original metal wire, but these wires had to be cut in order to reassemble the model. The smallest fragment of the base (roughly 1 cm^2) was badly cracked and mostly held together by the layer of adhesive on the surface. One of the taller stalks is attached to this small fragment of the base. There was masking tape holding this stalk to the paper card base. The tiny glass beads glued to the glass base are loose in some areas and some have been lost, especially along the breaks. Finally, the flower-like glass element attached to the glass base appears to be missing a central section.

Fig. 12. Similar model of *Podocoryne carnea* in the collection of the University of Wisconsin, Madison. Leopold and Rudolf Blaschka, Nr. 173 *Podocoryne carnea*, about 1890, glass, metal, paints, and resins. University of Wisconsin Zoological Museum. (Courtesy of Dr. Ilia Guzei)

The life-sized part of the model appears intact but has some yellowed adhesive and is no longer attached to the card. In addition, most of the original adhesive used in the model has yellowed. Both the model and its paper card base were also very dirty and had areas of masking tape residue. The model was repaired at least once previously, as indicated by a smear of adhesive on the card underneath the enlargement and the messy application of shellac where the life-sized version had been attached to the card.

4. TREATMENT

4.1 Consolidation and Cleaning

Because the materials used to make the models are fragile and especially sensitive to water, cleaning and treatment needs to be minimally invasive and use as few solvents as possible. The cleaning protocol developed consisted of dusting the models, including the cards, with a very soft, dry brush and low-powered vacuum. In most cases, this was followed by a light solvent cleaning using ligroin (petroleum distillate), a nonpolar solvent, on a soft brush (fig. 13).

Cleaning the hydra model was complicated by the tiny glass beads glued to the base, many of which were loose or easily dislodged. To keep the surface of the base as intact as possible, it was consolidated with a 10% to 15% (w/v) solution of Paraloid B-72 in acetone before cleaning.

Fig. 13. During cleaning. The stalk on the left has been cleaned, the stalk on the right has not. (Courtesy of The Corning Museum of Glass)

Despite the consolidation, some glass beads, especially around the breaks, came loose. They were all collected and readhered along the joins after the model was reassembled.

4.2 Reassembly

The four remaining fragments of the base were readhered with Paraloid B-72 in acetone applied directly to the break edges from a tube. Because the base is not flat, a sand box was used to support the pieces while the adhesive set. Acetone on a brush was used to clean up the excess adhesive. The large stalk in the middle was attached to the smallest section of the base, which was badly broken and cracked, held together only by the layers of glue on the surface. This small section of base was warped because of this damage and could not be properly aligned. Its repair required further loss compensation, as described in the next section.

4.3 Loss Compensation

The smaller losses along the outside of the glass base were not filled because they were not needed for structural support and were not aesthetically disruptive. The large loss in the center of the base was filled using a cast sheet of Paraloid B-72. This process is done almost entirely away from the object, making it very suitable for fragile materials such as the Blaschka models.

4.3.1 Casting Paraloid B-72

Since Stephen Koob and I first presented our method of casting Paraloid B-72 for filling losses in glass at the CCI conference in 2011 (Koob et al. 2011), we have continued to develop our technique and have found new ways to use it. Some of these improvements were presented in 2013 at the ICOM-CC Glass and Ceramics interim meeting in Amsterdam (van Giffen, Koob, and O'Hern 2013). What follows is a description of the improved process and some tips.

Our basic recipe:
30 g Paraloid B-72
100 mL acetone
20 mL ethanol

First, the Paraloid B-72 chips are dissolved into the acetone. It is easiest to do this without agitation by suspending the Paraloid B-72 in a cheesecloth bag, just touching the acetone (as described in Koob 2006, pp. 50–51). Once the Paraloid B-72 is fully dissolved, the ethanol is added to help slow down solvent evaporation. Pigments and fumed silica can be added as needed to get the desired color and transparency. These are mixed with a small amount of solvent before they are added to the mixture to prevent clumping. Colored Paraloid B-72 chips can also be used to color the mixture.

The mixture is then poured into an open mold and placed in a plastic bag, as can be seen in figure 14. The casting can be removed when it is set but still flexible (fig. 15), usually after a few days but sometimes much longer depending on the size of the molds.

The resulting sheet of Paraloid B-72 is then cut to the desired shape. This can easily be done with scissors, since the casting is still flexible. It is then joined to the object by simply applying acetone to the edges. Paraloid B-72 adhesive from a tube can also be used but may create bubbles along the edge.

The fill does not need to be cut to the exact size and shape of the loss. If it is slightly larger, it can be trimmed with a scalpel or scissors near or on the loss. Acetone can also be used to gently dissolve away the excess while the fill is being attached to the object.

Fig. 14. Paraloid B-72 solution in open-faced silicone molds inside polyethylene bags. The molds were made using small pieces of Plexiglas. (Courtesy of The Corning Museum of Glass)

Tips for the casting process:

- Too much ethanol can lead to condensation inside the bag. This can interfere with the setting and appearance of the resin.
- It is a good idea to limit the amount of air left in the bag. This helps keep a higher concentration of solvent near the resin, which decreases the chance of getting air bubbles in the cast sheet.
- Thinner plastic bags work better because the solvent leaves the system a little faster but is still retained long enough to prevent bubbles from forming.
- Remember that there will be about 70% shrinkage in thickness. This is not really a problem because there is no lateral shrinkage, as the solvent evaporates from the largest surface areas.
- The shrinkage makes it harder to get thicker castings. You may need to add resin solution daily or every 2 days to get the desired thickness. It will also take longer to set.
- Knowing when to remove your casting from the solvent bag can be tricky. A good test is to twist the mold; if the edges pull away, it is probably safe to take it out.

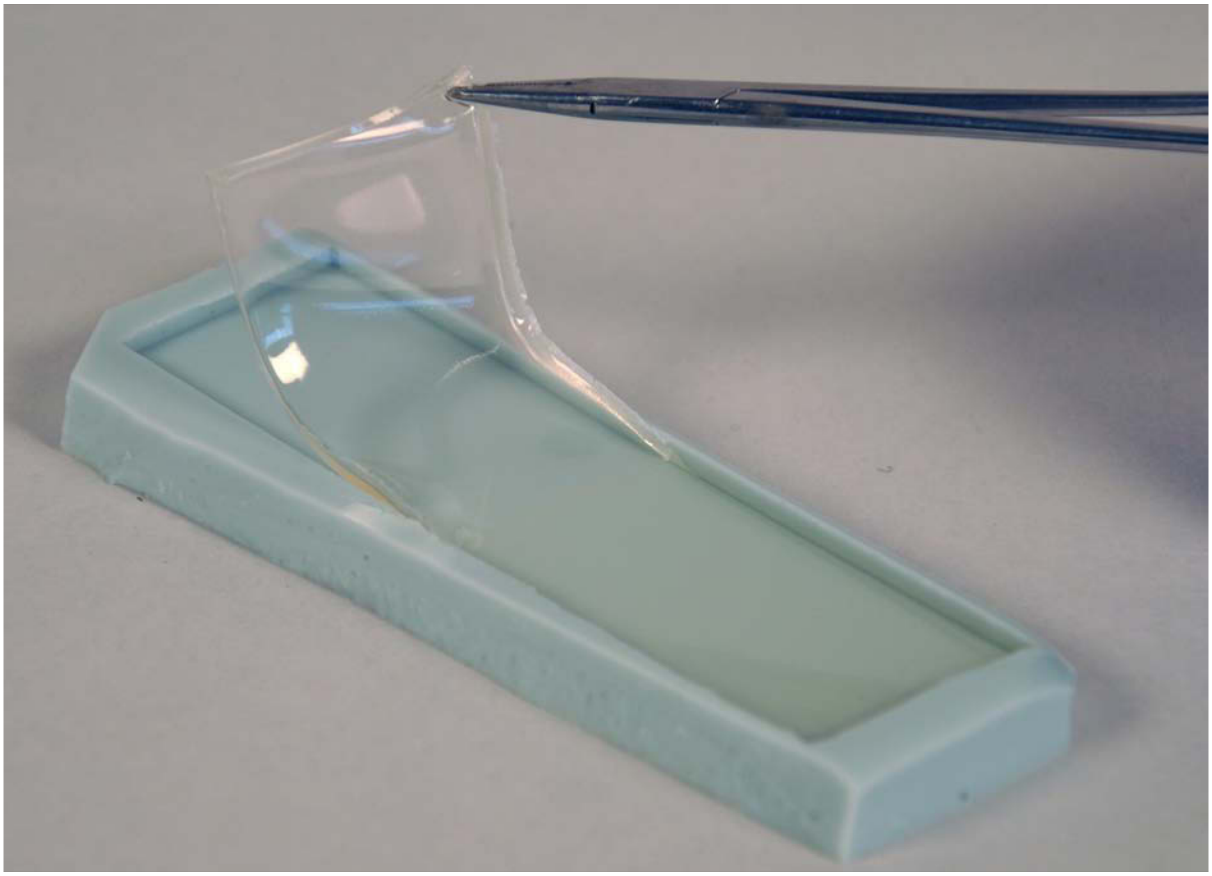

Fig. 15. Removing the set, but still flexible, Paraloid B-72 sheet from the mold (Courtesy of The Corning Museum of Glass)

Tips for manipulating the casting:

- If the Paraloid B-72 is too flexible, if it slumps or will not hold its shape, a low-temperature (35°C–40°C) oven can be used to drive off the remaining solvent. However, if this is done too soon, bubbles will form. In some cases, bubbles can add a desirable visual effect.
- If the Paraloid B-72 is not flexible enough but still needs to be shaped or cut, heat or a solvent chamber can be used to soften it.
- Heat can also be used to soften a fill into a mold to obtain a strong curvature (fig. 16).
- A hot spatula can be used to locally heat and shape the fill (fig. 17).

4.3.2 Fill on the Blaschka Model

A hot spatula was used on the cast Paraloid B-72 fill for the hydra model. Because the central section of the base was not in perfect alignment with the rest of the fragments, the fill had to be adjusted to provide a better transition and more structural support. This was done in situ after the fill was cut out and tacked into place with acetone by softening and shaping the fill with a hot spatula.

The underside of the fill was painted with Golden Acrylic paints to match the base. New glass beads similar in size to the originals were scattered on the fill and secured by using a drop of acetone to soften the Paraloid B-72 underneath. The glass beads that had been collected over the course of the treatment were applied to the base where beads were missing, especially along the joins and the edges of the loss.

Fig. 16. This piece of cast Paraloid B-72 was heated with a heat gun and then placed in a mold until it was fully cooled in order to obtain a strong curvature. (Courtesy of The Corning Museum of Glass)

Fig. 17. The folded rim on the fill for this date vase was created with a hot spatula by locally softening the Paraloid B-72 until it could be folded over. (Courtesy of The Corning Museum of Glass)

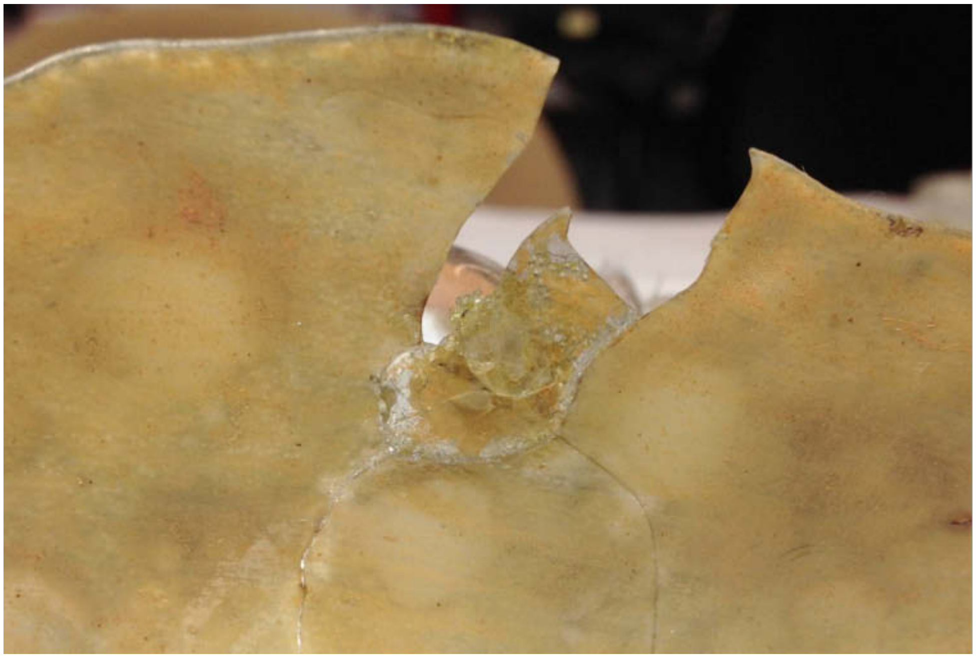

Fig. 18. Large loss in glass base after reassembly of remaining fragments (Courtesy of The Corning Museum of Glass)

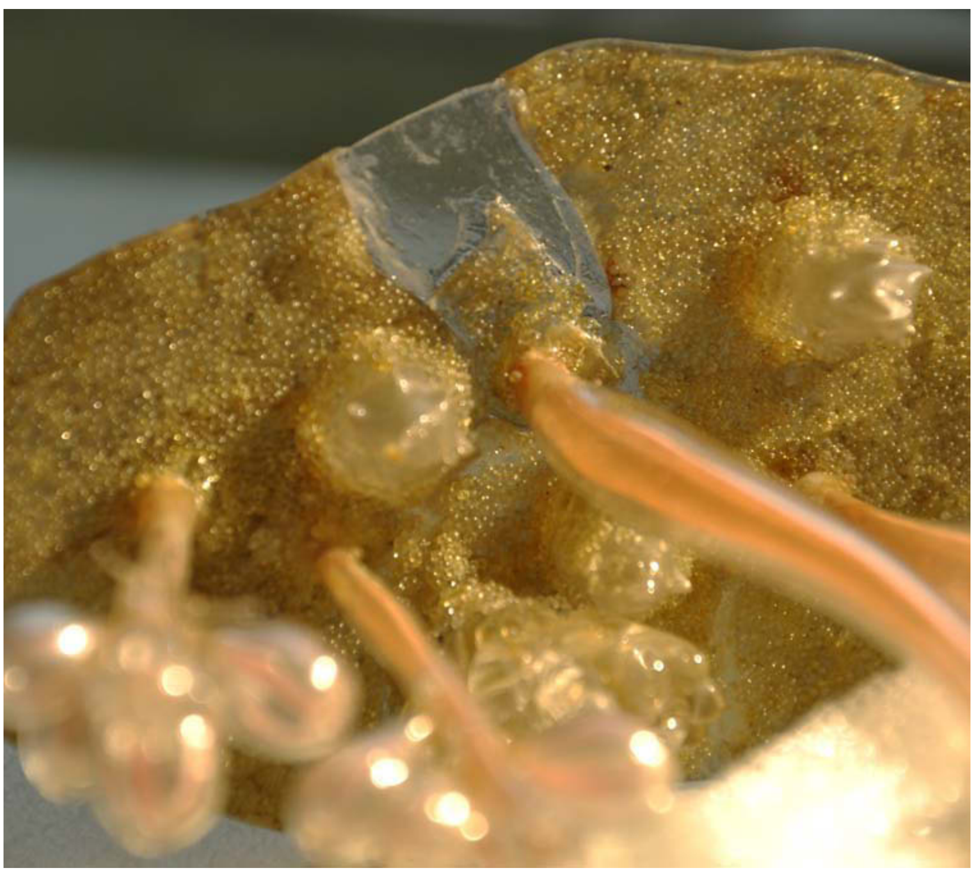

Fig. 19. Cast Paraloid B-72 fill in glass base before addition of glass beads and paint on the underside (Courtesy of The Corning Museum of Glass)

Fig. 20. Finished fill (Courtesy of The Corning Museum of Glass)

4.3.3 Cast B-72 Wedge

There was one other place where cast Paraloid B-72 was used during the treatment of Nr. 173 *Podocoryne carnea*. One of the stalks came loose during handling. It was reattached using Paraloid B-72 adhesive, but need a little extra support. A small piece of cast Paraloid B-72 was wedged into the join and smoothed down with a hot spatula, making it much more stable.

5. CONCLUSIONS

The glass models made by Leopold and Rudolf Blaschka are fascinating works of art that required incredible skill, patience, and talent to create. As more collections are rediscovered, the understanding of the scale and importance of the Blaschkas' production continues to expand. These models are some of the most fragile and complicated objects found in collections today. Unfortunately, their original use as teaching tools, their often poor storage conditions, and the sensitive nature of the materials used in their construction have resulted in many types of damage, including deterioration of the glass itself. A stable and appropriate climate is vital in order to slow down the deterioration of the glass and help reduce physical damage from internal stresses caused by differing responses to temperature and relative humidity fluctuations among the wide variety of materials used.

Conservation treatment of these delicate models should limit the use of water and other solvents and be minimally invasive, as was the case with the treatment of Blaschka model Nr. 173 *Podocoryne carnea*. The cleaning protocols developed and the careful use of Paraloid B-72, both as an adhesive and a fill material, successfully brought new life to this delightful model. The use of cast Paraloid B-72 to fill the loss in the glass base was especially advantageous because of the limited contact with the object during the creation process and the relatively clean and easy way in which it was joined to the object. The examination and treatment of this model proved to be a fascinating challenge that brought new insights into how the Blaschkas made their models and how they should be conserved.

REFERENCES

Koob, Stephen P. 2006. *Conservation and Care of Glass Objects*. London: Archetype Publications in association with The Corning Museum of Glass.

Koob, Stephen P., Sarah Benrubi, N. Astrid R. van Giffen, and Nathalie Hanna. 2011. "An Old Material, a New Technique: Casting Paraloid B-72 for Filling Losses in Glass." *Symposium Proceedings (CD), Adhesives and Consolidants for Conservation: Research and Applications*. Ottawa, Quebec: Canadian Conservation Institute, paper 35, 1–14.

Larson, Katherine A., and Alexandra Ruggiero. 2017. "The Blaschka Legacy in Worldwide Collections: A New Resource." *Journal of Glass Studies* 59: 419–22.

van Giffen, N. Astrid R., Katherine Eremin, Susanna Kirk, Jim Tate, and Richard Newman. 2010. "Deterioration and Preservation of Blaschka Glasses." In *Glass and Ceramics Conservation 2010*, edited by H. Roemich, Paris: ICOM-CC in association with The Corning Museum of Glass. 53–62.

van Giffen, N. Astrid R., Stephen P. Koob, and Robin O'Hern. 2013. "New Developments for Casting Paraloid B-72 for Filling Losses in Glass." *Recent Advances in Glass, Stained-Glass, and Ceramics Conservation 2013*, edited by H. Roemich and K. van Lookeren Campagne. Paris: ICOM-CC. 53–60.

FURTHER READING

Brierley, Liesa. 2009. "Art Forms in Nature: Examination and Conservation of a Blaschka Glass Model of the Protozoan *Aulosphaera elegantissima*." *Studies in Conservation* 4 (54): 235–67.

Pantano, Carlo, Susan Rossi-Wilcox, and David Lange. 1998. "The Glass Flowers," In *The Prehistory & History of Glassmaking Technology*, edited by Patrick McCray. Westerville, OH: American Ceramics Society, 61–77.

Rossi-Wilcox, Susan, and David Whitehouse. 2007. *Drawing upon Nature: Studies for the Blaschkas' Glass Models*. Corning: Corning Museum of Glass.

Smith McNally, Rika, and Nancy Buschini. 1993. "The Harvard Glass Flowers: Materials and Techniques."*Journal of the American Institute for Conservation* 32 (3) Autumn/Winter: 231–40.

van Giffen, N. Astrid R., Katherine Eremin, and Richard Newman. 2012. "The Harvard Glass Flowers and More: A Technical Study." *Annales de l'Association Internationale pour l'Histoire du Verre* 18, Thessaloniki. 475–80.

van Giffen, N. Astrid R., Katherine Eremin, and Tracy Owen Drier. 2015. "Imitating Nature: The Materials and Preservation Needs of the Blaschka Glass Models." *Journal of Glass Studies* 57: 213–24.

van Giffen, N. Astrid R., and Stephen P. Koob. 2016. "Cleaning and Repairing Blaschka Glass Models: Challenges in the Preservation of Exquisite Reproductions of Nature." *Recent Advances in Glass and Ceramics Conservation 2016*, ed. H. Roemich and L. Fair. Paris: ICOM-CC. 205–14.

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“DO WHAT’S RIGHT”: THE CONSERVATION OF A DAVID HAMMONS MUD SCULPTURE

SASHA DROSDICK, ROGER GRIFFITH, AND LYNDA ZYCHERMAN

“Do what’s right,” said the artist, without looking at the sculpture or asking what treatment we proposed. During a surprise visit to the Museum of Modern Art’s conservation studio, the infamously laconic artist David Hammons uttered these three words that encapsulate decades’ worth of conservation theory and ethical debates. What does it mean to do the right thing in art conservation? The 28-inch tall, mud sculpture with wire, human hair, and black-eyed peas presents a plethora of conservation concerns. In 2013, the Museum of Modern Art acquired the sculpture in what appeared to be a deteriorated and unstable state. It required a Plexiglas bonnet for its inaugural exhibition at the museum in 2015. As the work was being deinstalled from that exhibition, a small piece of mud fell from the sculpture and landed on its base. This event, in addition to the work’s condition, led us to question its overall structural stability and strategy for basic conservation maintenance. Without the artist’s explicit guidance, distinguishing between his intentions and the natural deterioration of the sculpture’s inherently fragile materials was challenging. However, finding a solution that would stabilize the work without diminishing its spirit was a challenge that we eagerly accepted.

KEYWORDS: Contemporary art, Conceptual art, Mud sculpture, Unbaked clay, Consolidation

1. INTRODUCTION

Unceremoniously, and unannounced, David Hammons appeared in the Conservation Center of the Museum of Modern Art (MoMA) on a quiet Friday afternoon in May of 2016. He was accompanied by AC Hudgins, his friend and long-time patron. Serendipitously, this surprise visit coincided with our treatment of a Hammons artwork, which happened to stand nearby, and which Hudgins himself had donated in 2013. Seizing upon the opportunity to speak with the famously reclusive artist, we asked him his opinion about the recent damage to his work and how he suggested we move forward. Turning away from the sculpture, he said, “Do what’s right,” and then fell silent.

But what does it mean to a conservator, to do what’s right? This article will present the treatment of an unbaked mud sculpture by African-American conceptual artist, David Hammons (b. 1943). By recounting the accident that affected the artwork’s condition and how it came to enter the lab, this article will unpack the two main themes surrounding our treatment, focusing on the material limitations of unbaked mud objects and the complexities of dealing with living artists. It will also expose areas where more communication between conservation specialties and research is required.

Ultimately, we were forced to treat a sculpture that was neither constructed to last forever nor intended to enter a museum, all while negotiating the cryptic wishes of a living artist. This situation was unique; however, given the state of the art market and artists’ current practices, it is becoming increasingly more common.

2. THE ARTIST: DAVID HAMMONS

“I am an artist” Hammons said in 2001, “but I am not on the side of the art world” (Solomon 2001, 556). This statement, which Hammons made during one of his few official interviews, typifies the artist’s persona. Words like elusive, prickly, unpredictable, and inaccessible are often used to describe him. In 2016, during one of many Wattis Institute (San Francisco, California) events within the yearlong initiative dedicated to Hammons, then director of the Los Angeles Museum of Contemporary Art,

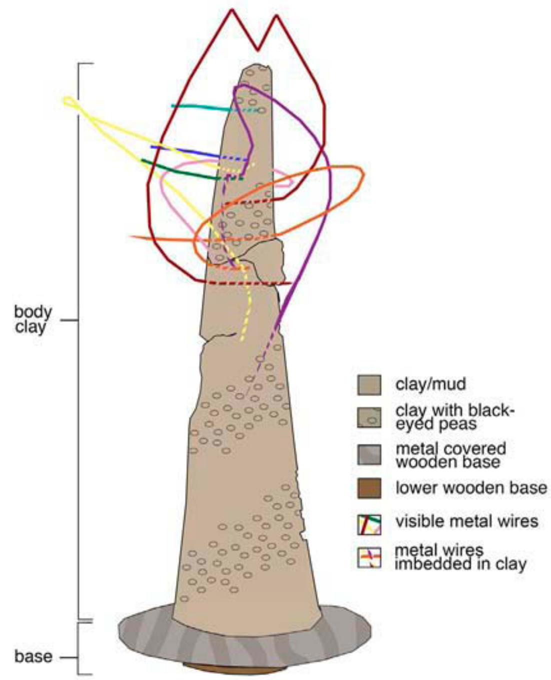

Fig. 1. David Hammons, *Untitled,* ca. 1976. Mud, metal, hair, wire, black-eyed peas, and rubber bands on metal base, 74.9 × 40.6 × 35.6 cm. Gift of the Hudgins Family in memory of Martina Hudgins. Museum of Modern Art, 52.2013. (Courtesy of The Museum of Modern Art, New York)
Fig. 2. Illustration of the three main components of *Untitled*

Philippe Vergne, played a recording of a rare lecture that Hammons gave in 1994. Hammons himself did not attend the Wattis Institute event. While artists are not often known for their smooth, social graces, it is *not* common for an artist who has done his best to avoid the art world to be so sought after by it. But despite his disinterest in the typical conventions of the art world, David Hammons is not an outsider artist. He is a California Institute of the Arts (Valencia, California) and Otis College of Art and Design (Los Angeles, California) graduate, and a MacArthur Fellow whose work is not only critically acclaimed but also financially lucrative (Schjeldahl 2002).

Unlike most contemporary artists who reach his level of success, Hammons has no traditional gallery representation. Nevertheless, he has had solo exhibitions at some of the most renowned galleries in the world, such as L&M Arts, Mnuchin Gallery, White Cube, ACE Gallery, and Tilton Gallery (Russeth 2015). A "philosopher-artist," as Franklin Sirmans called him in 2006, Hammons's work maintains relationships with surrealism, Dada, and assemblage, as well as identity and class politics (Sirmans 2006). In terms of his material practice, Hammons is known for using an array of detritus in his artworks, including, but not limited to, glass bottles, bottle caps, plastic milk crates, greasy paper bags, chicken bones, taxidermy, found tarps, plastic sheeting, and even Kool-Aid powder (Huberman 2016).

3. THE ARTWORK: *UNTITLED*, ca. 1976

This article focuses on Hammons's untitled, unbaked mud sculpture donated to MoMA in 2013 (fig. 1). The work is the only one of its kind in a museum collection and, unlike Hammons's many rock head sculptures that often receive more traditional treatments, it has never been subject to a conservation intervention. It stands at 29 in. tall and is comprised of three main components: a conical mud body, a circular wooden base covered in a thin sheet of metal, and metal wires with hair and string (fig. 2). Where it meets the base, the mud cone is at its widest, measuring 7 in. in diameter. It gradually narrows to 1½ in. at the top. The base extends approximately 2 in. outward from the cone on all sides. It should be noted that the term "mud" is the most accurate description of the material that Hammons used to make this object. Its exact contents are unknown, as is their source, but it does contain rocks and other inorganic materials, along with organics such as straw and grasses. Literature and treatment methods for both "mud" and "unbaked clay," however, are often grouped within the same category. Though the authors are aware of the wide range of definitions and frequent misapplication of the term "mud," we chose it consciously for the aforementioned reasons and will use it exclusively to describe this sculpture. While both materials can be "fragile and may be friable, crumbly, or cracked […] extremely porous and sensitive to moisture" their compositions can be very different (Rozeik 2009, 70). This article will not delve into the specifics of the different materials' compositions. It will offer only a summary of selected, relevant conservation treatments used for both mud and unbaked clay. It is interesting to note that while the literature on earthen architecture and mud brick is extensive and much discussed, the literature on treatment of unbaked earth objects is quite limited, especially considering the large number of such objects residing within museum collections.

The metal wires, approximately 0.05 in. in diameter, have been pushed into the mud. The ends either stick out at angles or are looped back through the mud, creating a series of orbit-like halos around the top third of the sculpture. Some segments of the wires are wrapped with colored string and punctuated with tufts of dark, curly human hair. Striations on the surface of the cone follow a spiral pattern, winding up from the base to the top. Following this spiral pattern, black-eyed peas have been pressed into a band that starts at the base and ends at the very tip of the cone. Encircling the top of the cone are remnants of colored rubber bands.

The work was first exhibited in 2015 for MoMA's exhibition *Take an Object* (fig. 3). Its deteriorated condition was already a concern to the curator, conservators, and registrar, so they had it installed under a custom Plexiglas bonnet. As the work was being deinstalled from the exhibition that a small clump of mud fell from the sculpture and landed on its base. This event, in addition to the work's condition, led us to question its overall structural stability and basic conservation maintenance plan. So precarious was the piece that the slightest vibration caused the cone to sway, creating a cloud of dust. Moreover, a large crack exposed an interior wooden dowel.

3.1 Condition

While its postexhibition condition included the loss of an additional clump of mud, its general condition remained much the same as before it went on display: it had numerous surface cracks, a 3-in. round partially detached clump of mud exposed the wooden armature, two fallen clumps of mud on the base, approximately 1-cu.-in. bits of unsupported mud dangled from crevices or sat in niches, the mud was detached from the armature, and there were points of weakness in the mud where the metal wires had been pushed through.

As if the condition of the cone were not challenging enough, various organic components added to the work's complexity. The remaining rubber bands had deteriorated, faded, become brittle, and broken apart, and the clumps of hair were covered in dust. The wooden base was uneven and did not securely support the weight of the sculpture. Numerous black-eyed peas had fallen, leaving lacunae where they had once been embedded in the mud. Moreover, some peas showed signs of past pest infestation. The

Fig. 3. Installation view of Hammons's *Untitled* installed between works by Lee Bontecou and Robert Rauschenberg in *Take an Object* at The Museum of Modern Art, August 22, 2015 to February 28, 2016. IN2334.7. (Courtesy of The Museum of Modern Art Archives, New York, photograph by John Wronn)

Fig. 4. Detail of peas and other organic materials (Courtesy of The Museum of Modern Art, New York)

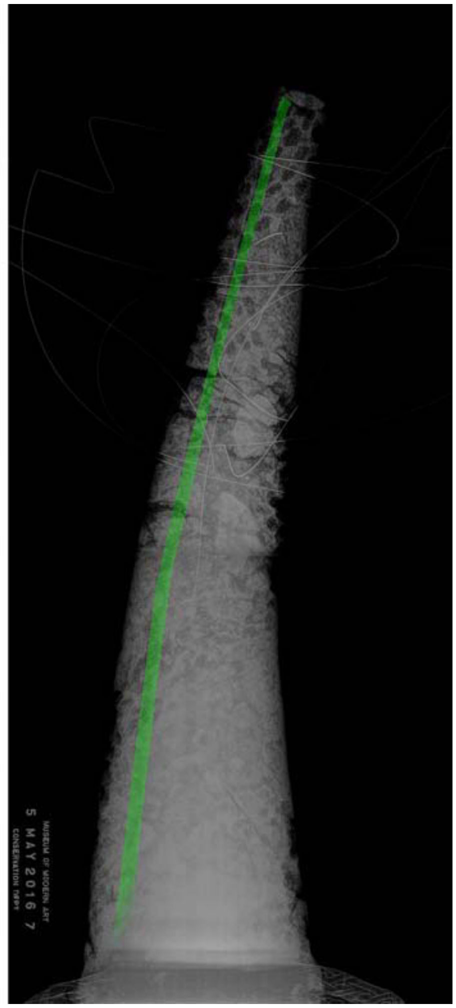

Fig. 5. Digital x-ray image (with visible image superimposed) (Courtesy of The Museum of Modern Art, New York)
Fig. 6. Digital image of annotated x-ray highlighting the presence of the wooden dowel (Courtesy of The Museum of Modern Art, New York)

metal sheet had also lifted from the edges of the wooden base, which was covered in dust, dirt, and cobwebs that had collected over time.

4. METHOD

The artist was not interested in discussing the conservation of this work further; thus, we had no guidance or recommendations. This limited our understanding of the circumstances regarding the production of the work, the artist's state of mind when making it, and his interpretation of the work. But while such information can be useful, working with artists can also have drawbacks. Conservator John Campbell wrote in his 2013 Object Specialty Group Postprints that when Hammons told MoMA conservators that the existing dust was integral to the understanding of his basketball hoop sculpture, *High Falutin'* (1990), they were hard-pressed to find a way to keep the dust undisturbed when designing a shipping crate (Campbell 2015). However, having been told specifically that the dust was essential, they did not have to attempt to decide what was relevant, or debate the appropriate level of cleaning. As difficult as their task was, it did not require guesswork. Given the complexity of this sculpture, its inherent fragility, and our limited access to the artist, we deployed alternative methods to address such questions: namely, x-ray radiography, literature review, interviews, and the making of a technical facsimile.

4.1 X-ray Radiography

Digital x-ray radiography did not divulge much new information on the inner structure or base of the sculpture. The similar densities of the mud and wooden dowel made it difficult to distinguish one from the other, even with beam filters and postcapture digital manipulations. The images demonstrate that only one wooden dowel is present within a solid mud body. A stone, invisible in visual examinations, was revealed on the very top of the sculpture. Cracks, misaligned segments, and pea divots are also visible; however, much of this can be seen by the naked eye. What remains unclear is how, if at all, the wooden dowel connects to the sculpture's base.

4.2 Literature Review and Case Studies

Researching the literature associated with mud materials gave us a better understanding of the work itself and the ways that similar materials have been treated. Unbaked clay is most commonly found in ethnographic and archaeological contexts. Mud brick, adobe, and rammed-earthen building have been studied within architectural and related conservation specialties.

When it comes to unbaked clay objects, however, there is less treatment-based literature. The most well-known unfired clay objects are probably cuneiform tablets. These have a unique conservation history: The British Museum used a firing-based treatment for the cuneiform tablets in their collection from 1948 to the early 2000s and, historically, the Museum of Fine Arts, Boston also fired their tablets (Thicket, Odlyha, and Ling 2002; Gänsicke et al. 2003). As this was in no way an appropriate treatment for the object under consideration here, other areas of research were explored.

As mud brick is also found in architecture and archaeological digs, in-the-field treatments seemed a more relevant avenue of research to pursue. In situ, ethyl silicates have been used to consolidate adobe mud brick since 1969, before which they were used for stone consolidation since the 1890s (Chiari 1987; Ferron and Matero 2011). Giacomo Chiari mentioned the use of ethyl silicates for small, unbaked clay sculptures in the Italian excavation of Turkmenistan of 1987 (López-Prat 2012, 671). Since then, commercially available ethyl silicates traditionally used for masonry have been tested more extensively (Grissom et al. 1999; Ferron and Matero 2011). Despite recent studies, further research and experimentation is still necessary. Conservators treating monumental Buddhist clay sculptures in Central Asia noted that the "lack of specific research in the field of preservation of [unbaked] clay sculptures" has meant that techniques "derive from personal experience/knowledge and the information is transferred among professionals" (López-Prat 2012, 671). Their paper in *Rammed Earth Architecture* discussed using poly(butyl methacrylate) (PBMA) dissolved in xylene as a coating strong enough to allow for the sculptures, carved from earthen walls, to be removed from their original locations. Within a greater discussion of the benefits and pitfalls of extraction and in situ techniques, they also mention more conventional in situ treatments using Paraloid B-72 (ethyl methacrylate/methylacrylate copolymer) and Primal AC-33 (acrylic emulsion) (López-Prat 2012, 671). Other consolidants commonly used in the field for unbaked clay, mud, rammed earth, and other similar objects and architectural details include Klucel G (hydroxypropyl cellulose), Methocel A4C (methylcellulose), and Mowital B30H (polyvinyl butyral) (Ventikou 2001; Rozeik 2009, 72; López-Prat 2012, 672; Chrétien 2016).

The most thorough testing on the consolidation and joining of an unbaked mud object in a museum collection was published by Christina Rozeik (2009), who discussed the treatment of a previously restored, ancient Egyptian unbaked mud statuette in the Fitzwilliam Museum (Cambridge, United Kingdom). She found that a 1% to 2% solution of Mowital B30H in Industrial Methylated Spirits (IMS) was not only effective for consolidation but caused the least amount of color alteration. Conservators at the Victoria & Albert Museum (London, United Kingdom) treated a Chinese unfired clay portrait with 4% Aquazol 500 [poly(2-ethyl-2-oxazoline)] in a 1:2 solution of water and IMS (Ventikou 2001). Similarly, at Matho, a Buddhist monastery in India, unfired clay ceremonial masks were consolidated using Klucel G and gap-filled with the same hydroxypropyl cellulose adhesive mixed with cellulose powder, chalk, and pigments. The rationale as to why Klucel G was selected was not revealed, but since the monks overseeing the treatment "needed their objects to have a perfect aesthetic" for religious reasons, it is likely that it was selected for its minimal surface alterations (Chrétien 2016, 32).

Understanding how these cultural forms related to Hammons's mud sculpture helped us place them in context on an art historical level, and highlighted social and cultural implications affecting their immaterial value. For instance, when treating unbaked clay religious objects for Matho monks in India, "the religious use of these objects is inextricably linked to their aesthetic condition, and their religious value can be restored only if their aesthetic integrity is rehabilitated" (Chrétien 2016, 32). While this may not relate to Hammons's work exactly, it does bring to light the importance of the immaterial value within objects for both spiritual communities such as Buddhist monasteries or Indigenous communities and artists whose works are based on conceptual practices (Chrétien 2016; Hornbeck and Moffett 2016).

Treatments performed on contemporary works such as those within MoMA's collection also helped to establish possible treatment options. Soil and turf elements of Martin Puryear's *For Beckworth* (1980), for instance, were treated at MoMA in 2009. Conservators coated the delaminating soil using two pressurized sprayers: one loaded with ethanol, the other loaded with the consolidation solution of 8.5% Aquazol 200 in a 1:1 mixture of deionized water and ethanol. For larger loose segments, a 20% solution of Paraloid B-72 was injected into the cracks using a syringe (Griffith 2009). Like the example with the Buddhist monks, the MoMA treatment was done in collaboration with the artist and staff in his studio. Comparing MoMA's treatments of Hammons's *High Falutin'* and *Untitled (Rock Head)* 2005 proved useful for the contextualization of the artist's practice, but were not particularly relevant in terms of methodology and materials. MoMA's *Rock Head*, like others in the series, had begun to shed hair; thus, the artist provided an envelope full of hair that he collected from a local barber shop. A crucial element that makes these case studies alike, from the Buddhist monks to Martin Puryear, is that they required intimate collaboration with the artist/makers or users of the objects.

4.3 Interviews

While some artists seek involvement with the conservation process, such as Martin Puryear, others, such as Hammons, sometimes prefer to be excluded. In Hammons's case, this might speak to the high degree of control that he maintains over his own market, image, and persona, a possible change in his attitude about conservation, or just how he prioritizes his work and time. Fortunately, MoMA trustee and donor AC Hudgins generously offered to ask his good friend a few questions on our behalf.

Through a casual interview (Hudgins asked Hammons questions that we had sent Hudgins via email), we learned things about the object that we otherwise could have only guessed. For instance, we learned that the cone's shape derives from the traffic cone that was used as a mold; that, at one time, the empty divots indeed had contained peas; and that more of the colorful rubber bands had once encircled it. We also learned that Hammons had unexpectedly brought it over to Hudgins's home soon after he made it and that, while in Hudgins's care, the sculpture had been knocked over. Having

Fig. 7. Image with traffic cone (Courtesy of The Museum of Modern Art, New York)

given the work to a close friend, Hammons had never considered that it would enter a museum collection.

While some of these answers yielded helpful information, they also left us with even more questions. When asked, for instance, how aggressively the museum should conserve the piece, Hammons deferred to the conservators. “They are the professionals,” he said. However, he then went on to say that “if they do too much it will not have the spirit.” But how do conservators ascertain the “spirit” of an object without assistance from the artist? If we do nothing and the piece falls apart, how much spirit will then remain? But how far can we go to save the “spirit” without losing it? Preserving the spiritual is, of course, a central concern for conservators whose work focuses on ethnographic art, and it often guides their treatments. Stephanie E. Hornbeck reminds us that conservators may consolidate friable or poorly bound pigments or coatings but would generally not add or retouch areas of loss on tradition-based objects (2009, 59). Given Hammons’s mandate and the slippery distinctions between contemporary art and ethnographic art, we were especially conscientious to negotiate these moral and spiritual concerns.

Past interviews and essays helped fill in more gaps. Because Hammons rarely speaks on the record, many of the quotes that are repeated in articles about him derive from a 1986 interview he did with art historian and curator Kellie Jones for the journal *Real Life* (1986). In these interviews, Hammons’s penchant for language-play is clear. Puns are common practice for Hammons, both in conversation and in his works, where he often chooses titles with cheeky puns that add levity to the often heavy subject matter. It is no surprise, then, that his love of wordplay would extend into more abstract territory with the word "spirit," which often comes up when discussing his work. Anthony Huberman, the Director and Chief Curator of CCA Wattis Institute, discusses the spirit in his essay introducing the yearlong series of events titled "David Hammons is on our mind" at the Wattis Institute: "He's after the pun on spirit—as in the drink, but also as in the presence of something far more abstract." Something much more than just the materials. "Materials are something one can see, and arguments are something one can understand, and that's just not what Hammons is after," said Huberman. He is not interested in things that are easily understood, or even seen. Not even things like the Whitney Biennial—the exhibition most artists spend their lives striving to be included in (Huberman 2016).

In the same vein of Ralph Ellison's *Invisible Man*, Hammons's interest in the nature of invisibility has been discussed at length by writer, poet, historian, and theorist Fred Moten. He desires to keep "the invisible invisible, or, at least...unrecognizable" (Moten 2017). This unrecognizable, invisible entity is what he is in search of —he "goes looking for spirits in music, poetry, and dirt" (Huberman 2016).

Hammons gave us his blessing to do what we thought was best. But, then, remaining consistent with both his genius and his persona, he added a pun, a riddle of sorts. If we do too much, it will not have the *spirit*, he said. But what is a *spirit* if not something invisible and unrecognizable?

4.4 Technical Facsimile

While waiting for Hudgins to conduct his interview, we made a technical facsimile to work through the sculpture's possible construction. Although flawed because we were forced to use different materials, such as commercially purchased clay with fine particles and good bonding properties, this experiment remained informative, specifically concerning possible methods of manufacture. When making a replica, we were not able to recreate the exact type of mud and fillers that Hammons initially used, which made testing consolidation and adhesion problematic. Rolling the slab of clay through a bed of peas caused them to become embedded. As the clay dried and contracted, the peas began springing out. It is likely that the same process occurred on *Untitled*, which could account for the number of peas that were lost. Similarly, some areas between the pea divots delaminated and the replica cracked nearly in half, exposing our wooden dowel two-thirds of the way from the top.

After the experience of making the model and based on Hammons's practice of using found materials as well as a visual examination of the surface, we assume that he used a found street cone as the mold for the mud that he could have found at the same site. The wooden dowel was likely inserted into the mold after the mud was packed into it and while it was still moist and malleable. Once the mud was dry enough to remove from the mold, we assume that the artist then rolled it through a bed of black-eyed peas. This would have pressed the peas into the surface, creating the spiraling striations. The pressure necessary to roll such a large piece of earth would have effectively embedded the black-eyed peas so that they would then be flush with the surface. The combined method of basically casting mud into the traffic-cone mold and then rolling the conical shape on a surface explains the overlapping, organically shaped borders in the clay and the presence of other organic materials seen fixed to the surface.

5. TREATMENT

Since determining the *spirit* was all but impossible, we used the limitations of the sculpture's fragile materials to devise a plan. We could not coat the whole thing since it could alter the surface color and texture. It could also create tide lines or a surface film that could later delaminate. The presence of the peas, wire, hair, rubber band, and colored string also complicated this procedure—we did not want to coat these elements unnecessarily or damage them further. The layers of dust on the surface would have been consolidated to that of the mud, which would have prevented deeper penetration and adhered these particles to the surface, making surface details more difficult to see. We could not use water or other solvents since there was little binder keeping the mud particles together and, since they were not bound to a stable armature, they could easily erode. We could not insert filler into the cracks since the cone was not stable enough to accommodate the added weight and pressure. Readjusting the misaligned sections was also futile since the area surrounding these breaks was so fragile that it could easily crumble if manipulated excessively, and returning powdery crumbles would have been all but impossible.

We could, however, determine the original location for the two largest detached clay clumps with the aid of images taken in 2013 and 2015 for the installation. These pieces were re-adhered using Jade R, the water-soluble, modified vinyl acetate copolymer, at stock concentration. The Paraloid B-72 solution that was used for the Puryear was attempted, but we quickly found that it was not compatible with the dried mud: it pilled immediately and was not absorbed. Unstable areas surrounding the area of loss would shift under even the lightest pressure; thus, the reattachment was performed carefully. Clumps that were being held in place only by gravity were also reattached with Jade R, which had good working properties and dried clear. Thus, inserting adhesive in inconspicuous locations behind the areas was done to limit additional loses. Areas that shifted when lightly touched were treated similarly using a syringe. This step occurred over several days, which gave time for the adhesive to dry and gentle tap testing could confirm whether sufficient adhesion had been achieved.

Once all loose elements were stabilized in their original locations, the wires and hair were gently dusted. Accumulated dust and cobwebs were also removed from the surface of the clay in localized areas with soft brushes and tweezers. This could be done only after the surface was more secure. Although very subtle, this minimal cleaning exposed fingerprints on the surface and enhanced the appearance of the colored string.

The last step of the treatment was to work with a crating company to design and build a storage crate that limited movement (fig. 8). Three guillotine-style braces were built to support the cone just below the metal wires, with one gently rested from above to prevent rocking. The base was cradled by five Ethafoam supports and secured to the frame by two padded two-by-fours. Both conservators and registrars agreed that the crate should allow anyone moving it to see how fragile its contents were; thus, plastic sheeting was wrapped around the plywood frame to allow for easy inspection. Lastly, the work was included on the "no travel list" in MoMA's TMS inventory system. It is currently one of only four sculptural works at MoMA that cannot be transferred to storage in Queens.

6. DISCUSSION

The main issues that surfaced during this unique treatment were of a technical and theoretical nature. Technically speaking, the fragility and solvency of unbaked mud objects makes their treatments challenging, if not infuriating. In addition, treatments are unfortunately often confined within the archaeological and architectural conservation spheres. While adobe and rammed-earth architecture has been discussed at length, there is no established procedure for working with similar smaller materials within a museum context. Communication between conservators working in the field on such treatments and those in museums is limited to more casual discussion as opposed to published literature, which

Fig. 8. Image of the custom crate made to house *Untitled*, as seen before plastic sheeting was wrapped around it (Courtesy of The Museum of Modern Art, New York)

reduces accessibility. Details regarding relevant treatments performed within institutions are not often disseminated; thus, valuable options can be institutionally confined. The range of treatment methods discussed in subsection 4.2 show that while options are available, they are rarely systematically tested. This may reflect the unique nature of the objects themselves and how difficult it is to create representative facsimiles for experimentation.

Fig. 9. Detail view before treatment (Courtesy of The Museum of Modern Art, New York)

Fig. 10. Detail view after treatment (Courtesy of The Museum of Modern Art, New York)

From a more theoretical standpoint, the experience of working with a living artist can be as complex as working with a unique, fragile object. While artists can be a good source of information, understanding their "intentions" can be problematic (Wharton 2016). Artists' practices are ever evolving; thus, their own understanding of their work and language used to describe it may change over time. Of course, without an artist's explicit guidance, distinguishing between the materials they used, those that have collected over time, and the natural deterioration of said inherently fragile materials is challenging. While the concept of artistic intention is complex and should be thoroughly explored, the artist's viewpoint is only one of several that must be considered when making conservation decisions. For example, the perspectives of the owners (MoMA in our case, but Buddhist monks in the case study from India), viewers, and donors contribute to an object's values and historical position.

Given that Hammons seeks what cannot be understood (something's *spirit*, almost by definition, cannot be understood) our aim to "define" said entity was doomed from the start. We, however, did not want our concern for "losing the spirit" to result in total avoidance of treatment, because the sculpture would not have survived much longer. If our fear of losing the intangible essence of the sculpture resulted in its loss, its material presence would also be lost—not only to the artist but to the museum, the public, historians, and the donor.

7. CONCLUSION

As contemporary artists such as David Hammons continue to explore materials and abstract concepts, their work's circulation through conservation labs is inevitable. Increasingly, conservators and curators are developing protocol and surveys to make collaboration with artists and their studios more streamlined and accessible (Beerkens 2012; Cotte, Tse, and Inglis 2016). While this may help in many cases, it is important to remember that artists' practices, backgrounds, communication methods, comfort levels, and general interest and understanding is as complex, if not even more so, as their objects themselves. From the conservator's standpoint, and as much as we may fear admitting it, an artist's active involvement in the conservation process does not guarantee a smoother or more successful treatment. Our story is one of many that conservators around the world experience when dealing with contemporary artists and experimental materials. By sharing our discussion and handling of Hammons's *Untitled*, we offer, if not a precise treatment method, an example of how complicated objects and unanswerable questions can be approached.

Perhaps Hammons did not speak with us about *Untitled* because specific instructions are easily understood. Only by making us delve into the treatment without his guidance could we come to glimpse what cannot and should not be understood. So, we ask ourselves another unanswerable question: did we "do what's right?" What we do know is that our treatment was a balancing act. We were able to slow the sculpture's deterioration process without excessive intervention. When David Hammons instructed us to "do what's right," we were not sure if he knew what he was asking. But after exploring the artist, his practice, and this object further, we believe that he knew exactly.

ACKNOWLEDGMENTS

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REFERENCES

Beerkens, Lydia. 2012. "The Artist Interview: For Conservation and Preservation of Contemporary Art: Guidelines and Practice." Heijningen: JAP SAM Books.

Campbell, John T. 2015. "Living artists and the Conservation of Contemporary Objects: Preserving an Aesthetic of Decay." *Objects Specialty Group Postprints, Volume Twenty*, *2013*. Washington, DC: American Institute for Conservation (AIC). 20: 195–206.

Chiari, Giacomo. 1987. Consolidation of Adobe with Ethyl Silicate. Control of Long Term Effects Using SEM. In *5th International Meeting of Experts on the Conservation of Earthen Architecture*, Rome: ICCROM: 25–32.

Chrétien, Céline. 2016. "Preserving what is Right: Finding Similarities Between Collaborating with a Living Artist and Buddhist Monks." O*bjects Specialty Group Postprints, Volume Twenty-Two, 2015.* Washington, DC: American Institute for Conservation (AIC). 22: 25–36.

Cotte, Sabine, Nicole Tse, and Alison Inglis. 2016. "Artists' Interviews and Their Use in Conservation: Reflections on Issues and Practices." *AICCM Bulletin* 37 (2): 107–118.

Ferron, Amila, and Frank G. Matero. 2011. "A Comparative Study of Ethyl-Silicate–Based Consolidants on Earthen Finishes." *Journal of the American Institute for Conservation* 50 (1): 49–72.

Gänsicke, Susanne, Pamela Hatchfield, Abigail Hykin, Marie Svoboda, and C. Mei-An Tsu. 2003. "The Ancient Egyptian Collection at the Museum of Fine Arts, Boston. Part 1: A Review of Treatments in the Field and Their Consequences." *Journal of the American Institute for Conservation* 42 (2) Objects Issue: 167–192.

Griffith, Roger. 2009. Treatment Report, Martin Puryear *For Beckwith,* 1980. Unpublished manuscript, Museum of Modern Art, New York, NY.

Grissom, Carol A., A. Elena Charola, Ann Boulton, and Marion F. Mecklenburg. 1999. "Evaluation Over Time of an Ethyl Silicate Consolidant Applied to Ancient Lime Plaster." *Studies in Conservation* 44 (2): 113–120.

Hornbeck, Stephanie E. 2009. "A Conservation Conundrum: Ephemeral Art at the National Museum of African Art." *African Arts* 42 (3): 52-61.

Hornbeck, Stephanie E., and Dana L. Moffett. 2016. "Altered Surfaces, Taking the Long View: Applications of Ethnographic Conservation Practices to the Conservation of Contemporary Art." *Studies in Conservation* 61 (2): 84–90.

Huberman, Anthony. 2016. Introduction from David Hammons is on our mind. *California College for the Arts (CA) Wattis Institute*. Accessed September 30, 2017. http://wattis.org/view?id=4,368

Jones, Kellie. 1986. "David Hammons, interview." *Real Life* 16: 2.

López-Prat, Monica. 2012. "Buddhist Clay Sculptures in Central Asia: Conservation and Restoration Problems." In *Rammed Earth Conservation,* edited by C. Mileto, F. Vegas, and V. Cristini. London: Taylor & Francis Group. 669–673.

Moten, F. 2017. David Hammons Institute: Fred Moten on Ralph Ellison's Invisible Man. Lecture given at California College for the Arts (CCA) Wattis Institute. March 10. https://wattis.org/view?id=411

Rozeik, Christina. 2009. "The Treatment of an Unbaked Mud Statue from Ancient Egypt." *Journal of the American Institute for Conservation* 48 (1): 69–81.

Russeth, Andrew. 2015. "Looking at Seeing: David Hammons and the Politics of Visibility." *ARTnews,* February 17. http://www.artnews.com/2015/02/17/david-hammons-and-the-politics-of-visibility/

Schjeldahl, Peter. 2002. "The Walker: Rediscovering New York with David Hammons." *The New Yorker,* December 23. https://www.newyorker.com/magazine/2002/12/23/the-walker

Sirmans, Franklin. 2006. "Searching for Mr. Hammons." In *David Hammons: Selected Works*. New York: Zwirner & Wirth.

Solomon, Deborah. 2001. "The Downtowning of Uptown." *The New York Times Magazine,* August 19: 256, 554–556. https://www.nytimes.com/2001/08/19/magazine/the-downtowning-of-uptown.html

Thickett, David, Marianne Odlyha, and Denise Ling. 2002. "An Improved Firing Treatment for Cuneiform Tablets." *Studies in Conservation* 47 (1): 1–11.

Ventikou, Metaxia. 2001. "A Chinese Figure in Unfired Clay: Technical Investigation and Conservation Treatment." *V&A Conservation Journal* 38. http://www.vam.ac.uk/content/journals/conservation-journal/issue-38/a-chinese-figure-in-unfired-clay-technical-investigation-and-conservation-treatment/

Wharton, Glenn. 2016. "Artist Intention and the Conservation of Contemporary Art." *Objects Specialty Group Postprints, Volume Twenty-Two, 2015.* Washington, DC: American Institute for Conservation (AIC). 22: 1–12.

FURTHER READING

Lefevre, L., and Y. Pre. 1996. "Dessalement de statuettes en terre crue d'Asie Centrale conservées au Musée Guimet." *Le dessalement des matériaux poreux: 7èmes journées d'études de la SFIIC*. Champs-sur-Marne, France. 91–103.

Rava, A., and V. Bertone. 2005. "Problemi di restauro della terra cruda: il caso della scultura di Mastroianni alla Galleria Civica d'Arte Moderna di Torino." *III Congreso Nazionale dello IGIIC: Lo Stato dell'Arte*. Palermo, Italy. 208–215.

Chiari, G., A. Invernizzi, and G. Bertolotto. 1993. "Investigation and Restoration of Clay Fragmentary Statues from Old Nisa Turkmenistan. *Conferência Internacional sobre o estudo e conservaçao da arquitectura de terra.* Silves, Portugal. 228–230.

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RESURRECTING DELLA ROBBIA'S *RESURRECTION*: CHALLENGES IN THE CONSERVATION OF A MONUMENTAL RENAISSANCE RELIEF

SARA LEVIN, NICK PEDEMONTI, AND LISA BRUNO

The Resurrection (ca. 1520–1524) by Giovanni della Robbia, underwent its first full-scale treatment since being acquired by the Brooklyn Museum in 1899. Examination, disassembly, cleaning, reassembly, inpainting, and remounting of all 46 sections of the relief was completed in just 10 months for inclusion in the August 2016 show *Della Robbia: Sculpting with Color in Renaissance Florence* at the Museum of Fine Arts, Boston. The large scale and time constraints of the project required the expertise of all 12 of the museum's objects conservators. Protocols were developed for documentation and treatment to maintain consistency while remaining flexible when unique challenges arose. This article discusses the treatment approach, how and why some 19th century restoration materials were removed and some left in place, as well as the new mounting system that was implemented. X-ray radiography helped define the extent of previous structural repairs. Nineteenth century terracotta restorations and original ceramic were distinguished with thermoluminescence dating. Original repairs, construction and glazing techniques, as well as traces of polychromy and gilding were documented and studied with x-ray fluorescence spectroscopy, scanning electron microscopy/energy dispersive x-ray spectroscopy, Fourier transform infrared reflectometry, and Raman microspectroscopy. Analysis showed similarities in glaze composition with other examples of the della Robbia workshop. Multiband imaging revealed unique characteristics of glazed details on the Christ figure and donor portrait.

KEYWORDS: Giovanni della Robbia, Resurrection, Glazed terracotta, Ceramic, Renaissance, Brooklyn Museum, Thermoluminescence dating, Multiband imaging, Conservation, Treatment, Lead glaze, Tin glaze, Mounting

1. INTRODUCTION

Resurrection of Christ (fig. 1) is a glazed terracotta lunette by Giovanni della Robbia, the third generation of the della Robbia family to run the Florentine workshop begun by his great uncle, Luca. Its large scale overwhelms the viewer with a tour de force of dynamic postures and colors. Christ rises from the tomb at the center, flanked by angels and Roman soldiers fleeing in fear, though one is slumped over asleep. The garland border is bursting with energy, animals in chase amid lush flora and ripe fruit. The donor portrait at Christ's right is instead distinguished by calm amid the action. The portrait depicts the wealthy Florentine trader Niccolò di Tommaso Antinori, with hands clasped in prayer and brow wrinkled in thought. Glazes and colors, especially skin tones, have a wide range, emblematic of Giovanni expanding the palette of his predecessors Luca and Andrea. The marked difference in color and dramatic staging is especially apparent in comparison to Luca's *Resurrection*, with its refined figures and glazes restrained to white and cobalt blue (Santa Maria del Fiore, Florence, 1442–1445).

2. HISTORY AND PROVENANCE

The lunette was acquired in 1899 as a gift from then President of the board of the Brooklyn Institute of Arts and Sciences (which later became the Brooklyn Museum), A. Augustus Healy. Healy had purchased the relief in Florence in the summer of 1898 directly from the Antinori family, by whom it was originally commissioned circa 1520 for their villa outside Florence, Villa Le Rose. The *Resurrection* is thought to have been commissioned either by Niccolò before his death in 1520 or by his son Alessandro in commemoration of his father soon after death. Niccolò was a powerful Florentine merchant whose enterprise centered around the silk trade, and included a company of gold-beaters that would have supported the creation of luxury fabrics. By the 16th century, the Antinori family controlled a vast swath of properties, in addition to entrepreneurial enterprises and public offices (Antinori 2007). The fact that

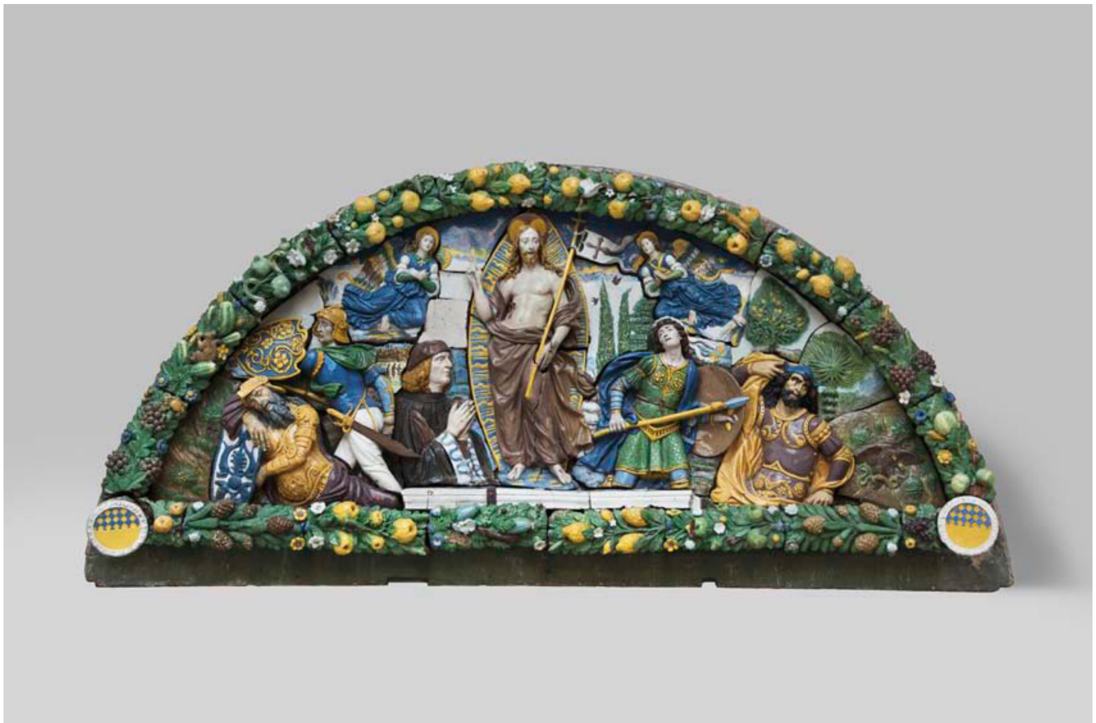

Fig. 1. Before treatment. Giovanni della Robbia, *Resurrection of Christ*, ca. 1520–1525, glazed terracotta, 174.6 × 364.5 × 34.9 cm. Brooklyn Museum, 99.5 (Courtesy of the Brooklyn Museum)

we can trace the *Resurrection*'s provenance directly from its original location to the museum is rare for a della Robbia in the United States (Cambareri 2016).

Although it is known that the lunette once hung in the Villa Le Rose, its exact placement in the complex is not certain. According to a record from the Brooklyn Museum archives, the *Resurrection* was created to adorn the villa's chapel (Board of Trustees 1898). However, the 1899 yearbook states that the object was made to hang over one of the villa's entryways, its shape corresponding to the pediment above a doorway (Brooklyn Institute of Arts and Sciences 1899). In the winter of 2016, Sara Levin visited the Villa Le Rose in an effort to identify the lunette's original location. The niche above the main entry doorway, which is inside the villa's main courtyard, appears to have been a likely location for the relief. Although the pediment is now small, it is apparent from a seam running along the top of the doorway that it has been reduced in size after a previous renovation. Two iron brackets protrude from either side of the doorway that appear to belong to a previous mounting system and likely mark the bottom of the former niche. Measurements were taken by the staff at the villa of the area, which measures 160 cm × 350 cm (fig. 2). This is almost the exact height of the relief as measured currently (subtracting the extending height of the backboard), though the relief is 14.5 cm wider than the niche. The difference in width may be due to different spacing between elements on their current mount. The original chapel was also visited, which is now a private dining room. Although there is no niche, the walls on either end of the room appear large enough to have fit the relief.

Like other della Robbia reliefs, the terracotta sections of the *Resurrection* would have been originally installed directly into the wall using mortar. After the purchase of the lunette, the tiles were removed from the wall and secured to the wooden backboard that we have today. There are no records of when and how this was done. Upon acquisition by the Brooklyn Museum, the piece was installed outside of the Trustees'

Fig. 2. Main entrance from the Villa Le Rose courtyard, showing measurements that correspond to the size of the *Resurrection*

Room on the first floor of the building and celebrated as a masterpiece of the budding collection. As the museum's galleries were developed, the relief was moved into the Italian Renaissance hall on the third floor. Sometime in the late 1930s, it was moved again into a newly renovated Italian Renaissance gallery on the fifth floor, where it remained for more than 70 years. It isn't until 1989 that we have the first conservation record, when Ellen Pearlstein, Jane Carpenter, Beverly Perkins, and Leslie Ransick Gat went up on scaffolding to conduct an examination. During their treatment, the object was cleaned overall in-situ and small elements reattached, but no significant structural work was performed (Pearlstein et al. 1989).

Due to changing gallery exhibitions and themes, the relief was repeatedly walled in at various times during the 1980s, 1990s, and early 2000s. By 2012, then director, Arnold Lehman, made the decision that the *Resurrection* had to be deinstalled to allow the space to become a gallery for South American Art. At this time, the object was cut from the wall, remaining attached to two structural iron braces, and taken to off-site storage. There it sat undisturbed for two years until Marietta Cambareri, Museum of Fine Arts, Boston (MFA) curator of Decorative Arts and Sculpture, inquired about including it in the MFA's 2016 exhibition, *Della Robbia: Sculpting with Color in Renaissance Florence*, breathing new life into the *Resurrection*.

3. EXAMINATION AND DOCUMENTATION

In August of 2015, the lunette was brought back to the Brooklyn Museum so that it could be documented and assessed for stability and future travel. Many serious condition problems were

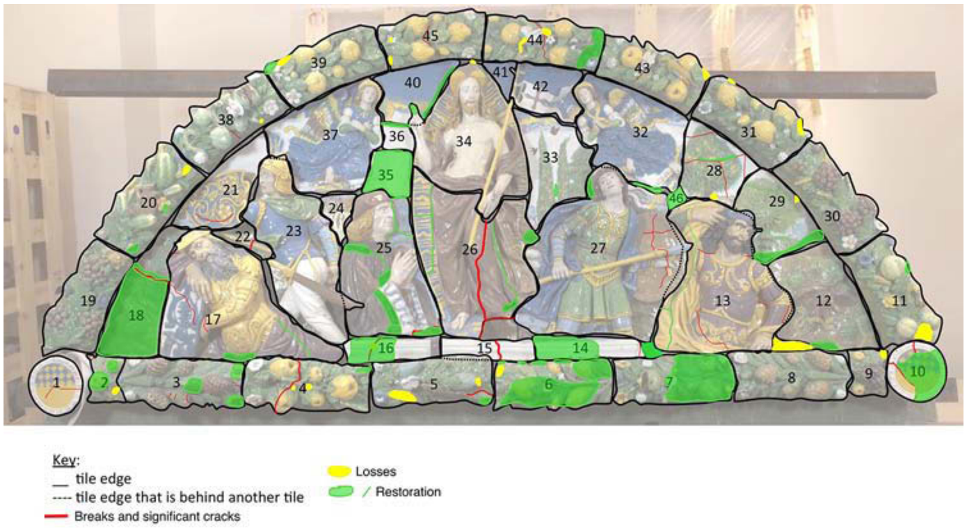

Fig. 3. Condition diagram before the tiles were removed from the backboard (Courtesy of the Brooklyn Museum)

immediately obvious—a large break extended the length of Christ's left leg, and his left foot was separated along with several other detached fragments. Most of the tiles were loose on the backboard due to aging mounting materials; some were barely being held in place at all. Previous restorations were also evident, some of which had visibly deteriorated over time. It became apparent that the individual tiles would have to be removed from the backboard in order to be more closely assessed. Before doing so, a condition diagram was created for all 46 tiles that comprise the relief (fig. 3). Each tile was assigned a part component (pc) number that would be used to track them in the museum's collections database, TMS.

The *Resurrection*'s tiles had been secured to the board's front using a combination of screws, metal wire, and ferrous brackets. Most of these elements were embedded in plaster, which was reinforced in some places with burlap. Despite, or perhaps because of, the numerous attempts at reinforcement, the materials were failing and unstable. The haphazard system had added significant weight and stress over time, and the ferrous hardware had become highly oxidized (fig. 4).

As the tiles were deinstalled (fig. 5), we noticed at least three different numbering systems that mapped each individual tile to the board, with printed tabs of paper attached to the backboard and crayon or pencil written directly onto the verso of the tiles and backboard. The sets of numbers may reflect remounting and reinstallation campaigns in the museum's past.

Fig. 4. Two tiles that had been plastered together with previous mounting materials, after deinstallation (front, side, and back views) (Courtesy of the Brooklyn Museum)

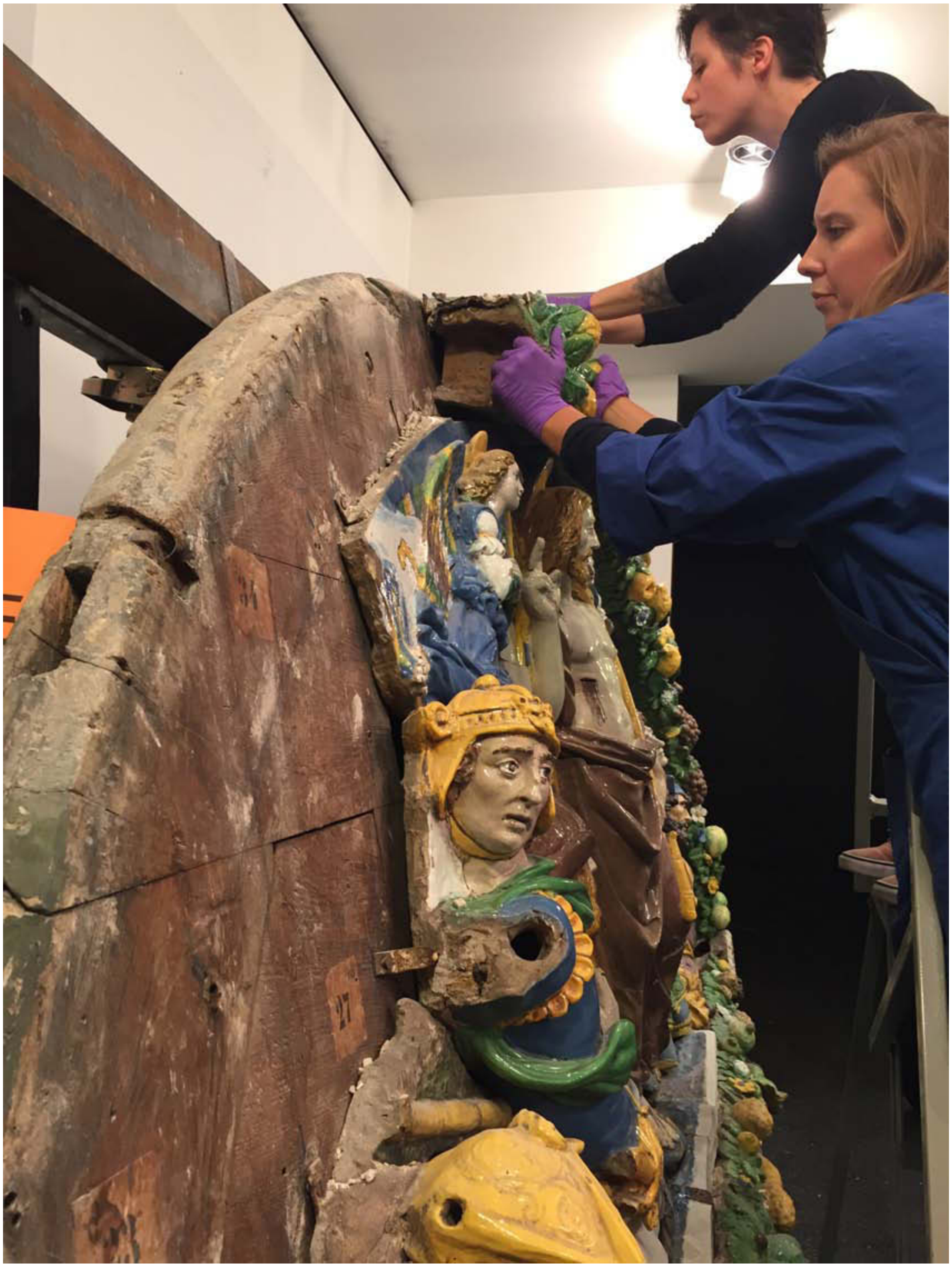

Fig. 5. Brooklyn Museum conservators Jakki Godfrey and Kate Fugett removing the tiles (Courtesy of the Brooklyn Museum)

After removal, each of the 12 objects conservators in the lab were assigned at least two tiles to document, assess, and treat. This allowed us to divide the work to make it more manageable and to have many trained eyes on the object to investigate original materials. We created custom treatment logs for each tile so that conservators could make their own notes on individual tiles in a uniform format and track their work in case it became necessary, because of other exhibition and loan commitments, to transfer their work to another person midtreatment. Regular meetings allowed us to share unique observations, deliberate over treatment questions, and foster a consistent approach.

4. PREVIOUS RESTORATION AND MOUNTING MATERIALS

Our first treatment challenge was to distinguish materials and techniques of the original work from mounting and restoration media to ensure that we would not remove any original material during treatment. In addition to visual and microscopic examination, several different analytical techniques were used. Before treatment began, x-ray radiography was performed to determine the extent of metal hardware within and underneath the plaster. In addition to the mounting brackets, x-ray imaging revealed that some large joins were bridged with metal scraps, as was seen along the break separating the back of Christ's right leg and mandorla. Bridging materials included nails, metal tabs, and a rasp (fig. 6). Treatment began with reducing plaster from the back and sides to remove hardware, reduce excess weight, and expose original ceramic. The plaster itself was white and homogenous, which allowed us to differentiate it visually from older, beige mortar repairs that could be seen beneath the plaster in some instances.

On the front, painted restorations were also evident in many areas, such as on Christ's two raised fingers and on many flowers, leaves, and fruits along the garland border. These restorations consisted of a low-fired terracotta that was covered in a gesso-like material and painted to match surrounding glaze. A sample of the restoration terracotta and two samples of what was thought to be original ceramic were sent to Oxford Authentication for thermoluminescence (TL) analysis. The firing date of the original ceramic was found to be consistent with the Renaissance, while the restoration was shown to be "less than 150 years old" (Oxford Authentication 2016). The restoration campaign is therefore likely from the late 19th century as it is thought to have been carried out before the object entered the Museum in 1899. A sample of wood from the backboard was taken for identification and reported to be "most likely

Fig. 6. Left: x-ray radiograph (80 kV, 1.5 mA, 5 s, Cu filter) of Christ's legs, proper right side; Right: the same area shown during treatment as metal elements embedded in plaster were exposed (Courtesy of the Brooklyn Museum)

Chestnut" (Alden 2015). As chestnut was available in both North America and Europe, this was not indicative of where the board was produced, unfortunately.

5. ORIGINAL MATERIALS AND TECHNIQUES

Examining the materials and techniques of production was a wonderful opportunity to gain more knowledge about the Giovanni della Robbia workshop. Being the third in the line of della Robbia masters, his practice is also the least studied from a technical point of view. The clay used by the della Robbias has been widely investigated, comprised of a marl with a high calcium oxide content.[1] This type of clay is well suited for lead glaze because its thermal expansion coefficient is higher than other clays and closer to that of lead glaze, encouraging a strong bond between the clay and glaze, which can prevent crazing upon cooling (Barbour and Olson 2011). The calcium-rich marl is light beige and therefore easily distinguished from restoration clays, which are a darker hue. However, we found that in some instances for the border tiles, Giovanni used a red terracotta base for structural elements and covered it with the light-colored marl only for presentation surfaces. Presumably, this allowed the workshop to use a less valuable type of clay to create the bulk of the highly three-dimensional structures and reserve the calcium-rich marl for the tile's glazing surface (fig. 7). It may also be a technique of a specific craftsman in the workshop at the time or used for certain structural advantages. The same strategy of layering two types of clay is also found on Giovanni's relief *Saint Donatus Purifies a Well*, made around the same time as the *Resurrection* (Hykin 2016).

As the tiles were being cleaned, we also examined them for any original markings. We found a few numerals etched into the clay, when it would have been wet, but we did not find a cohesive numbering

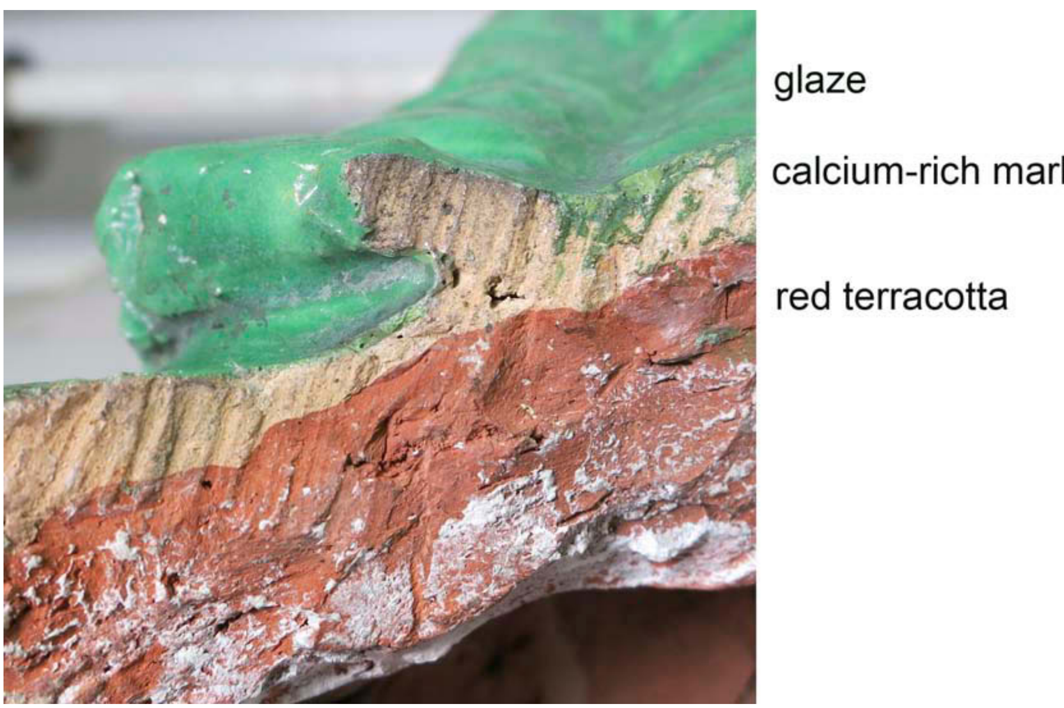

Fig. 7. The side of a border tile, showing the top green glaze layer, thin beige marl, and thick red terracotta substrate. Green restoration paint and plaster residues are also present (Courtesy of the Brooklyn Museum)

Fig. 8. Sketches on the top of a border tile likely illustrate the tile itself, with leaves and three pinecones on the left and a squirrel on the right. This may have been a sketch for the only squirrel in the relief, located on another tile on the lower left side of the border garland (Courtesy of the Brooklyn Museum)

system. One of the border tiles has two sketches visible on its top surface: one that may be the garland itself with pinecones and one that appears to be a squirrel. The glazed squirrel, for which it might have been a sketch, appears on a different garland on the left side of the relief (fig. 8).

Like the clay, della Robbia glazes have also been widely studied. Portable x-ray fluorescence spectroscopy (p-XRF) showed that the *Resurrection* glaze components are largely consistent with elements that have been reported in previously published research. They include lead and tin in all glazes; cobalt in the blues (Kingery and Aronson 1990, Pappalardo et al. 2004); copper in the green[2]; antimony in the yellow (Duran et al. 2011); and manganese in the purple, brown, and black (Zucchiatti and Bouquillon 2011). Iron was found to be the primary colorant for skin tones. Scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM/EDS) analysis of glaze samples performed by Richard Newman at the MFA also detected higher traces of antimony and manganese in the dark skin tones versus the lighter tones (Newman 2016). Arsenic was not found in the blue glaze, as it has been found in other examples of the della Robbia blues dating after 1520 (Pappalardo et al. 2004 and Zucchiatti et al. 2006). This may support an earlier dating of the relief, but further research would be required to support such a claim.

Traces of gilding are present throughout the relief. Remnants can be seen on Christ's mandorla, as might be expected, but also on the Antinori family crests, soldiers' armor and weapons, and—surprisingly—in trees in the background and on leaves and flowers throughout the garland (fig. 9). Traces of mordant in the forms of a starburst and rays of light can be seen in specular reflection in the sky to Christ's right. The extensive use of gilding, evident from what is extant, indicates that the spectacular colors and vibrancy of the relief would have been extravagantly highlighted with gold, much of which has been lost over time.

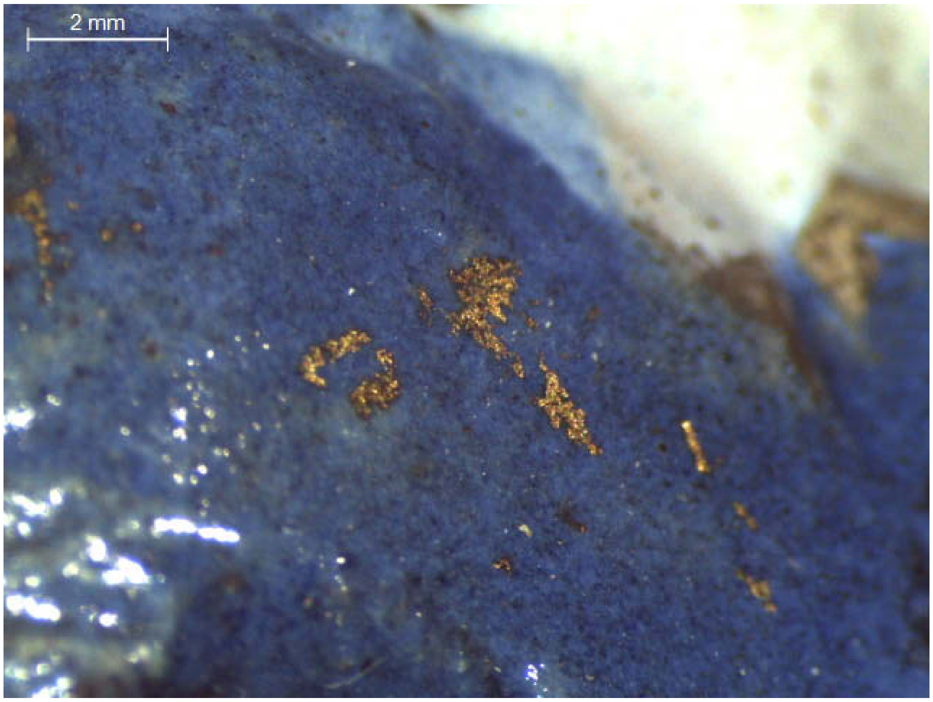

Fig. 9. Traces of gold on the sleeping soldier's shield (Courtesy of the Brooklyn Museum)

There are also significant traces of red cold painting in protected areas of Christ's drapery, such as the edges (fig. 10), inside folds, and inside his wounds. Analysis of a sample by the MFA using FTIR and Raman microspectroscopy identified the paint as vermilion with lead white in an oil and protein binder (Derrick 2016). Paint was likely used on the drapery and wounds because the technology for making red glaze was not known in Italy in the 16th century except as a luster (Padeletti and Fermo 2003). Red is

Fig. 10. Traces of red cold painting on the edge of Christ's robes, over brown glaze (Courtesy of the Brooklyn Museum)

therefore the color of cold painting on terracotta that was most common at the time. Several examples of cold painting on other della Robbia works differ from the *Resurrection*, however; the areas that were painted were often left unglazed, such as Andrea della Robbia's *Virgin* and *Christ* in Moulins-sur-Allier, Musée Anne-de-Beaujeau (Le Hô and Labbe 2011). The use of both glaze and red paint by Giovanni implies that costs were not spared in the execution of the relief.

Multiband imaging was performed on select tiles to see if anything further could be learned about Giovanni's complex glazing technique.[3] Two examples were particularly instructive. Christ's skin has a markedly yellow cast, but it could not be discerned at first if the yellow hue was internal to the glaze or due to an applied resin of some kind. UV reflectance imaging (UVR), which is well suited to illustrating surface textures, did not show evidence of an overall surface coating. Instead, it revealed prominent brush strokes that delineate musculature in Christ's chest, abdomen, and arms in a very painterly manner. When reexamined under the microscope, the faint individual brushstrokes appeared integral to the glaze. Although barely visible in normal light, they became apparent in UVR due to the fact that yellow glazes tend to absorb strongly in the UV range, making them contrast with the surrounding glaze (fig. 11). From a distance, these details lend a yellow glow to the skin overall. Such subtle renderings in Giovanni's glazing technique are noteworthy because they reflect the broader Renaissance interest in articulating human anatomy.

The Marchese Antinori figure was also photographed with multiband imaging. His brown cloak has a highly variegated texture, dark-brown background, and light-brown wavy lines. The design of the fabric is difficult to see in normal light due to the texture but is exposed more clearly in the infrared region (fig. 12). The moire design suggests a luxury fabric such as watered silk. Such a detail seems particularly fitting considering that the silk trade and luxury fabrics were central to Antinori's business.

6. ORIGINAL REPAIRS

Some of the ceramic figures suffered from severe drying cracks and breaks that appear to have occurred during the first firing. A green or yellow glaze was applied to these areas as a type of "original" repair

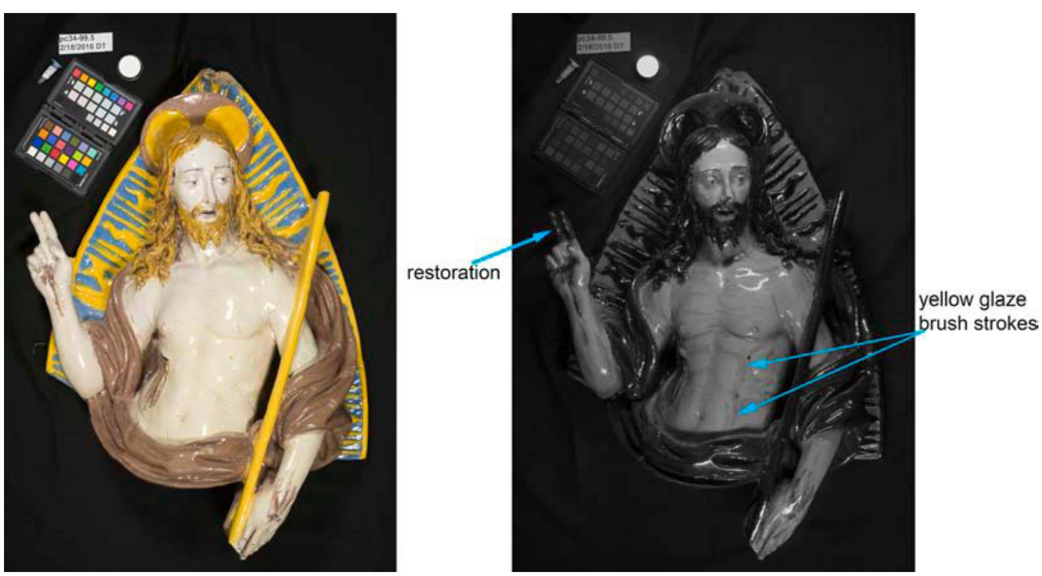

Fig. 11. Left: Visible light image; Right: UVR image showing yellow glaze highlights (which appear dark gray) on Christ's torso, chest, and arms (Courtesy of the Brooklyn Museum)

Fig. 12. Left: Visible light image. Right: Infrared reflectance image (IRR) illuminating the glaze design in the cloak, similar to watered silk (Courtesy of the Brooklyn Museum)

before the second firing and is visible on the backs and along break edges (fig. 13). Inherently weak, these areas often had to be retreated in later restoration campaigns. In some instances, such as on Christ's legs and on the Antinori figure, these flaws created areas that are severely stepped. Mortar repairs are also evident on the back. These repairs were visually distinguishable from the later plaster restoration campaign, as they are more cream-colored compared to the plaster and highly aggregate. Unlike the plaster repairs, the mortar repairs were found to be highly stable; as such, they were left in place during our treatment campaign.

Fig. 13. The break edge of a tile that had been readhered before the second firing with green glaze (Courtesy of the Brooklyn Museum)

7. TREATMENT APPROACH

Working as a team under a tight deadline is a challenge that many conservators face. As described previously, all 12 objects conservators in the Brooklyn Museum lab contributed to the treatment, 2 of whom were hired to be dedicated to the project, while the other conservators worked simultaneously on objects for other loans or exhibitions. Due to the large scale of the *Resurrection* and many hands at work, it was important to maintain consistency while remaining flexible when unique challenges arose. Although general guidelines were established for plaster removal, reversal of failing joins, choice of adhesive, fill materials, etc., each section of the relief was approached individually when evaluating its stability and the exact extent of intervention that would be taken. Then curator of European Art, Dr. Rich Aste, was consulted about aesthetic compensation for lost elements and the degree to which losses were replaced. If losses were deemed visually distracting, reversible replacements were created that were modeled after similar pieces extant in other locations. Regular department meetings and establishment of timely treatment goals enabled us to complete the treatment in 10 months, in time for exhibition.

All plaster that was supporting previously installed iron brackets and metal hardware repairs was removed with mallet and chisel (fig. 14). This aided in lessening the weight of the relief, reducing the weight of the

Fig. 14. Conservator Erin Anderson reducing plaster with mallet and chisel (Courtesy of the Brooklyn Museum)

tiles by an average of 2 lbs. each. Some plaster was kept in place on the verso of select tiles if removing it was considered detrimental to the stability of the object. The ferrous brackets and other miscellaneous metal elements used for previous joining were deemed historic and bagged according to their pc number for possible future study. Surfaces were cleaned with pressurized steam, avoiding areas of unstable glaze, gilding, and original red cold paint. Further reduction of grime and overpaint was performed with scalpels where necessary. Nineteenth century restorations of decorative elements were kept because they are also part of the history of the object and removing them would have required inventing new forms or recreating redundant forms with new materials.

Fragments were joined with 40% w/v Paraloid B-72 in acetone, which was bulked with glass microballoons where the break edges contained gaps. The long vertical break at the center of Christ's legs and surrounding breaks were repaired with a 3:1 mixture of Paraloid B-72 (40% w/v in acetone) and Paraloid B-48N (40% w/v in acetone). Also known as the "Tullio blend," this mixture was formulated by The Metropolitan Museum of Art to provide exceptional shear strength for the reconstruction of the marble *Adam* by Tullio Lombardo (Riccardelli et al. 2014). The adhesive mixture was chosen in this instance because of the orientation of the large break and weight of the fragments, which makes the join highly susceptible to shear stress (fig. 15).

Large structural gaps were bridged with detachable fills made with West System 105 epoxy tinted with dry pigments and bulked with glass microballoons. The epoxy putty was molded over a lightweight balsa wood core for internal support while the adjacent terracotta was covered with plastic wrap. The fill was adhered, after curing, with 40% w/v Paraloid B-72 in acetone. Distracting losses of decorative elements, such as leaves or fruits, were recreated by taking a mold of a matching element and casting a replacement with plaster. In cases in which a mold could not be taken, replacement pieces were modeled by hand with

Fig. 15. Christ's legs during treatment (left) and after treatment (right) (Courtesy of the Brooklyn Museum)

Milliput epoxy putty. Fills were inpainted with Golden Acrylic emulsion paints and surfaced with Golden Porcelain Restoration Glaze (gloss). A laser-printed paper label with each pc number was applied to the verso of each tile with 20% w/v Paraloid B-72 in acetone.

All excessive overpaint covering original glaze was removed. If the restoration paint on the terracotta restorations was in good condition, however, it was kept and, where necessary, was coated with ~25% Paraloid B-67 in petroleum benzine to enhance gloss. Paraloid B-67 was chosen because it could be reversed without affecting the paint below. If the restoration paint was highly degraded, cracked, and flaking, it was removed. In some instances, the paint required touch-ups and was isolated with a clear coating of Paraloid B-67 before being painted over with acrylics.

8. REUSE OF THE WOODEN BACKBOARD

The previously used wooden backboard was chosen for remounting. The board retains historical value since the tiles were attached to it at some point during the 19th century. Additionally, the board remains in good structural condition and provides adequate support for the *Resurrection*'s tiles.

The backboard was made using a combination of joining techniques. Mortise and tenon joints and rubbed joints were used on the perimeter stile. The center rail and center stile run perpendicular to one another and join in the center with a cross-lap joint. Their terminating ends mortise the perimeter stile. The bottom rail does the same. Each of the mortise and tenon joints are further secured with wooden pegs that span the full depth of the board. The spaces between the rails and stiles are compensated with equally thick wooden panels that were installed from the board's verso into a rabbet lap joint along the opening's perimeters and secured with animal glue and flat-head slotted iron screws.

On the backboard's verso is attached a single piece of flat ¼-in.-thick steel bar, approximately 2 in. wide. The steel armature is secured to the rails and stiles with flat-head slotted iron screws. The backboard shows evidence of more than one method for mounting the tiles (holes, nails, labels, inscriptions, outlines in graphite or chalk, etc.), suggesting that more than one mounting material or method was used at the Brooklyn Museum or prior to purchase of the *Resurrection*.

9. MOUNTING

Each tile was mock mounted to the backboard's front face to understand how well the tile aligned with its adjacent tiles but also to determine the ideal location for brass clips to be used to secure the tile efficiently and safely. The existing outlines drawn onto the backboard aided significantly in evaluating how the tiles fit together. A printout of each tile's before-treatment photograph was used to annotate the clip locations and record any other tile-specific considerations and potential mounting issues.

The larger figural tiles and the *Resurrection*'s border tiles were particularly heavy and had elements that stood in high relief. This made mounting them directly to the backboard using only clips a precarious consideration. Therefore, a heavy-duty foam insert was fashioned to partially fill the cavity and add extra structural support (fig. 16). The insert also reduced the risk of the tile shifting from its position once it was mounted.

A Mylar template was created for each individual tile. The outer and inner edges of the tile's contact surface were outlined, as well as the location of the mounting clips and any extra foam padding or inserts

Fig. 16. Mount maker Michael Mandina fitting a foam insert into the back cavity of one of the Roman soldiers (Courtesy of the Brooklyn Museum)

to be used for support. The clips and padding were labeled according to their associated mounting hardware numbers (an identification number, e.g., 99.5 pc2_2, is punched into each clip). The foam inserts were made using Ethafoam 900, a high-density polyethylene foam, 9.5 pcf (152.2 kg/m^3) that is resistant to creep (Dow Chemical Company 2017), wrapped with smoother ¼-in. to ½-in. Ethafoam sheets. These were secured to the backboard using ¼ in. × 3- to 6-in. zinc-plated hex lag screws that fit into predrilled holes (half the total depth) of the Ethafoam 900 block; 3/8 in. × 8 in. screws were used for the supports of the crests at each corner. Zinc washers, 5/16 in., were used to pull and secure the foam inserts to the board.

The clips holding the tile to the backboard were fashioned from 1/8-in. stock brass rods and assembled using silver solder, followed by machine working to the desired shape. The brass clips were covered with Benchmark Sueded Polyethylene on the interior surface in contact with the ceramic and screwed to the backboard using 8-in. × 1½-in. screws.

Several border tiles required adjustments in their mounting so that their heights better transitioned aesthetically with the adjacent tiles. A platform was created and installed beneath these tiles with screws (8-in. × 2-in. flat-head Phillips screws). The foam block inserts for these specific tiles were attached to the platform. The platforms were made from 1-in. Medex board and shaped to follow the contour of the back of the tile to ensure that the tile was secure and not rocking when in position.

All of the tiles were first mounted in the conservation lab space, enabling the mount maker, Michael Mandina, and conservators easy access to machinery, equipment, and materials for making adjustments to the overall mounting design and its associated clips and padding inserts. This system methodology ensured that the tiles and the mount screw holes were accurately placed.

During the initial mounting phase, the Mylar templates were taped to the backboard and adjusted accordingly as each tile was fitted onto the board. Each tile was mounted over the Mylar template on the backboard using the platforms, Ethafoam inserts, brass clips, and supplemental padding. Adjustments were performed on an ongoing basis (fig. 17).

During the initial mounting phase, an order of installation was also developed to safeguard from locking tiles out and knowing the proper order of installation for mounting components.

Due to the weight and size constraints of the entire *Resurrection* assemblage, the final mounting of the tiles was conducted in a larger, more accessible space on the first floor near the crating workshop. This

Fig. 17. Conservator Nick Pedemonti securing tiles to the backboard during the initial mounting phase (Courtesy of the Brooklyn Museum)

allowed easier lifting and transportation of the whole piece with the museum's gantry system. After the tiles were all mounted in the conservation lab spaces, the whole assemblage was dismounted in the reverse order of installation and carefully transported in sections to the final installation location.

The Mylar templates were removed at this stage; each mounting hole was marked with blue tape and labeled with the pc and mount numbers. This would aid during remounting, helping relocate the associated holes with their brass clips and Ethafoam inserts. For the final mounting, the backboard would be covered with a ¼-in.-thick black Volara sheet. The backing sheet served several purposes; it provided extra padding to the *Resurrection*'s tiles, helped prevent subsequent shifting once tiles were mounted, and provided a uniform black background in the negative space between the tiles.

Before laying the black Volara sheets onto the backboard, each mounting screw hole was filled with a projecting bamboo skewer that extended approximately 1 in. out of the backboard. The Volara sheet (running the full length of the board) was laid over this prepared surface; it was then gently pressed down toward the backboard evenly. The pressure against the bamboo skewers punched holes through the Volara's surface, thus marking the location of every mount and their associated screw holes. The Ethafoam inserts and large brass clips were laid over the Volara holes and their contours were marked and cut out of the Volara to fit the mount directly against the board. This process was repeated for the board's upper half as well (fig. 18). The tiles were then installed, one by one, onto the Volara-covered backboard, making adjustments as needed to ensure a secure mount.

Fig. 18. Backboard fitted with foam inserts and Volara (Courtesy of the Brooklyn Museum)

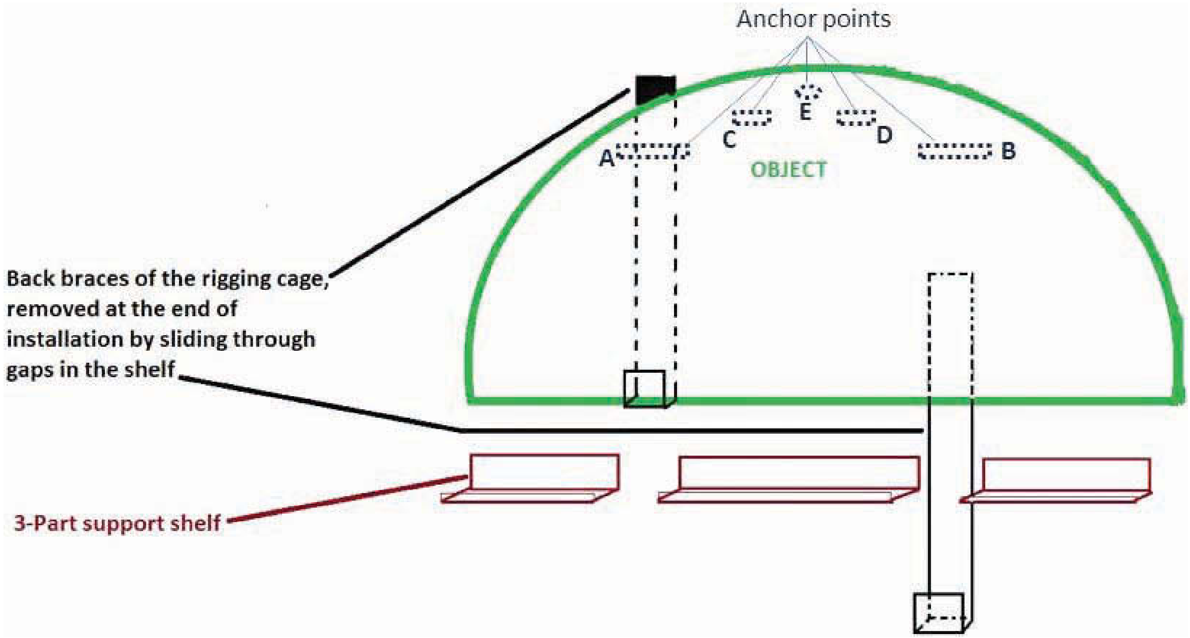

Fig. 19. Diagram illustrating how the rigging apparatus is removed and how the relief hangs on the wall (Courtesy of the Brooklyn Museum)

In locations where the tiles were close to each other and risked contacting, an Ethafoam wedge covered in thin black Volara was fashioned and placed between the tiles. This helped further secure and stabilize the assemblage as a whole. Final touches were made at the end, including inpainting of brass mounts and platforms to match surrounding tiles and backboard, and covering the visible white Ethafoam inserts and padding with black Volara.

Fig. 20. *Resurrection of Christ* after treatment, inside its inner crate (Courtesy of the Brooklyn Museum)

10. RIGGING

To enable installation of the object for exhibition, the MFA collaborated with us to devise and assemble custom equipment for rigging the full assemblage. A Mylar template of the verso of the backboard, which outlined its outer edges and metal armature, was first sent to the MFA for reference so that they could fabricate the necessary elements. The resulting rigging system, designed by Dante Vallance, collections engineer at the MFA, allows the relief to be lifted with a gantry and secured to a wall, where it is supported by a structural shelf. The tailor-made rigging apparatus was assembled and attached to the lunette's backboard at the Brooklyn Museum after all of the tiles had been mounted. It was then used to lift the lunette into a vertical position for packing, and remained on the object while it was transported to Boston. Once at the MFA, the same apparatus was used to install the object onto the exhibition wall (fig. 19).

11. CONCLUSION

The full-scale treatment of the *Resurrection* has not only allowed this masterpiece to be included in the MFA's groundbreaking exhibition, where it could be appreciated in context with other great works of its kind, but it has also brought the dynamic, colorful relief back to life so that it can be enjoyed by new audiences for years to come (fig. 20). It is a rare occurrence that conservators are able to know the complete history of an object. Because the *Resurrection* had only been in two locations—the Antinori Villa and the Brooklyn Museum—after leaving the Giovanni della Robbia workshop, evidence of what happened to the object in those two locations could be unraveled. While questions remain, the object allowed its story to be told through the remaining evidence of past interventions. The lab's ability to identify and study original and restoration materials gave us the confidence to make appropriate treatment decisions regarding cleaning, handling of old restorations, and reconstruction, as well as learn more about the workshop's original practices. Extensive collaboration between conservators and the mount maker throughout the process enabled us to devise a mounting system that made each tile secure in preparation for travel. The 19th century hardware that has been stored in the conservation lab's study collection and the terracotta restorations that remain on the object can also serve as examples of conservation history. Reusing the previously constructed backboard not only saved time and reduced costs but allowed the historic board to remain with the object. We hope that the approach and decision-making process used during this treatment can serve as an example for future projects of this type and scale.

ACKNOWLEDGMENTS

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NOTES

1. For studies of della Robbia clay composition, see Bouquillon 2011; Olson and Barbour 2011 and 2001; and Hykin et al. 2007.

2. Although the use of copper as the main colorant for green reflects findings of other studied examples (Zucchiatti and Bouquillon 2011; Hykin et al. 2007; Agosti et al. 1997), it differs from the results of Sendova et al. who found green to be a subtractive mixture of blue and yellow colorants in a relief attributed to Luca (2007). Thus, some limited variation appears to have existed in workshop mixtures.

3. Multiband imaging was performed with a modified Nikon D610 DSLR (IR/UV filters removed). Visible images were taken with an IDAS-UIBAR filter (375- to 700-nm bandpass) attached to the lens, illuminated with Genaray SpectroLED-14 lights (output: 5600 K). UV reflectance images use an X-Nite BP1 (320- to 670-nm bandpass) and X-Nite 330 filter (270- to 375-nm bandpass). Infrared reflectance images were taken using mounted lights in the imaging area, with an X-Nite 830 filter (830-nm longpass) attached to the lens.

REFERENCES

Agosti, Giovanna, Andreina Andreoni, Bruno Fabbri, Francesca Kumar, Giancarlo Lanterna, Claudio Mingazzini, Pietro Moioli, Rosanna Moradei, Claudio Seccaroni and Maria Grazia Vaccari. 1997. “Una pala in terracotta invetriata di produzione Robbiana: metodi integrati di indagine e restauro.” *OPD Restauro* 9. 73-90, 64-67.

Alden, Harry A. 2015. Wood identification report. Alden Identification Service, Chesapeake Beach, MD.

Antinori, Piero. 2007. “The Antinori Family from Archive Documents and Family Memories.” In *Futuro Antico: The History of the Antinori Family and their Palace*, edited by Giovanna Naldi. Florence: Fratelli Alinari. 8–149.

Barbour, Daphne and Roberta J.M. Olson. 2011. New methods for studying serialization in the workshop of Andrea Della Robbia: technical study and analysis. In *Della Robbia: dieci anni di studi/ dix ans d’études.* Genova: Sagep Editori. 56–61.

Board of Trustees. 1898. Minutes from a meeting of the board, Oct. 14. Unpublished document. Brooklyn Museum.

Bouquillon, Anne. 2011. “Terra, vivi per me cara e gradita…” In *Della Robbia. Dieci anni di Studi – Dix ans d’études*, edited by A. Zucchiatti, A. Bouquillon, and M. Bormand. Genova: Sagep é Editori. 24–31.

Brooklyn Institute of Arts and Sciences, 1899. *Eleventh Year Book of the Brooklyn Institute of Arts and Sciences.* Brooklyn: Brooklyn Institute of Arts and Sciences.

Cambareri, Marietta. 2016. Della Robbias in the New World. In *Della Robbia: Sculpting with Color in Renaissance Florence*. Boston: MFA Publications. 105–127.

Derrick, Michele. 2016. Analysis of red pigment report. Museum of Fine Arts, Boston, MA.

Dow Chemical Company. 2017. ETHAFOAM™ 900 polyethylene foam technical product information. Accessed 04/21/17. http://www.qualityfoam.com/docs/ethafoam-900.pdf

Duran Adrian, Jacques Castaing, Patrice Lehuédé , and Anne Bouquillon. 2011. “Les pigments jaunes des glaçures de l’atelier des Della Robbia.” In *Della Robbia. Dieci anni di Studi – Dix ans d’études*, edited by A. Zucchiatti, A. Bouquillon, and M. Bormand. Genova: Sagep é Editori. 44–49.

Hykin, Abigail, Flavia Perugini, Richard Newman, and Marietta Cambareri. 2007. "An overview of the treatment and analysis of Italian Renaissance terracotta sculpture at the Museum of Fine Arts, Boston." *Glass and Ceramics Conservation 2007: Interim Meeting of the ICOM-CC Working Group preprints*. Nova Gorica. Goriski muzej Kromberk: ICOM-CC Working Group. 120–129.

Hykin, Abigail. 2016. "Materials and Techniques." In *Della Robbia: Sculpting with Color in Renaissance Florence*. Boston: MFA Publications. 129–143.

Kingery, David and Meredith Aronson. 1990. "The glazes of Luca della Robbia." *Faenza; Bolletino del museo internazaionale delle ceramiche in Faenza* 77: 221-225.

Le Hô, Anne-Solenn and Laurence Labbe. 2011. "L'emploi de la polychromie à froid dans le sculpture robbiesque: étude de cas. In *Della Robbia. Dieci anni di Studi – Dix ans d'études*, edited by A. Zucchiatti, A. Bouquillon, and M. Bormand. Genova: Sagep é Editori. 96–103.

Newman, Richard. 2016. Brooklyn *Resurrection* Summary of Analyses. Museum of Fine Arts, Boston, MA.

Olson, Roberta J. M. and Daphne Barbour, 2001. "Toward a new method for studying glazed terracottas: Examining a group of tondi by Andrea della Robbia." *Apollo* 154 (475): 44–52.

Oxford Authentication. 2016. Thermoluminescence analysis report. Oxfordshire, England.

Padeletti, G. and P. Fermo. 2003. "How the Masters in Umbria, Italy, Generated and Used Nanoparticles in Art Fabrication During the Renaissance Period." *Applied Physics A: Materials Science and Processing* 76 (4): 515–525.

Pappalardo, G., E. Costa, C. Marchetta, L. Pappalardo, and F. P. Romano. 2004. "Non-destructive Characterization of della Robbia Sculptures at the Bargello Museum in Florence by the Combined Use of PIXE and XRF Portable Systems." *Journal of Cultural Heritage* 5 (2): 183–188.

Pearlstein, Ellen, Jane Carpenter, Beverly Perkins, and Leslie Ransick-Gat. 1989. Examination and Treatment Report, March. Brooklyn Museum, Brooklyn, NY.

Riccardelli, Carolyn, Jack Soultanian, Michael Morris, Lawrence Becker, and George S. Wheeler. 2014. "The Treatment of Tullio Lombardo's *Adam*: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49: 49–116.

Sendova, M., V. Zhelyaskov, M. Scalera, and C. Gulliford. 2007. "Micro-Raman Spectroscopy Characterization of della Robbia Glazes." *Archaeometry* 49 (4): 655–664.

Zucchiatti, Alessandro, Anne Bouquillon, István Katona and Assunta D'Alessandro. 2006. "The 'Della Robbia blue': A case study for the use of cobalt pigments in ceramics during the Italian Renaissance." *Archaeometry* 48 (1): 131-152.

Zucchiatti, Alessandro and Anne Bouquillon. 2011. "Les glaçures: atout maître des Della Robbia." In *Della Robbia. Dieci anni di Studi – Dix ans d'études*, edited by A. Zucchiatti, A. Bouquillon, and M. Bormand. Genova: Sagep é Editori. 32–43.

SOURCES OF MATERIALS

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STRUT YOUR STUFF: THE USE OF STRUT CHANNEL AS A SUPPORT SYSTEM FOR OBJECTS

KARL KNAUER

The Naval History and Heritage Command's newly formed Conservation Branch has developed several means of supporting heavy objects, such as a ship's bells, using assemblies constructed from the widely available strut channel and accessories.

KEYWORDS: Strut channel, Unistrut, Superstrut, Bells, Ship's bell, Mount, Pallet, Naval History and Heritage Command, Navy

1. INTRODUCTION

The Conservation Branch of the Naval History and Heritage Command (NHHC), founded in September 2015, is currently in the process of developing its laboratory and facilities within the NHHC Collection Management Facility in Richmond, Virginia. As equipment and resources are procured during this initial setup phase, the Conservation Branch has developed some workarounds and what we believe are novel methods for supporting objects using a strut channel.

The strut channel, also called a metal framing channel, is a widely available "standardized formed structural system" (Wikipedia. s.vv. "Strut channel") available in variations, including lengths up to 20 ft. with different permutations of perforations or slots. It is available in several electroplated galvanized finishes, electrogalvanized as well as stainless steel alloys. One of its great strengths is that components are assembled with standard threaded fasteners to make weldless connections with simple tools, such as a hacksaw and wrench. It is commonly used in industrial spaces to support electrical wiring, network cables, and piping and is known by several brand names, including Unistrut and Superstrut. It can be made into strong shapes using easily available connector parts of various orientations.

2. TILTING APPARATUS

Accessing the underside or interior of heavy objects can be harrowing; positioning and keeping a heavy object securely in a desired orientation can be difficult. Such is the case for many of the larger, heavier ship's bells in the NHHC collection, which are smooth, rounded shapes with few places to grip safely. Underside access may be needed to assess a bell's interior condition (e.g., checking for the presence of paints containing lead pigments), to assess or remove the bell's clapper mechanism, or to install hanging hardware.

Rather than relying on rope or strap rigging methods to attempt accessing the interior of moderately sized bells, I devised a tilting rig constructed from sections of a strut channel to tilt such bells to a 90° orientation, thereby allowing such access.

This contraption acts as a second-order lever. For example, when tilting a bell weighing 240 lbs. ("W") with an opening diameter of 20 in. ("X") and using standard 60-in. lengths of strut channel ("L"), we would need to provide only 80 lbs. of force ("F"), as demonstrated in this equation:

$$F \times L = W \times X$$
$$F = (W \times X) / L$$
$$\text{e.g., } F = (240 \text{ lbs.} \times 20 \text{ in.}) / 60 \text{ in.} = 80 \text{ lbs. of force}$$

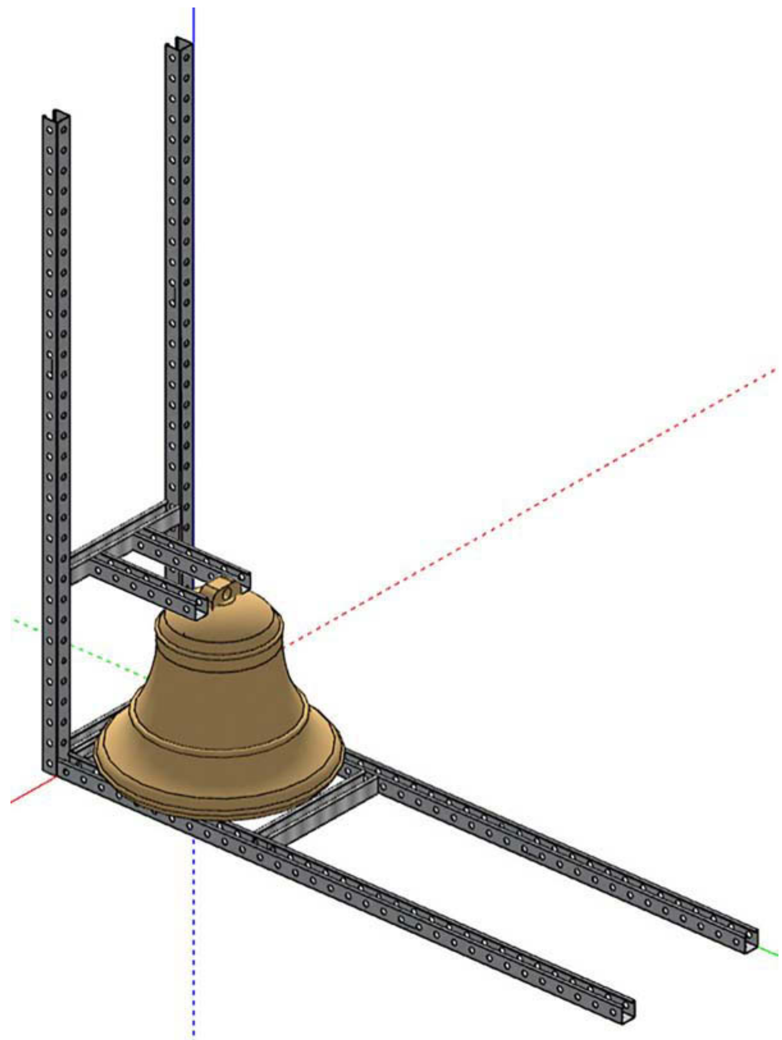

Fig. 1. Concept design for a tilting rig constructed from strut channel (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-003)

This threefold mechanical advantage is preferable to risking the physical safety of the person attempting to lift or tilt the bell's entire weight of 240 lbs. or risk damaging the object by relying on a concentrated area of the object's rim as the tipping point.

The actual assembly of this rig was accomplished using many of the components depicted in figure 2. Standard 60-in. lengths of strut channel were joined with 90° strut corners to serve as the tipping point, with the ends of length mitered so that there could be two bolts through each length into this corner component. Flat corner brackets and four-hole tee brackets were used to attach the cross-braces.

To construct the rig around an actual object, I started by prefabricating the base section, with the lengths of strut channel spaced at a distance wide enough to support the object as well as allow underside access upon completion of the tilt. The outermost cross-brace was left off at this point so that this prefabricated base assembly would be able to slide under the bell unencumbered, as the bell was elevated slightly with wooden cribbing at its center to accommodate the rail-like lengths of the base section. I slid the preassembled base section under the object and transferred the object's weight to the strut channel rails of

Fig. 2. A selection of strut channel and associated fittings (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 170515-N-NO147-001)

this base by removing the wood cribbing. Pieces of cut cardboard tube and blue board were used to protect the bell's rim from direct contact with the strut channel lengths.

The outermost cross-brace could then be applied to the base section, as depicted in figure 3. This was followed by attaching the two upright lengths of strut channel and both of the cross-braces. The upper cross-brace was positioned at a height just above the head of the bell so that two cantilevered sections of strut channel could be attached to the brace around the bell's topmost extension, thereby preventing the bell from moving along the y-axis of the rig. Cardboard edge protectors and thick polyethylene sheeting were used to protect the surface of the copper alloy bell from these steel strut channel extensions.

The contoured gap between the back of the bell and the uprights was blocked with enough material to fill the space and help support the object when tilted, such as sections of wooden cribbing and wedges as

Fig. 3. The base section of the partially assembled rig with a bell in place (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-001)

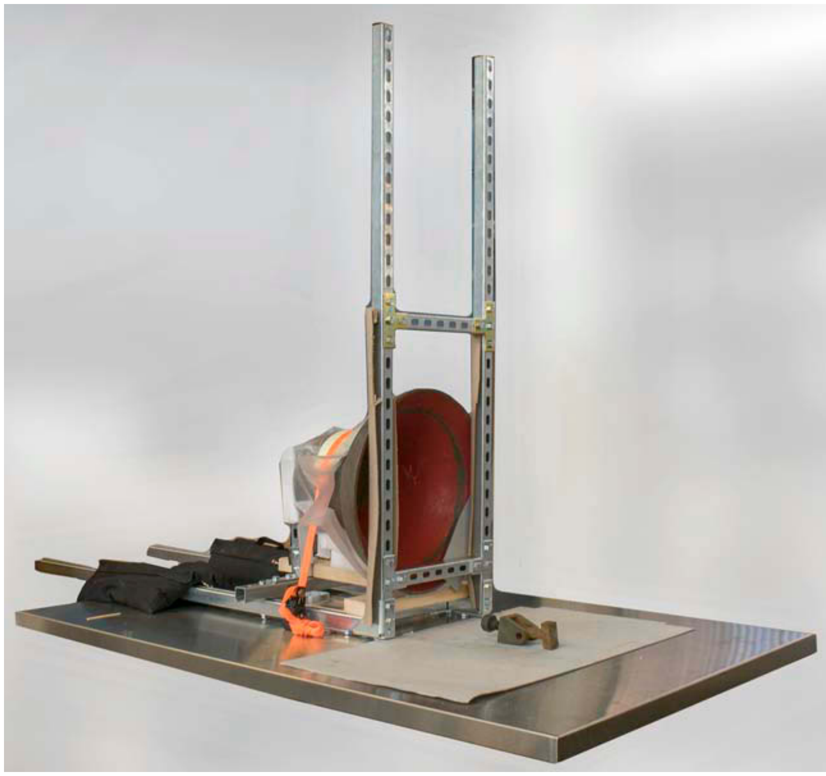

Fig. 4. The fully assembled rig on a tabletop with an approximately 240 lb. bell attached, in its tilted orientation to make the underside and interior accessible, in this instance to assess the interior paint and remove the remnants of the clapper mechanism (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-004)

well as polyethylene foam along the bell's surface at the rear. Ratchet-strapping ensured that there was no lateral movement.

Once this rig was fully assembled and the object was fully secured, the bell was tilted, with force applied to the lengths of strut. Just before reaching the tipping point, a second person guided the bell down to its new orientation by carefully pulling on the strut channel lengths that were originally upright. Once in its final position, I had the option of applying weights to the strut channel lengths that were horizontal for an added sense of security. The underside and interior of the bell were then accessible and relevant condition issues were addressed.

3. MOUNTING: A CASE STUDY

The Conservation Branch was asked to develop a storage solution for a badly cracked, 135-lb. ship's bell from the USS *Rainier* (AE-5; Lassen-class ammunition ship).

Typically, bells in the collection are stored by strapping them to a pallet, either above the waist or at the head. With this bell, we feared that strapping may put additional stress on the crack and risk propagating it, as illustrated in figure 5.

As an alternative to strapping, I proposed creating an interior column to provide support to the bell on the underside/interior of the bell. Although I first considered using a square steel tube (i.e., hollow structural

Fig. 5. A mock-up demonstration of stresses that may occur in a cracked bell with the downward force from strapping at the top of the bell or above the waist (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-006)

section) to achieve this, I realized that it would require laborious modifications. Additionally, we did not have access to welding equipment. Instead, I chose a component known as a “post base,” which is designed for use with a strut channel and secures it in a vertical orientation perpendicular to this base.

Strut channel column load data provided by the manufacturer indicate that the length needed to support this particular bell, a length between 12 in. and 18 in., would be able to support column loads on the order of 10,000 lbs. (Thomas & Betts 2015). These column loads already incorporate safety factors but are clearly sufficient for a bell of this weight.

I sought a pallet as a surface upon which to attach the post base and found a 24-in. square high-density polyethylene (HDPE) pallet manufactured by Orbis, which is closer to the diameter of this bell and preferable to the larger standard-size pallet, 48 in. × 40 in. I drilled through the HDPE pallet and used bolts, washers, and nuts to secure the post base to it (fig. 6).

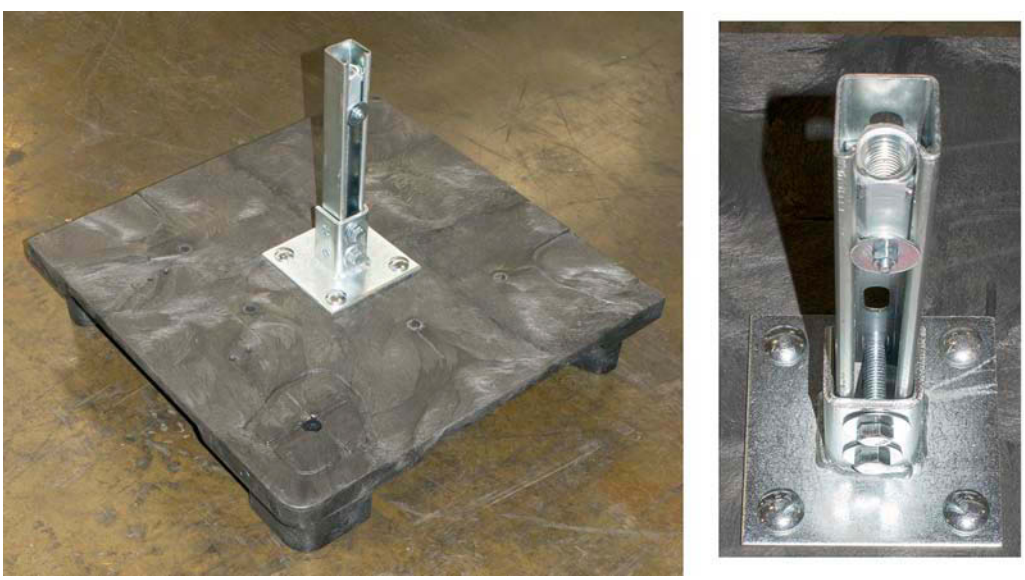

Fig. 6. The strut channel affixed to a pallet with a post base and hardware to serve as a mounting column, with inset detail of the strut channel component and accessories (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-005)

Fig. 7. A diagram illustrating the modified coupling nut, washers, and isolating layers attached to the USS *Rainier* bell prior to lifting and mounting (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-007)

I installed a modified coupling nut through the hole in the bell's head and secured it with a bushing and set screws, as pictured in figure 7. Several washers and isolating layers were added to protect the interior paint layers as well as the bell metal surfaces.

The added benefit of this threaded assembly attached to the bell was that it could be used not only to secure the bell to the mount at the final step but could also be used to lift the bell onto the column in the first place. We lifted it by using a shouldered machinery eye bolt in the coupling nut assembly on the bell in conjunction with a chain hoist and gantry.

Finally, once the bell was in place on the mount, I removed the lifting eye bolt and passed a longer bolt through the threaded assembly attached to the bell and into the second coupling nut that was secured earlier within the strut channel column.

Fig. 8. The USS Rainier bell on its final, secured, strut channel assembly (US Navy photo by Naval History and Heritage Command Collection Management Facility staff/Released 180305-N-NO147-002)

Although more of the bell's surface area is currently supported with the threaded assembly washers (relative to the surface area of the rim's edge), the bottom of the supporting post base caused deflection in the HDPE pallet. This deflection occurred over the course of several weeks as we waited for the rim-supporting polypropylene shims, brand name "Wobble Wedges," to arrive. Fortunately, those shims worked well to distribute some of the weight at the rim and to alleviate most of the HDPE pallet deflection. However, such deflection may not have occurred in the first place if the shims had been used soon after mounting the bell on the strut channel column.

4. CONCLUSION

It is hoped that these strut channel systems will prove useful to conservators and others tasked with collections care. The affordability, ubiquity of component parts, and ease of assembly make strut channel systems a viable and attractive option for those in need of customizable solutions within the confines of limited resources. We will continue to develop strut channels for other applications and look forward to the adaptations made by others for varied collections materials.

ACKNOWLEDGMENTS

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REFERENCES

Thomas & Betts. 2015. Superstrut Metal Framing System. Accessed June 1, 2017. https://www.reynoldsonline.com/ASSETS/DOCUMENTS/ITEMS/EN/TBCOH1041_2X6_Broc.pdf

Wikipedia. s.vv. “Strut channel.” Last updated May 31, 2017. https://en.wikipedia.org/w/index.php?title=Strut_channel&oldid=783177664

FURTHER READING

Lever Mechanical Advantage Equation and Calculator—Case #3. Engineers Edge, LLC. Accessed June 1, 2017. http://engineersedge.com/calculators/levers/page_levers_3.htm

SOURCES OF MATERIALS

Superstrut, 12-Gauge Electrogalvanized Half Slot Steel Strut Channel, Strut Channel Connectors, and Threaded Components
The Home Depot
12300 Jefferson Davis Hwy.
Chester, VA 23831
http://www.homedepot.com

Post Base, Morris Products 17454 Single Channel, 4 Hole, Square
Morris Products
53 Carey Rd.
Queensbury, NY 12804
http://www.morrisproducts.com

24 × 24 Modular Pop Pallet, HDPE
ORBIS Global Headquarters
1055 Corporate Center Dr.
Oconomowoc, WI 53066
800-890-7292
info@orbiscorporation.com
http://www.orbiscorporation.com/products/plastic-pallets/retail-display-pallets/24-x-24-modular-pop-pallet

Wobble Wedges, Hard, Natural [Color], Polypropylene
PO Box 18144
Boulder, CO 80308
http://www.wobblewedges.com

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MODIFYING RIVET FASTENERS IN HISTORIC ARMORS: SEVERAL OPTIONS

KATHERINE CUFFARI AND DEBRA BRESLIN

A multiyear arms and armor treatment project at the Philadelphia Museum of Art introduced the occasional need to remove and replace the rivet fasteners that join plates and straps in historic armor objects. Several systems were employed to modify fasteners over the course of the project, with multiple aims: retaining the required strength of the fastener system; harmonizing the aesthetic of the armor object with minimal visible alteration; and minimizing the risk of mechanical damage during the course of treatment and in the future. The presented solutions were not devised solely by the authors; one was generously shared with the authors by an armor conservator and several were developed in concert with mount makers. Together, this collection of approaches to problems posed by armor fasteners was shared in the 2017 AIC Objects Specialty Group "tips" session.

KEYWORDS: Armor, Rivet, Reversible fastener

1. INTRODUCTION

The Philadelphia Museum of Art (PMA) is home to a notable collection of over 1,200 European arms and armor objects, the majority of which were bequeathed to the museum in 1977 by collector Carl Otto Kretzschmar von Kienbusch. During a recent multiyear project to prepare collection objects for publication in a pending catalogue, objects conservators encountered a range of challenges posed by fastening systems that joined straps and plate armor components. Like many types of objects seen as both utilitarian and highly collectible, armor objects have a history of significant mechanical and structural repair. Though earlier restorations often employed blacksmithing techniques, in recent decades there has been a strong engagement of modern conservation ethics in the treatment of these collections within museum contexts.

European plate armors are generally constructed of individual steel or ferrous metal plates, or lames, joined by leather straps, rivet fasteners, and occasional hinges. Components to protect different parts of the body are connected to one another with straps and buckles; the leather does the work of supporting and articulating the steel. Metal rivets are used to affix leather straps to the undersides of the plates—the straps often link multiple plates in series to create articulating components that bend along with the body in motion. Rivets also attach hinges, buckles, and linings to armors. Often, a domed rivet head is visible on the exterior of the armor plate, and the narrow solid post of the rivet passes through holes in the plate and leather. The bottom end of the post is peened with a hammer during fabrication, spreading the metal to fully cover the hole and create pressure on the join. "Blind" rivets, flat or peened on both top and underside surfaces, are used when successive plates are layered and must lie flush against one another. Sliding rivets pass through an oblong slot in the steel instead of a round hole, allowing for additional movement along the plane of the armor plate.

Given its strength and flexibility, leather is perfectly suited for joining steel plates during an armor's use life. Unfortunately, the nature of leather deterioration proves deeply problematic to the objects over time. Deteriorated straps can prevent the proper closure or assembly of armor components. In the worst cases, depending on the nature of the armor's structure, leather failure can lead to the complete detachment and disassociation of individual plates from a single component. Consequently, armors almost universally have been structurally repaired and leather straps replaced multiple times with the aim of keeping (or making) plate armor components intact and strong enough to be assembled. The removal and replacement of damaged leather necessitates the destruction of the rivets. Examining the interiors of armor objects is particularly revealing, as they usually bear several generations of leather and widely varied rivets and washer types (fig. 1).

Fig. 1. Interior of a gorget (neck defense) showing different generations of leather straps and multiple fastener and washer types. Artist unknown, German, *Field Armor*, c. 1500, ferrous metal, copper alloy, leather, Philadelphia Museum of Art, 1977-167-4, Bequest of Carl Otto Kretzschmar von Kienbusch (Courtesy of Philadelphia Museum of Art)

While the presence of original leathers is unusual, it is obviously cause for extreme care. We only modified or removed straps that we and the curator were confident were 19th or 20th century restorations. In the interest of minimal intervention, we repaired and reinforced existing leather straps without removing fasteners whenever possible.

The use of traditional hammer-peened rivets involves risks that conservators prefer to avoid on historic objects, including drilling or grinding to remove fasteners and hammering in immediate proximity to historic surfaces to secure replacement rivets. As an additional challenge, the proportions of commercially available solid rivets are incompatible with historic armor. As a result, we employed alternative solutions to peened rivets when possible. In some instances, existing fasteners were structurally sound and serving their intended function but were aesthetically disharmonious with the rest of the object. Surface treatments were devised that allowed for retention of these fasteners.

Structural problems in armor objects can be addressed in multiple ways, some of which do not require physical intervention. Custom mounting structures can be fabricated to support component parts of an armor without altering the object, for example. This short presentation focused solely on instances in which modification and replacement of mechanical fastening systems was necessary to accommodate anticipated handling, photography, storage, interpretation, and display.

2. AESTHETIC ALTERATION OF EXISTING FASTENERS

One breastplate in the collection presented two examples of problematic fasteners from previous restoration efforts (fig. 2).

Fig. 2. Artist unknown, German, *Breastplate with Fauld and Tassets*, 1475–1500, iron alloy, Philadelphia Museum of Art 1977-167-134, Bequest of Carl Otto Kretzschmar von Kienbusch (Courtesy of Philadelphia Museum of Art)

Several modern screws had been employed in a prior restoration. The screw-and-nut assemblies were a conservative choice—they were reversible, performed the necessary joining function to protect the object, and had been safer to install than peened rivets. The appearance of slotted heads on the exterior of the armor, however, was aesthetically problematic (fig. 3).

We also encountered rivets that were mismatched in size and metal surface when compared to surrounding fasteners (e.g., one steel rivet head surrounded by brass rivet heads). The heads of these rivets were often undersized in comparison to the other rivets on the armor, likely due to the aforementioned problem of the proportions of modern solid rivets (fig. 4).

To address the aesthetic problems posed by otherwise effective fasteners, we created sheet-metal caps that were adhered to the existing fastener heads. After unsatisfactory initial experiments with the heads of upholstery tacks and with the assistance of a mount-making colleague, we turned to custom hemispheres fabricated of sheet brass. Circles were cut from sheet stock with a jeweler's saw and shaped with a dapping die and punches (fig. 5).

The caps were mechanically distressed; toned as needed with cold chemical patinas, toned waxes, or lacquers; and adhered to the fastener head with a viscous solution of Paraloid B-48N in acetone bulked with glass microballoons. The resultant caps balanced the appearance of the existing fasteners with the surrounding rivet heads without requiring removal and replacement (fig. 6).

Fig. 3. Slotted-head screw used as fastener on tasset, surrounded by brass-headed rivets. 1977-167-134 (Courtesy of Philadelphia Museum of Art)

3. RIVET REPLACEMENT

Some condition problems necessitated the removal and replacement of fasteners, particularly when the replacement of straps was required and when fasteners were missing entirely. In these instances, we used grinding and cutting bits on variable-speed rotary tools on the interior of the object to remove the peened edges from the rivet post and free the underlying washer. Protective barriers were used to

Fig. 4. Undersized steel rivet head surrounded by larger brass-headed rivets. 1977-167-134 (Courtesy of Philadelphia Museum of Art)

Fig. 5. Dapping die and punches with new covering caps made from cut sheet brass (Courtesy of Philadelphia Museum of Art)

guard against damage of the surrounding surfaces. Several replacement fastener types were then employed in reassembly depending on the configuration of the object and the work required of the fastener.

Fig. 6. After treatment images of brass caps adhered over the existing fastener heads shown in figures 3 and 4 (Courtesy of Philadelphia Museum of Art)

Fig. 7. Assembled, brass-plated threaded fastener with locknut and integral washer, fabricated by armor conservator Ian Ashdown.

3.1 Threaded Fastener

Whenever the configuration of armor plates provided sufficient space for use of a nut on the interior surface, we used reversible threaded fasteners to minimize risk in assembly and ease retreatment. During a consultation about armor treatment questions, armor conservator Ian Ashdown generously gave us a threaded fastener assembly that he fabricated, which served as our prototype (fig. 7).

We began with two options for rivet heads. Using a jeweler's saw, we either removed the heads from the restoration rivets that we had removed from the armor or we removed the heads from new commercial solid rivets. These heads were soldered onto a threaded rod of appropriate gauge (generally 4-40 or 6-32) and the rod was cut to length after a test assembly. Nuts with integrally attached smooth washers (nonmarring locknuts with spring-lock washers, also called Keps nuts or "K-nuts" without external teeth) were purchased to match the threaded rod. The locknuts with washers were dipped in a nitric acid solution to remove their bright galvanized surface and patinated with Birchwood Casey Presto-Black to minimize the industrial appearance of the fastener on the interior of the object. Figure 8 illustrates the fabrication steps for fastener and washer assembly.

Rivet heads were toned with patinating solutions, toned lacquers, and/or toned waxes. Threaded fasteners used to attach waist straps to a backplate are illustrated in figure 9.

3.2 Split-Tube Fastener

In concert with mount-making colleagues, we devised another option that was useful when a nut used to anchor a threaded fastener would have damaged an underlying plate and when no individual fastener was bearing a lot of weight. For this split-tube fastener, we soldered an annealed brass tube to the rivet head. This "rivet" was held in a jig and a jeweler's saw used to bisect most of the length of the tube (fig. 10).

Fig. 8. Fabrication of a threaded fastener at PMA: reused or new rivet head soldered to a threaded rod, and locknut with an attached washer darkened for use on the interior (Courtesy of Philadelphia Museum of Art)

When inserted through a strap, steel plate, and washer, this annealed tube was pliable enough to be spread apart with a steel awl. When fully opened, the splayed brass fastener effectively compressed the sandwiched layers, lay flat against the interior surface, and could easily be removed without the use of grinding tools (fig. 11).

3.3 Peened Rivets

In a few instances, neither of the previous solutions were viable options. Solid peened rivets were employed when an underlying armor plate prohibited the use of a threaded fastener and nut assembly and individual fasteners and straps needed to bear significant weight. Peened rivets were also employed to

Fig. 9. Threaded fastener attaching a waist strap to a backplate. Artist unknown, Northern Italian, *Gorget and Cuirass for use in the field*, ca. 1510, etched and blackened ferrous metal, leather, Philadelphia Museum of Art, 1977-167-150, Bequest of Carl Otto Kretzschmar von Kienbusch (Courtesy of Philadelphia Museum of Art)

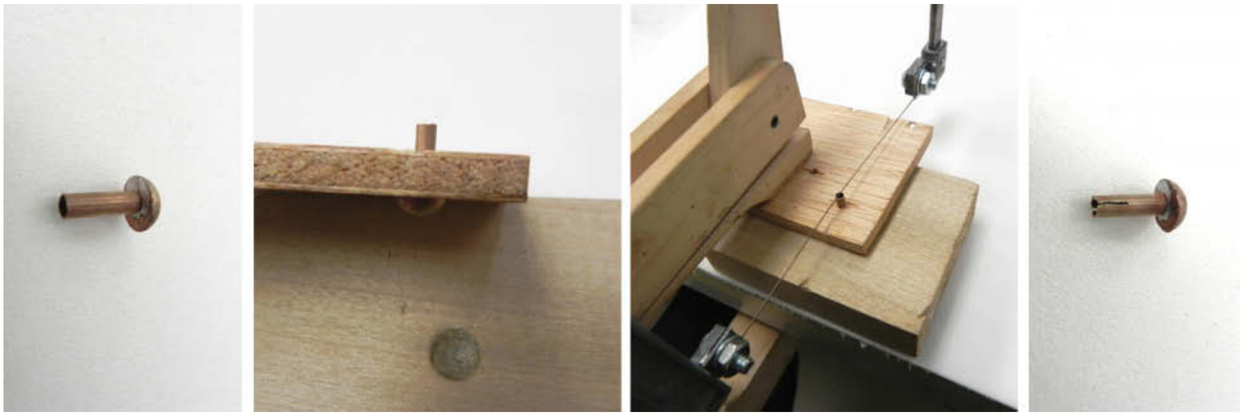

Fig. 10. Steps in fabrication of a split-tube fastener (Courtesy of Philadelphia Museum of Art)

attach buckles onto straps since a smooth underside surface was required. For the breastplate, backplate, and gorget seen in figure 9, the curator requested wholesale replacement of straps because the prior restoration straps were too short for the components to be assembled with appropriate proportions. As the weight of the breastplate and backplate is borne by the buckled shoulder straps, which anchor at only one point each, split-tube fasteners were not a good choice. These plates also lie directly on the gorget when assembled, leaving no room for the interior nut that would be required to affix a threaded fastener.

The proportions of commercial solid rivets do not match those of historic armor objects; the heads of large rivets tend to match the most recent rivets on the objects, but the posts are too large to fit through the holes in the plates. Conversely, the rivets that fit through the holes have heads that are too small (fig. 12).

We used a belt sander or lathe to reduce the diameters of the posts of large rivets and cut the posts to appropriate length after a test assembly. We created a small rivet set in a solid 2-in.-diameter brass rod using a burr grinder in a rotary tool to create a small semicircular recess that could accommodate and

Fig. 11. Exterior and interior views of a split-tube fastener holding a strap onto a pauldron (shoulder defense). Pompeo della Cesa, *Armor for tournaments fought on foot over the barrier*, ca. 1590, etched, gilded, and blackened ferrous metal, leather, Philadelphia Museum of Art 1977-167-37, Bequest of Carl Otto Kretzschmar von Kienbusch (Courtesy of Philadelphia Museum of Art)

Fig. 12. Comparison of modern commercial rivet (left) and historic restoration rivet (center); commercial rivets held near holes in a breastplate (right).

protect the rivet head during peening. The small size of the rivet set allowed for flexibility in placement, which is helpful when one needs to safely support the entire armor object in a configuration that allows for hammering of one rivet post. During attachment of the new leather straps, the rivet posts were peened over washers, using a ball peen hammer and the rivet set (fig. 13). Steel rivets were used on this armor to match the surrounding hardware on the object (fig. 14). We used brass rivets when brass-capped

Fig. 13. Rivet set and ball peen hammers (Courtesy of Philadelphia Museum of Art)

Fig. 14. Peened fastener attaching shoulder strap to backplate. *Gorget and cuirass for use in the field*, 1977-167-150 (Courtesy of Philadelphia Museum of Art)

rivets already existed on the object. Brass posts were immediately discernable as replacement fasteners from the interior of the plate, and the greater malleability of the metal facilitated the hammering process.

4. CONCLUSION

When modification or replacement of rivets and other fasteners in historic armor objects is required, a range of techniques can be employed to produce well-matched, sufficiently strong fasteners that minimize alteration of and risk to original components.

ACKNOWLEDGMENTS

We are extremely grateful for the generosity of a wide range of colleagues and for their willingness to share knowledge, expertise, and troubleshooting during our years of work with arms and armor collection objects at the PMA. We share particular thanks to the following for their contributions over the course of the project: Ian Ashdown, Conservator of arms and armor, Onnens, Switzerland; Edward Hunter, Armorer and Conservator, Metropolitan Museum of Art; Hermes Knauer, Conservator Emeritus, Metropolitan Museum of Art; Rebecca Kolodziejak, Mount Maker, PMA; Michael Studebaker, former Mount Maker, PMA; Dirk Breiding, the J.J. Medveckis Curator of Arms and Armor, PMA; Pierre Terjanian, Arthur Ochs Sulzberger Curator in Charge, Department of Arms and Armor, Metropolitan Museum of Art (formerly Curator of Arms and Armor, PMA); Sally Malenka, The John and Chara Haas Senior Conservator of Decorative Arts and Sculpture, PMA; Melissa Meighan, Conservator of Decorative Arts and Sculpture, PMA.

SOURCES OF MATERIALS

Solid Rivets, Threaded Rod, Locknuts with Washers, Brass Hollow Tubing, and Brass Sheet
McMaster-Carr
200 New Canton Way
Robbinsville, NJ 08691
609-689-3000
http://www.mcmaster.com

Jeweler's Saw, Dapping Die and Punches, and Silver Soldering Supplies
Rio Grande
7500 Bluewater Road
Albuquerque, NM 87121
800-545-6566
http://www.riogrande.com

Birchwood Technologies Presto Black BST4 for iron/steel, and Antique Black M20 for copper alloys
Birchwood Laboratories, LLC
7900 Fuller Road
Eden Prairie, MN 55344
800-328-6156
http://www.birchwoodtechnologies.com

Paraloid B-48N and Glass Microballoons
Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
http://www.talasonline.com

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"STENCIL FILLING" TECHNIQUE FOR CERAMICS AND THE USE OF RAKING LIGHT DURING THE FILLING PROCESS

PAULA ARTAL-ISBRAND

The filling of losses is one of the typical steps of a conservation treatment involving a broken ceramic (fig. 1). Each conservator has one's favorite materials, tools, and techniques to do this. I use a dental-grade plaster for larger losses and Flügger Acrylic Filler (fig. 2) for smaller losses. Rather than tinting my fill materials—both of which are white—I prefer to complete the filling work and integrate the fills through retouching in a separate step.

Filling the narrow margins along the adhesive joins without getting excess spackling compound onto the clean adjoining edges is practically impossible (fig. 3). Instead, the conservator has to go back and remove the excess once the fill has dried. This step is not only time-consuming but it can sometimes be difficult to remove the excess fully. This is especially challenging when the ceramic object is an unglazed or slip-finished earthenware, because the surface is rough and porous and traps the fine fill material, resulting in a whitish veil—or "ghosting"—that takes additional time to remove.

Fig. 1. Achilles Painter, Athens (Greece), *White-ground lekythos* (oil flask), 450–445 BC, terracotta with slip and added colors, 33.4 × 11.6 cm. Worcester Art Museum, 1900.65, before filling joins between sherds.

Fig. 2. Fl**ü**gger Acrylic Filler
Fig. 3. *White-ground lekythos*, detail, filling of sherd join margins with spackling compound deposits on unprotected sherd edges

To protect the edges adjoining a join from getting any or only minimal fill material onto them, I fabricate my own stencils from thick acetate film by cutting slits into them through which I apply the fill material (figs. 4 and 5). I typically fabricate several stencils with different-sized slits to fit different-shaped joins.

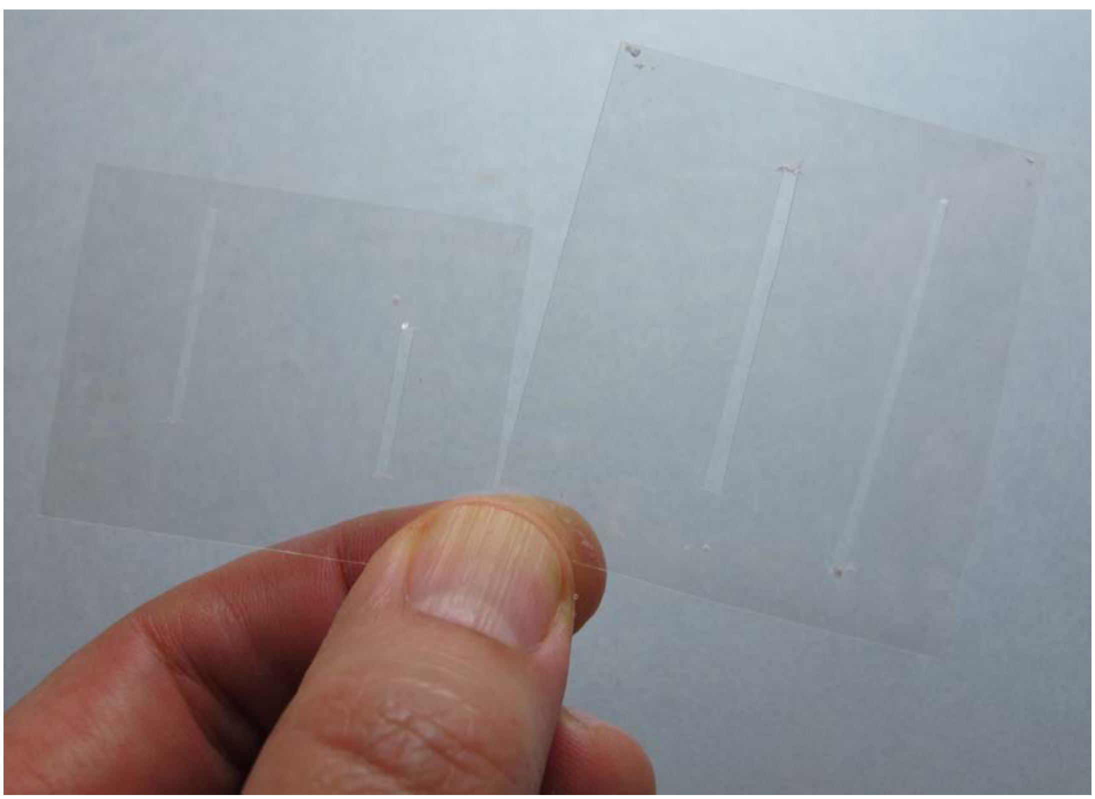

Fig. 4. Acetate film stencils

Fig. 5. *White-ground lekythos* (oil flask), Achilles Painter, detail, sequence of the stencil filling process using a micro-spatula, followed by shaping the fills with a scalpel

Fig. 6. Raking light setup for shaping fills on *White-ground lekythos*

Fig. 7. *White-ground lekythos*, detail, in raking versus normal-light conditions, the former showing the surface topography of fills much better than the latter

Sometimes two applications are needed because the fill material shrinks as it dries. The subsequent shaping of the fills is done using scalpels (see fig. 5) and glass paper under magnification. I do not use sandpaper because it is too abrasive for ceramics. Glass paper is softer.

I do fill-shaping work under raking light (figs. 6 and 7) only because under normal light it is difficult to discern the topography of the bright white fill. The raking effect, on the other hand, clearly shows the topography. I recommend using raking light conditions whenever using a white filling compound—this can apply not only to objects conservation but paintings conservation as well. One word of caution: make sure to use a cool light to avoid heating the surface of the artwork.

SOURCES OF MATERIALS

High-Quality Dental Plaster
Philadelphia Dental Plaster & Stone (formerly Samuel H. French & Company)
3195 Tucker Rd., Building A
Bensalem, PA 19020
215-245-0130
Tom Longstreth, Mfg. Director: 215-913-6349

Fl**ü**gger Acrylic Filler
TALAS
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
http://www.talasonline.com/

Acetate Film
Dick Blick Art Materials
401 Park Dr.
Landmark Center–Fenway
Boston, MA 02215
617-247-3322
http://www.dickblick.com/

FlexOvit Glass Paper
Amazon
https://www.amazon.com/Flexovit-Glasspaper-Sanding-Sheets-Grade/dp/B000Y8L80Y?th=1

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PEPPER WAX: AN ORGANIC SQUIRREL DETERRENT FOR LEAD

LAUREN FAIR AND ADAM JENKINS

Damage from squirrels to lead garden sculpture at the Winterthur Museum, Garden & Library occurred over several decades and was so widespread that almost every lead sculpture was relegated to storage to stop the problem. Within the last decade, many original lead pieces have been conserved and returned to the gardens. A cayenne pepper wax recipe has been employed as part of the annual maintenance program and so far has done the trick to deter squirrels. This tip presents the practical side of how to mix the wax, how to apply it, and what to expect in terms of its appearance and maintenance needs.

KEYWORDS: Lead, Cayenne, Pepper, Wax, Squirrels, Outdoor sculpture

1. INTRODUCTION

Many design movements were influencing American estates and gardens throughout the 18th to 20th centuries, with inspiration from the formal Italianate, Renaissance Italian, or picturesque English garden styles. Achieving these styles hinged on the right ornaments—from structures and benches to water features and sculptures, as well as sundials, astrolabes, armillary spheres, urns, and planters.

Historically, collecting garden ornaments was a luxury for the rich and a passion of the elite (Israel 1999). Such was the case with Henry Francis du Pont, founder of the Winterthur Museum, Garden & Library, who was not only an avid collector of American decorative arts but also an avid gardener. He was extremely involved in the decision making over the design of his gardens, down to every last detail (fig. 1).

While garden ornamentation was made in a variety of materials—such as stone, wrought iron, bronze, and cast stones—lead became a popular material in 17th- to 18th-century England, as it was easily worked and highly durable. Shops in London increasingly made and sold lead statuary, vases, cisterns, and decorative downspouts, which were in high demand by English nobility (New England Garden Ornaments 2015). This allowed for casting repetitive forms and made it even easier for American collectors to reproduce the English garden aesthetic, a tradition much revived at the end of the 19th century in America.

Of Winterthur's 400 plus garden ornaments, over 100 of them are made of lead. Only three of the sculptures are displayed outside in the gardens today; all of the others not mounted on a wall or roof are in storage (fig. 2). This is because over the years the squirrels had their way with them, and the only solution at the time was to bring them inside. According to institutional knowledge, this took place during the 1980s and 1990s. This was also during a time when garden objects had no comprehensive oversight. During the past ten years, this has happily changed, and now Conservation, Gardens, and Curatorial work together to manage a thorough and successful treatment and maintenance program of the garden object collection.

2. SQUIRRELS

There are over 200 species of squirrels, inhabiting six of the seven continents (fun fact: no squirrels live in Australia) (National Geographic 2010). The species that inhabit North America, and the United States

Fig. 1. Winterthur Gardens, view of reflecting pool from East Terrace (Courtesy of R. Lautman and Winterthur Museum)

specifically, can be grouped into five different types: the gray squirrel, of which there are several species, including the Western black squirrel; the fox squirrel, which is the largest; the little red squirrel; the ground squirrel; and the flying squirrel, which is nocturnal. The most common in the area of Eastern Pennsylvania and Delaware is the Eastern gray squirrel, or *Sciurus carolinensis* (fig. 3).

Squirrels' incisors grow continuously, as do those of all rodents and some other animal groups. This means that their teeth will continue to grow in length and ultimately compromise the health of the

Fig. 2. Images of lead sculptures in barn storage at Winterthur (Courtesy of Winterthur Museum)

Fig. 3. The Eastern gray squirrel

squirrel if not worn down through gnawing. Lead is in many ways an ideal material to chew on from a squirrel's perspective. It is a softer metal, and many of its corrosion products, including lead(II) acetate, are sweet. In fact, writers of the Classical Era (e.g., Cator the Elder, Columella, and Pliny the Elder) "…recommend lead (or lead-coated) vessels in the preparation of sweeteners and preservatives added to wine and food. The lead conferred an agreeable taste due to the formation of 'sugar of lead' (lead(II) acetate)" (Wikipedia. s.v. "Lead" 2017).

People always ask what, in fact, happens to squirrels when they chew on lead. We have found varying opinions on whether the squirrels get lead poisoning from their habit or if it passes through their system since they are consuming larger chunks and not breathing in particulates. Regardless, they live long enough to teach their young the practice and can do amazing amounts of damage to lead flashing, roof material, and, of course, to our lead garden sculpture (fig. 4).

3. PEPPER WAX AS A SOLUTION

There is a lot of scientific literature on controlling rodents, particularly the proceedings from many vertebrate pest conferences (Fitzgerald et al. 1995; Gill et al. 1995; Mason 1998). For some reason, there was a particularly large amount published in the mid- to late 1990s. Much of the research centers broadly on the use of peppers, capsaicin in particular, or cinnamon oil, particularly cinnamamide or cinnamaldehyde.

Fig. 4. Details of squirrel damage to lead sculptures

We learned about the idea of pepper wax for lead outdoor sculpture anecdotally: Adam heard about it being used in England, but we do not know who came up with the original idea. There are many academic publications about using pepper or cinnamon to control small mammals in the late 1980s—for instance, by adding it to birdseed to keep squirrels out of feeders (Fitzgerald et al. 1995).

We came up with a wax formula and began testing it in three places starting in 2014. In addition to Winterthur, we also employed it at the Mount Cuba Center in Hockessin, Delaware, where they have a variety of lead sculptures out in their gardens, and on several lead urns at Rittenhouse Square, a preeminent park in Philadelphia, Pennsylvania.

The wax recipe consists of the following:

- Three parts Be Square 195 microcrystalline wax—A wax with a melting temperature of approximately 195°F that contains normal paraffinic, branched paraffinic, and naphthenic compounds
- One part Be Square 175 microcrystalline wax—A wax with a melting temperature of approximately 175°F to 180°F containing a higher concentration of branched hydrocarbons that make it much less crystalline than paraffin or hard microcrystalline waxes
- 3% by weight Petronauba C—A synthetic carnauba wax used in modifying wax coatings to impart a degree of hardness that allows for adequate buffing and taking on a shine
- 25% by weight cayenne pepper[1]
- Equal amount by weight ShellSol D38 or other mineral spirits solvent

We make it by mixing the three waxes and melting them over a hot plate. Using an empty paint can from the hardware store as the mixing container works well. This is done under a fume hood and while wearing all appropriate personal protection equipment, including gloves, an apron, and safety glasses.

Once the wax mixture is liquid, the cayenne pepper is carefully added and stirred in. The cayenne is "cooked" into the wax for 15 to 20 minutes, turning the wax mixture orange.[2] Finally, the wax is removed from the heat and an equal weight of mineral spirits is added. This is what makes the wax mixture a paste at room temperature. The solution is quickly stirred together and then strained through a few layers of cheesecloth into its final receptacles to remove the pepper grains. Lauren usually does not do this final straining step and nevertheless has had good results with the wax mixture that she prepares and uses.

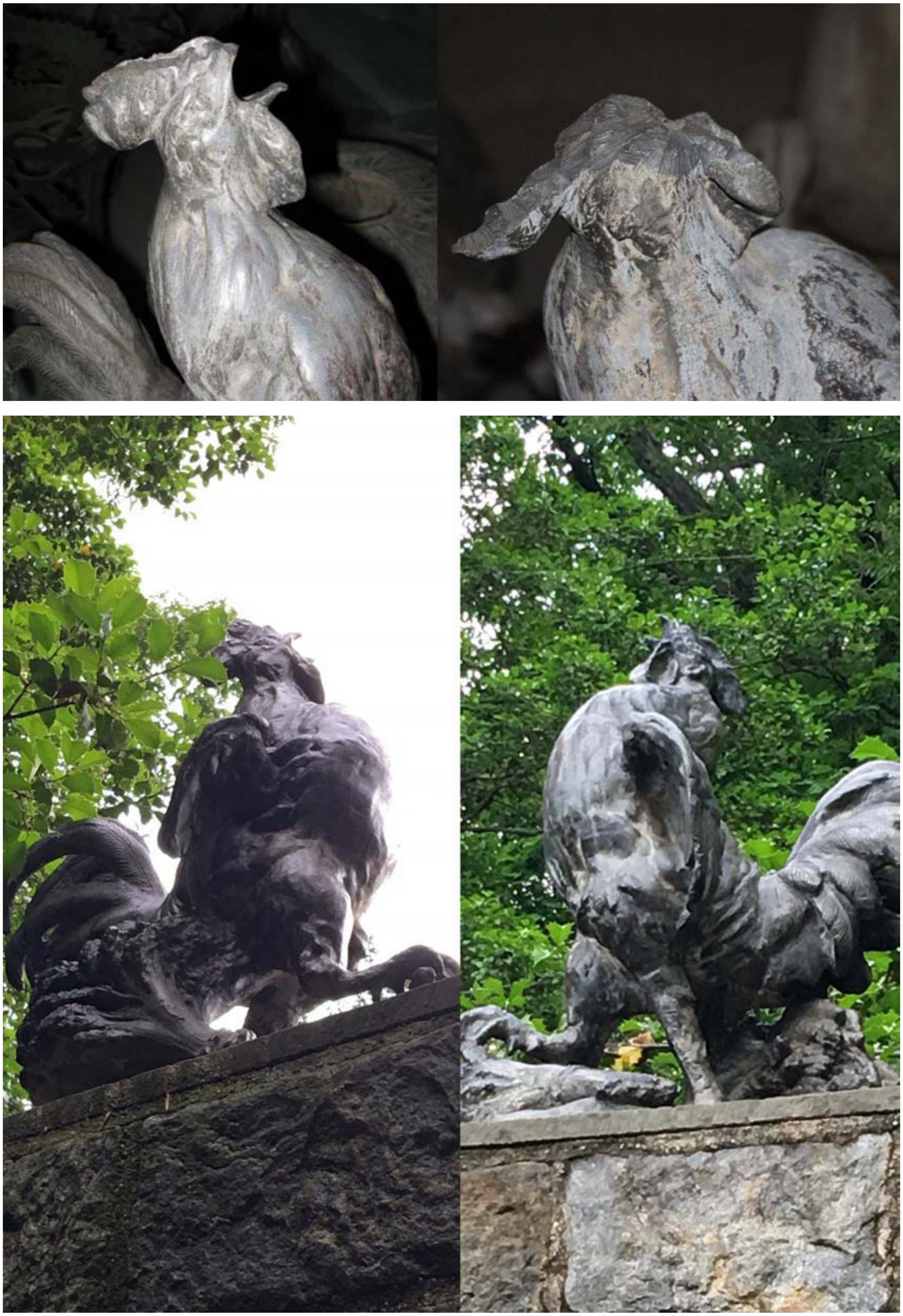

Fig. 5. Winterthur lead roosters before treatment (top left, top right) and after treatment and reinstallation into the gardens (bottom left, bottom right). Roosters, 1908-1927, lead, 70 cm H × 52 cm W × 36 cm D. Winterthur Museum, Garden & Library, 1969.4080.001 and 1969.4080.002 (Courtesy of Winterthur Museum).

3. PEPPER WAX IN PRACTICE

The wax can be applied cold or hot (with gentle heat from a propane torch or electric heating device). Care should be taken when heating near solder joins as those alloys typically melt at a much lower temperature than the lead itself. When applied cold, the pepper wax does not alter the surface in any significant way and yields the light-gray color that we see in an uncoated piece, whereas solder repairs are highlighted as darker areas. When applied hot, the pepper wax saturates the lead, leaving a darkened gray color, and helps to even out visually the variegations in the metal surface. In either hot or cold applications, once solvent has evaporated, the wax can be buffed to the desired degree with stiff bristle brushes and/or soft cotton cloths.

Cayenne pepper can be added to any wax mixture. The recipe provided earlier is not exclusive to this technique and practice; this is just the one that we have found works well in an outdoor environment in our region.[3]

The lead roosters at Winterthur (fig. 5) are two sculptures of several that have been treated in this manner in the southeastern Pennsylvania/Delaware region. They are now on an annual maintenance program and receive a fresh coat of pepper wax each year, like the other lead at Winterthur. We have not noticed any new squirrel damage to our lead sculptures since 2014, when the treatments began. At Mount Cuba, where the maintenance cycle is every two years, staff noticed only one "hit" by squirrels since 2014. Rittenhouse Square is also showing very promising results, by which we mean no new squirrel damage.

As chewing on lead by squirrels is a learned behavior, it can be reasonably expected that a significant reduction in activity will occur in the first cycle, with increased success in future cycles.

ACKNOWLEDGMENTS

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NOTES

1. We have not tried using capsaicin extract, which is colorless, in place of cayenne pepper. This should work just as effectively, in theory; we would love to hear from anyone who tries this.

2. Though the cayenne pepper imparts an orange color to the wax mixture, it does not cause a noticeable color change in the lead objects to which it is applied.

3. Adam was asked after the session if there is any concern about the effect that capsaicin might have on the metal. We have seen no negative effects on the objects, and being practically insoluble in water—0.00013g/L (Wikipedia. s.v. "Capsaicin" 2017)—it is unlikely to have any noticeable pH effect.

REFERENCES

Fitzgerald, Christopher S., Paul D. Curtis, Milo E. Richmond, and Joseph A. Dunn. 1995. "Effectiveness of Capsaicin as a Repellent to Birdseed Consumption by Gray Squirrels." *National Wildlife Research Center Repellents Conference*, DigitalCommons@University of Nebraska–Lincoln. http://digitalcommons.unl.edu/nwrcrepellants/16

Gill, Elaine L., Richard W. Watkins, Joanne E. Gurney, Julie D. Bishop, Chris J. Feare, Clare B. Scanlon, and David P. Cowan. 1995. "Cinnamamide: A Nonlethal Chemical Repellent for Birds and Mammals." *National Wildlife Research Center Repellents Conference*, DigitalCommons@University of Nebraska–Lincoln. http://digitalcommons.unl.edu/nwrcrepellants/19

Israel, Barbara. 1999. *Antique Garden Ornament: Two centuries of American Taste*. New York: Harry N. Abrams, Inc.

Mason, J. Russell. 1998. "Mammal Repellents: Options and Considerations for Development." *Proceedings of the Eighteenth Vertebrate Pest Conference*, DigitalCommons@University of Nebraska–Lincoln. http://digitalcommons.unl.edu/vpc18/13

National Geographic. 2010. Squirrels. https://www.nationalgeographic.com/animals/mammals/group/squirrels/

New England Garden Ornaments. 2015. A History of English Lead. The Sartorial Garden Blog. http://www.negarden.com/blog/a-history-of-english-lead

Wikipedia. s.v. "Capsaicin." Last modified October 8, 2018. https://en.wikipedia.org/wiki/Capsaicin.

Wikipedia. s.v. "Lead." Last modified November 3, 2018. https://en.wikipedia.org/wiki/Lead

FURTHER READING

Grout, J. 2017. "Lead Poisoning and Rome." Encyclopaedia Romana. Accessed February 15, 2017. http://penelope.uchicago.edu/~grout/encyclopaedia_romana/wine/leadpoisoning.html

SOURCES OF MATERIALS

Be Square 195 White microcrystalline wax, Petronauba C synthetic carnauba wax
Conservation Support Systems
PO Box 91746
Santa Barbara, CA 93190
800-482-6299
http://www.conservationsupportsystems.com/

Be Square 175 White microcrystalline wax
Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
http://www.talasonline.com/

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COPPER ELECTROFORMING: AN ALTERNATIVE TO CASTING FOR METAL REPLICATION

MARK ERDMANN

Reproduction of missing elements of an object or objects from a historic interior can be carried out using a variety of methods, including casting in various media. When an ornate or complicated replica needs to be carried out in metal, often the only option is casting. Casting has its disadvantages—including the need for significant equipment, setup, and expertise, or for subcontracting the work to a foundry. Electroforming can be an alternative to metal casting in some cases, as it can be done with less equipment, it captures very fine detail, and can produce a thin part with no shrinkage. This article describes the benefits and shortcomings of electroforming experienced in the replication of missing decorative hardware from a historic home.

KEYWORDS: Copper electroforming, Metal replication, Reproduction

1. INTRODUCTION

I was tasked with reproducing six pieces of hardware for missing bell pulls (fig. 1) from a historic home in Akron, Ohio. The extant pieces had been formed by repoussé in copper sheet; thus, there was a high degree of detail and they were quite thin. The finish was a dark copper patina, and matching the color and transparency was important. I chose electroforming as a means of reproducing the detail and thickness without shrinkage, in a material that could be chemically patinated to match the originals.

2. ELECTROFORMING DEFINITION, BENEFITS, AND SHORTCOMINGS

Electroforming is an electrolytic deposition process similar to electroplating that forms a metal object on a conductive mold or mandrel surface. A mold is made of the surface to be replicated, and if the object is relatively flat, one can electroform directly on the mold surface. If a three-dimensional object is required, the process is more complicated. Although I have experimented with different methods, I have not had the need to perfect them. Examples of three-dimensional possibilities include electroforming over a wax model that is later melted out, leaving a thin shell of metal. One could theoretically also electroform two or more shells in a multipart mold and then braze them together into a hollow form. However, the primary example given in this article is a low-relief, relatively flat object.

As previously mentioned, metal casting requires significant equipment, including a kiln to bake the mold, a furnace or other method of melting metal, and a workspace that can withstand a messy process. While the process of lost wax casting is easily understood, there are idiosyncrasies that can be fully grasped only through experience and training. In addition, there will be shrinkage with metal casting (1%–2% for bronze and brass). Electroforming avoids these problems.

The shortcomings of electroforming relate to the maintenance and control of the electrolyte solution. Industrial electroforming operations use continuous filtration, agitation by air bubbling, electrolyte monitoring and adjustment, and temperature control. For small-scale reproductions in low quantities, it has been my experience that these are not essential.

Fig. 1. Bell pull hardware, ca. 1915, copper and textile, 5.2 × 6.1 × 1.4 cm (left), 5.2 × 5.8 × 0.8 cm (right), Stan Hywet Hall and Gardens, Akron, Ohio (Courtesy of Stan Hywet Hall and Gardens, photograph by John Seyfried)

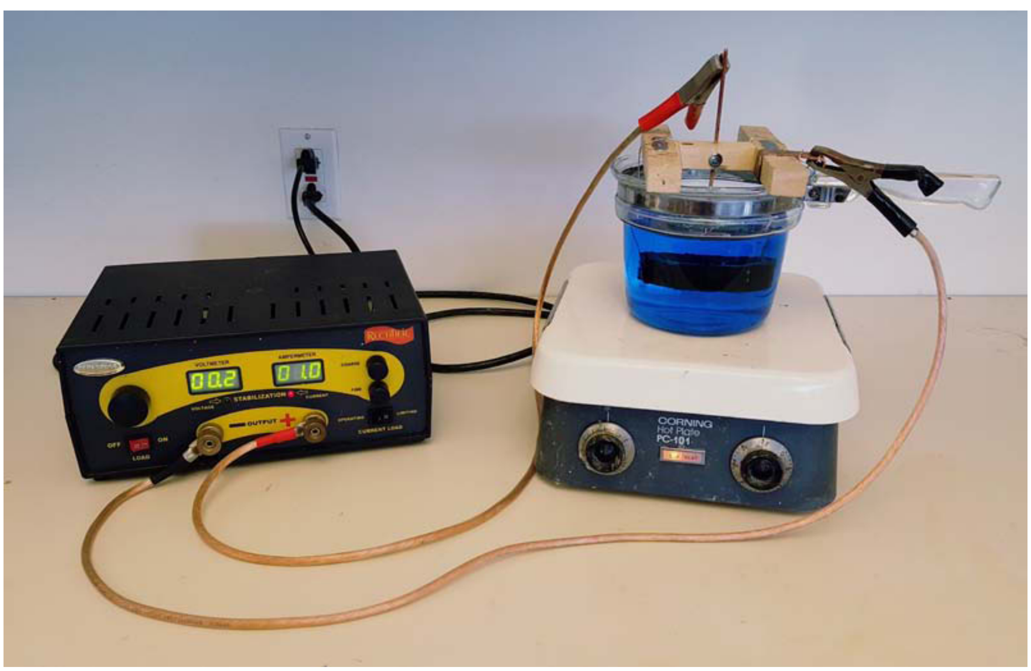

Fig. 2. Electroforming rectifier, magnetic stirrer, and electrolyte solution

3. EQUIPMENT AND SUPPLIES

The only piece of specialized equipment needed is an adjustable DC power supply, such as an electroplating rectifier. These vary in price from about $78 to $780, depending on amperage capacity, programmability, and quality. The electrolyte solution needs to be contained in a glass beaker or even a glass casserole dish to fit the size of the mold and anode with some room for circulation. My equipment setup is shown in figure 2. The electrolyte solution is made of a salt of the metal to be formed, deionized water, and acid. Recipes are available online, and solutions are available commercially. The remaining equipment includes RTV silicone rubber, fine bronze powder, a copper anode, copper wire, wire cutters, and jeweler's pliers.

4. PROCESS

4.1 Mold Preparation

I made a silicone mold of the object to be formed. I made sure that the mold had the required depth to achieve the desired thickness at the edges in keeping with the thickness of the original bell pull. In order to conduct the electrical current to the mold surface, I added a copper perimeter wire, held in place with copper staples pushed into the surface. The perimeter wire should be made with wire long enough to

Fig. 3. Silicone rubber mold prepared with copper perimeter wire and dusted with bronze powder

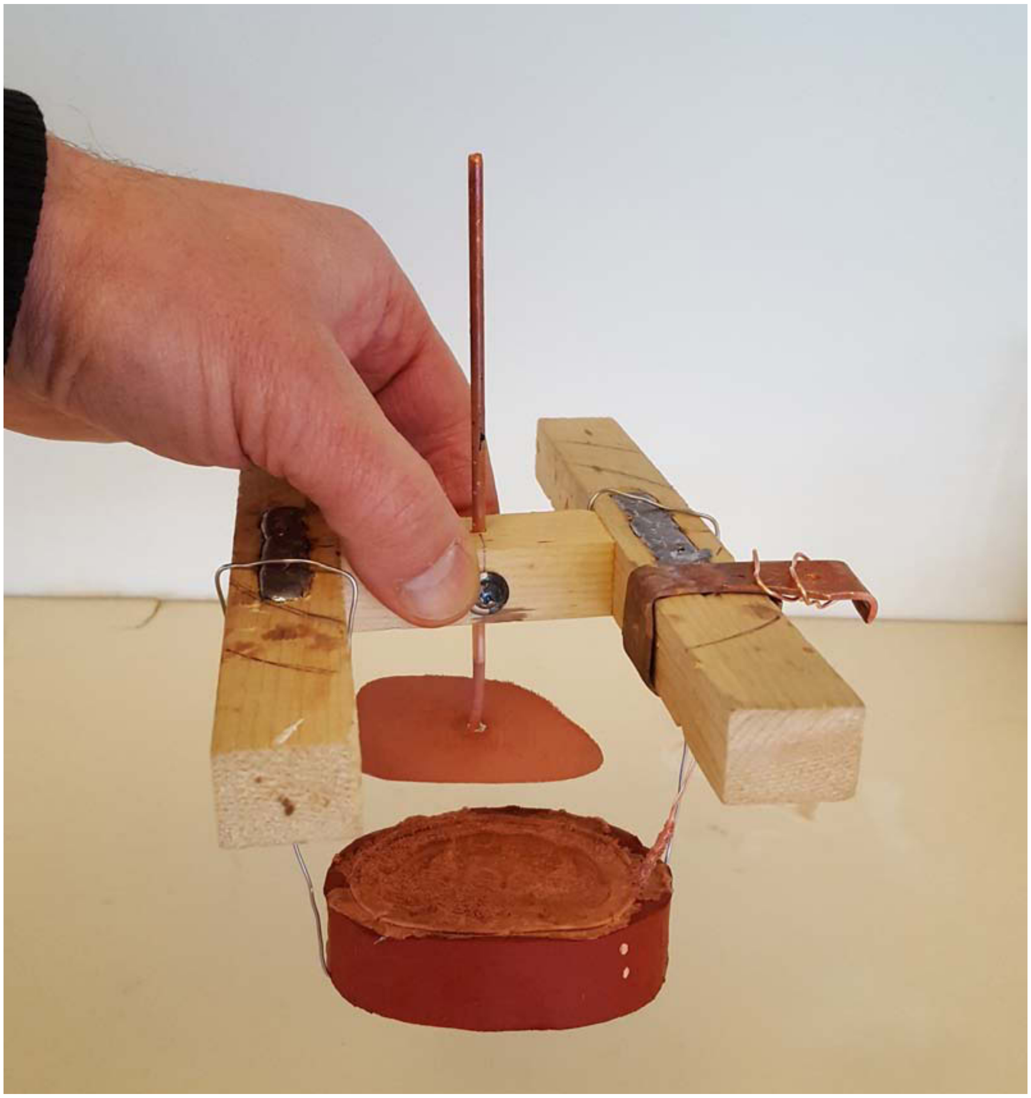

Fig. 4. Wooden harness with copper anode and prepared mold suspended by stainless steel wires

extend out of the electrolyte bath and connect with the negative lead of the power supply. Once wired in this manner, I coated the mold surface with bronze powder, in pale gold, lining grade. The image in figure 3 shows the prepared mold. The metal powder, unlike the more widely available mica powders, creates a conductive surface on the mold up to or slightly beyond the perimeter wire. Conductive paint is commonly used in the electroforming and jewelry industries, however I cannot comment on its performance. I already had bronze powder on hand, so I chose to use it instead. I did encounter entrapped air bubbles in crevices of the mold, which I suspect may have been caused by the use of powder rather than paint. Further experimentation in this area would be informative.

4.2 Anode

Since the objects were to be formed in copper, I made the anode out of copper sheet with a copper rod brazed onto the back. The anode should be of equal or greater surface area than the mold surface for proper current flow. The desired thickness of metal to be formed should be taken into account when determining the thickness of the anode, as metal is continuously dissolved into the electrolyte during the process, consuming the anode.

An important convenience I used during the process was a wooden harness (fig. 4) that I designed to suspend the mold (cathode) and anode in the electrolyte without touching each other. The harness had enough weight to counteract the tendency of the electrode cables to pull the mold or anode out of position.

4.3 Electrolyte

The electrolyte recipe I used was borrowed from the artist Eric T. Caldwell (Caldwell n.d.) and was effective in achieving the quality required for this project:

8 oz. copper sulfate

1 qt. deionized water

30 mL sulfuric acid

Eric additionally recommended the use of a commercial brightener and leveling agent; however, I did not find it to be essential for this application.

4.4 Rectifier Settings and Time

The electroplating rectifier I used was set in amperage-limiting mode to prevent fluctuations, keeping the current flow constant. Current was set at or near the lowest possible setting for the rectifier, which was 0.9 amps. A rule of thumb for current flow suggested by a professional in the industry is 0.1 amps/square inch of mold surface (Hemsley 2000). The actual calculated current flow for the process described here was 0.12 to 0.18 amps/square inch. The mold was left in the electrolyte for 30 to 48 hours.

5. ADJUSTMENTS AND MODIFICATIONS

Periodically, I removed the anode from the electrolyte, rinsed it with tap water, and scrubbed it with a Scotch-Brite pad to remove a brown sludge and thin oxidation layer that accumulated on the surface. To prevent these accumulations, I experimented with heating the electrolyte to approximately 110°F but did not observe any noticeable difference in performance. I also tried reversing the polarity for a few minutes every hour to smooth out the coarse granular growth, but this significantly slowed growth and caused contamination of the electrolyte solution. I also tried using a commercial electroforming solution that contains a brightener/leveling agent. The initial results produced a very smooth, shiny surface. However, after leaving the process overnight, the solution accumulated a brown sludge over the anode, cathode, and beaker surfaces, and growth slowed dramatically. Discussion with a technical representative from the supplier indicated that the solution needs to be closely monitored and filtered, and additions made of more brightener every 8 hours of use, on average. In spite of implementing these suggestions, I still did not achieve the same growth rate as I did with my own electrolyte solution.

6. RESULTS

In the end, the resulting objects very closely duplicated the surface detail and texture from the molds. The back of the electroformed surface, which was the “growth” surface, was very granular (fig. 5),

Fig. 5. Freshly electroformed copper, illustrating its coarse crystalline growth habit

whereas the surface facing the mold accurately captured fine detail from the silicone mold. The thickness achieved was approximately 1 mm. To improve the strength and weight of the objects, I flooded the backs with low-temperature brazing alloy, composed of silver, copper, zinc, and cadmium (fig. 6). This also facilitated the addition of brazed-on bushings that enabled three of the elements to interface with the bell-pull mechanisms. The six replicas, two originals, and accompanying hardware are pictured in figure 7.

Considerations for future projects would include the use of an aquarium pump for agitation of the electrolyte, the use of a programmable rectifier that would enable periodic reversal of the current to help smooth out granular growth, and the use of conductive paint rather than bronze powder to potentially avoid entrapped air bubbles causing voids in the surface.

Fig. 6. Reverse of electroformed sample having been reinforced with silver brazing alloy

Fig. 7. Six replicas and two originals (far right, top and bottom), with reproduction chain links and levers for interface with the bell-pull mechanisms (Courtesy of Stan Hywet Hall and Gardens, photo by John Seyfried)

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REFERENCES

Caldwell, Eric T. "Electroforming Solution Recipes." Caldwell Sculpture and Design Website. Accessed March 9, 2018. http://www.erictcaldwell.com/technique/#/copper-patination/

Hemsley, Henry H. 2000. "Copper Electroforming Problems." Accessed November 3, 2018. https://www.finishing.com/0000-0199/085.shtml

SOURCES OF MATERIALS

60 Amp Plating Rectifier
Pepe Tools
7601 SW 34th St.
Oklahoma City, OK 73179
405-745-4054
www.pepetools.com

Brazing wire, Copper wire, sheet and rod
McMaster-Carr Supply Co.
200 Aurora Industrial Pkwy.
Aurora, OH 44202-8087
330-995-5500

Bronzing powder, lining grade
Mohawk Finishing Products
PO Box 22000
Hickory, NC 28603
800-545-0047
www.mohawk-finishing.com

Copper(II) sulfate pentahydrate
The Science Company
7625 W. Hampden Ave., Unit 14
Lakewood, CO 80227
800-372-6726
www.thesciencecompany.com

Jewelry pliers and wire cutters, Midas Bright Electro-forming Copper Solution, Midas Brightener/Replenisher for Electroforming
Rio Grande
7500 Bluewater Rd., NW
Albuquerque, NM 87121
800-545-6566
www.riogrande.com

Mold Max 60 Silicone Rubber Compound
Smooth-On, Inc.
5600 Lower Macungie Rd.
Macungie, PA 18062
610-252-5800
www.smooth-on.com

Sulfuric Acid, Reagent grade ACS
Fisher Scientific
800-766-7000
www.fishersci.com

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FAST FILLS FOR BIG GAPS

RACHEL C. SABINO

The best method for creating a very deep fill in semi-translucent stones such as marble is to gradually build up successive layers of material(s) to achieve a satisfactory match in both color and density. However, if the treatment must be completed in a shorter time than this more controlled method requires, the materials best suited to produce a quick set over a large volume pose problems of opacity, cost, and/or reversibility. This tip instead makes use of high-density polyethylene foam covered with a thin skin of bulked and tinted epoxy resin to achieve a time-effective, economical, reversible, and aesthetically pleasing fill.

KEYWORDS: Loss compensation, Marble, Ethafoam, Epoxy resin, Onyx powder

1. THE RELIEF

This large fragment of a marble relief reflects in spirit and style the avid return around 1500 to classical models and their incorporation in contemporary sculpture (fig. 1). While nothing is known of its original context or function, it most likely formed part of a commemorative or triumphal monument in Rome. Both the cornucopia beneath the putto's outstretched proper left leg and the terminus of the swag draped over his shoulder contain oak leaves—the emblem of the formidable Della Rovere family of Bologna, from the ranks of whom two Renaissance popes hailed: Sixtus IV and Julius II. The crossed keys under an umbrella-like canopy—the armorial device for the Holy See when the papal throne was temporarily vacant—provide another potential clue as to the original source of the fragment.

2. SCOPE

The object entered the collection of the Art Institute of Chicago in 1962 and received only one documented treatment in 1977, when unsightly incrustations were mechanically removed and it was cleaned with an aqueous surfactant. Consigned to storage, it languished for the better part of three decades until 2016, when it was designated as one of nearly 700 objects to be installed in the newly designed Deering Family Galleries of Medieval and Renaissance Art, Arms, and Armor opening the following spring. The relief was to be installed at considerable height in a gallery containing other stone works similarly reminiscent of the early antique. Since so many objects needed to be prepared for installation, the relief could not be given the luxury of a gradual, stratified approach to filling the largest losses.

3. CONDITION

The carving is largely intact and the stone is in overall sound condition but with some surface weathering and resultant loss of detail. The papal insignia appears to be a later modification recarved from a previous form—most likely additional vegetation at the end of the swag hanging from the proper right shoulder. Recarving is suggested by the relative whiteness and less-weathered appearance of this area; its position slightly lower than the plane of the rest of the relief; the roughly keyed surface of the marble just below it; and the style of carving that differs appreciably from the rest (fig. 2). The lower half of the putto's missing proper right arm does not lie in the same plane as the insignia, and the nature of the break edge and the condition of the exposed marble along it gives the impression that this damage predates the recarving. The front of the proper left foot is also missing. A large square notch is present at the top proper right corner, perhaps made during extraction of the relief from its original context.

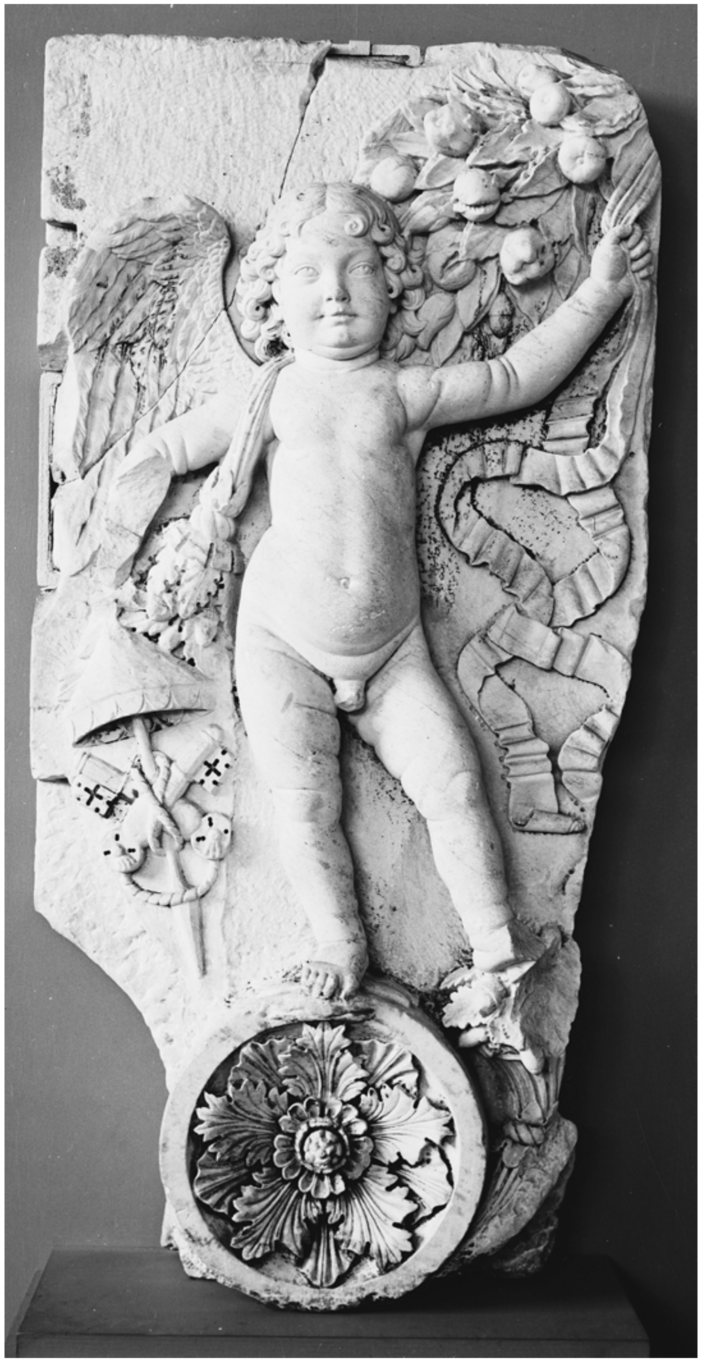

Fig. 1. Black-and-white image of the relief before treatment. Italian, School of Andrea del Verrocchio, *Putto with Papal Insignia*, 1475/1500, marble, 149.9 × 73.7 cm, The Art Institute of Chicago, 1962.100 (Courtesy of the Art Institute of Chicago)

More crucially, there is a massive triangular fragment on the top proper right corner with associated chips and lacunae of varying dimensions along the break edge. In a previous campaign of stabilization, this fragment had been secured in place with four iron cramps. Over time, the expansion of the rusting metal caused the stone to cleave away from the cramps at the top and proper right-side edges, resulting in losses so significant as to expose the cramps themselves. The loss at the top edge measures approximately 30 cm long and 4 cm deep (fig. 3). The loss on the proper right side measures approximately 45 cm long and

Fig. 2. Detail of the papal insignia, likely a recarving (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

4 cm deep. The primary void also extends to a significant portion of the putto's outermost wing feathers (fig. 4). On the verso, lesser spalls are present in association with the cramps, as is a copious amount of disfiguring rust staining, but overall the morphology of the damage is not the same as that on the exposed sides (fig. 5). Perhaps this more benign condition is attributable to their relatively more sheltered position. A significant amount of rust staining has migrated through to the front of the relief, lending it a decidedly yellow appearance.

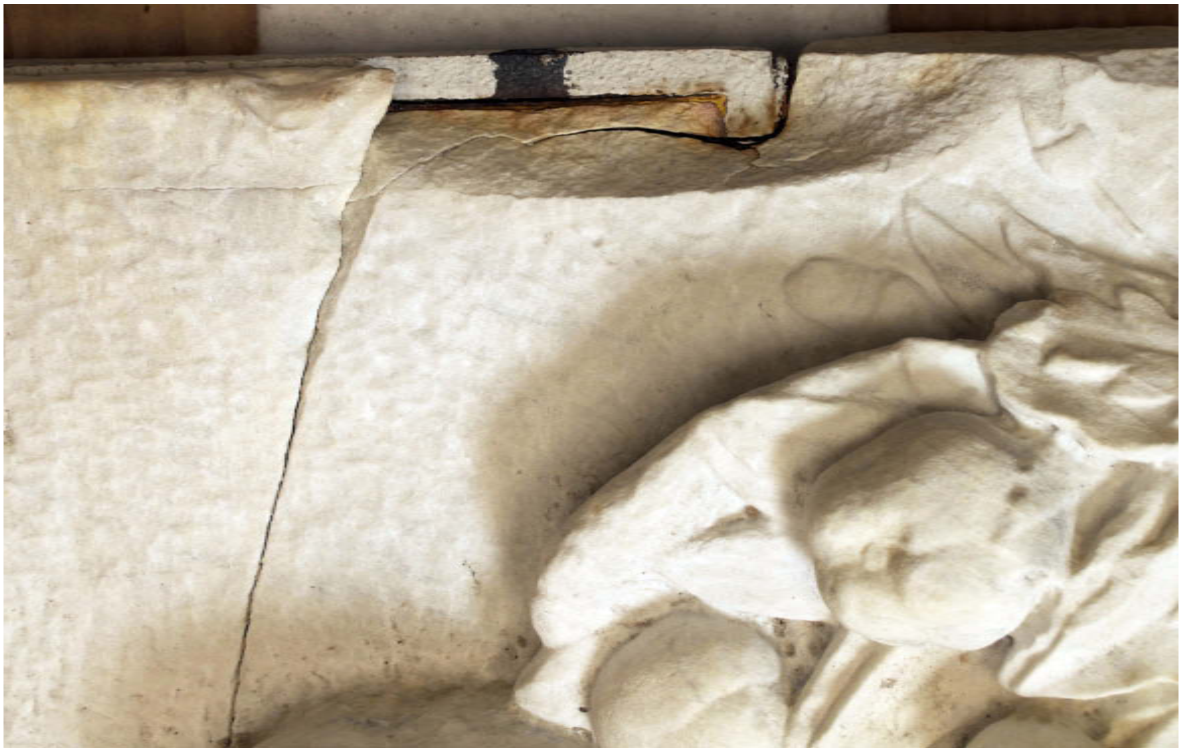

Fig. 3. The loss on the top edge of the fragment (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

4. TREATMENT OBJECTIVE

The tight time frame of this treatment, coupled with the logistical obstacles of performing radiography on such a large piece of stone, precluded exhaustive testing or definitive confirmation of the solidity of the cramps and the stability of the join. However, the familiarity conferred by repeated handling during initial examinations afforded some reassurance that the cramps, aided by a new mounting system, would continue to hold the pieces together safely. The scope of treatment was therefore confined to making aesthetic improvements with loss compensation in the two largest gaps; along the outside of the putto's wing; along the break edge of the primary fragment on the recto; and within the square notch at the top proper right corner. In addition, wherever possible, the overall appearance of the stone would be harmonized by mitigating staining and discoloration.

5. THE DECISION TREE

There were any number of methods by which to approach this loss-compensation treatment, each method presenting advantages and disadvantages.

5.1 Plaster

Plaster, whose economy and ease of use made it attractive, was initially considered for filling the largest losses. Most often, plaster is too dense for filling marble (even for weathered, ancient ones that tend to be more forgiving than the highly polished decorative ones of subsequent centuries), resulting in shadows on either side of the fill. But occasionally, with skillful retouching, plaster can be a viable option for marbles

Fig. 4. The loss on the proper right side of the fragment (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

that are themselves quite dense and are not positioned in such a way to receive a good deal of transmitted light. This particular object was a borderline case. It would receive no transmitted light whatsoever, but despite being relatively dense, the tonality of the marble was comparatively warm relative to plaster. This tonal discrepancy could probably have been rectified by adding pigments to the plaster before hydrating it or by a campaign of calculated retouching.

Ultimately, the topography of the break edges and the presence of the metal cramps contraindicated its use. Even with the careful design and execution of dams or molds, it would have been all too easy to lose copious amounts of fill material through pinholes, slips, or faults, likely in a very messy way, nullifying the benefits of using plaster in the first place. In addition, the cramps sit slightly proud of the surface with a 3-mm gap around them (fig. 6). To look convincing, the new fills would also have to be set back this same 3-mm distance. It would be a formidable task to construct a dam or mold that would not create more problems than it solved: allowing the plaster to flow around and behind the dam, between the

Fig. 5. The cramps and the resultant staining on the verso of the relief fragment (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 6. The top cramp viewed from above showing its position slightly proud of the surface and the 3-mm gap in the stone around it (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

cramps, and through to the verso of the object; entrapping the dam material within the plaster, preventing its extraction after casting; and requiring copious amounts of tooling and shaping after casting to replicate the texture on the top surface.

To eliminate the problem of liquid plaster flow and the concurrent necessity for faultless dams, it might have been possible to apply the plaster in a more controllable form at a more advanced state of cure. Working with curing plaster means working quickly, as the window of such plasticity is quite narrow. It also means doing multiple applications if the volume is in excess of what can be handled at one time, as was certainly the case in this instance. Not least, the chore of dealing with plaster dust and ghosting is something that conservators strive to avoid.

But the final determining factor weighing against the use of plaster was the inadvisability of placing a hygroscopic material (to say nothing of the actual water present in the admixture) in such close proximity to the iron, even when taking proper precautions by thoroughly sealing the surfaces with acrylic resin.

5.2 Thermosetting Resins

A direct pour using a tinted epoxy was also an option. However, as was the case with plaster, any voids or pinholes in the dam or mold could produce results along a spectrum from inconvenient to calamitous. The directive to maintain 3 mm around the clamp would be even more difficult to achieve in resin and more difficult to reverse in the event that the pour went wrong. While it would most likely have been easier to separate the dam materials from the resin after curing, the risk of the epoxy migrating around the clamp or along the break edge of the fragment could not be justified. There is also the very real issue of cost: preparing a sufficient volume of a conservation-grade epoxy, accounting for the inevitable accompanying waste, would have been prohibitively expensive. Although the better-grade epoxies available to the marine and sculpture industries are more cost-effective, their aging properties are unacceptable.

Polyester resins are generally less expensive and better suited to casting very large volumes. However, they are challenging to use: they have extremely short working times and require resin-to-hardener ratios that are difficult to measure in the comparatively smaller volume necessary for these fills. They also produce a significant amount of heat, a potential danger not only to the object but also to the user.

5.3 Acrylic Resin

Recent experimentation (Wolfe and O'Connor 2005) has led to successful loss-compensation campaigns for decorative marbles using tinted and bulked acrylic resin-based fillers (Riccardelli et al. 2014). This development is most welcome, as acrylic fills retain all the best properties of epoxy-based fills (i.e., translucency, infinite modification) with none of the drawbacks (i.e., excessive hardness, toxicity, difficulty in reversibility). However, in the experience of this author, acrylic resin mixtures offer little advantage in terms of efficiency and can be, in fact, more time-consuming to prepare, apply, control, refine, and store between uses than epoxy-based fills.

5.4 The Solution

It became increasingly apparent that no single material would do the job and that it would be beneficial and expeditious to employ a combination of materials to create a core fill overlaid by another fill to simulate the marble.

For the core, six materials were evaluated for their appearance, ease of application and compatibility with the marble: acrylic resin bulked with paper pulp, strips of mat board, epoxy putty, separately-cast plaster forms, acrylic resin bulked with stone fillers, and foam. These were evaluated in combination with five candidates for the outer fill: acrylic putty, plaster, epoxy-based filler, bulked acrylic resin, and wax.

In the end, 9-pound, closed-cell polyethylene foam was chosen for use as the core fill. Despite having a cooler tonality than the stone, it could be shaped very easily and efficiently. Its opacity is greater than what would have been achieved with a resin bulked with paper pulp or stone fillers but less than that of plaster or acrylic putty.

Because the outer fill was designed to be relatively thin and the inner fill somewhat amorphous, the hardness of an epoxy presented a particular advantage in conferring stability and durability. For this, AKEPOX 5010 was chosen—a two-part, high-viscosity (knife-grade) epoxy resin. In addition to structural strength, other properties of this particular epoxy made it very advantageous in terms of efficiency: the 2:1 mixing ratio is easy to apportion by eye; it has a working time of 20 minutes; and it reaches full cure in approximately 12 hours. None of these parameters could have been achieved with an acrylic resin.

AKEPOX 5010 is semi-translucent with a slightly bluish-white tone. Therefore, strategic bulking using a wide array of fillers and pigments would be necessary not only to match the surrounding stone but also to counter the contrasting tonalities of both the resin and the underlying foam. Because the foam would occupy the majority of the void, the overlying epoxy and filler combination would have to be more translucent than normal to offset the opacity of the foam—an additional challenge.

6. TREATMENT

The entire surface and the abundant drill holes that punctuate the contours of the high relief areas were extremely dirty and covered uniformly with loose particulate matter alongside various stains and accretions (fig. 7). Prior to beginning the campaign of loss compensation, surface dirt and debris were

Fig. 7. The drill work delineating the contours of the relief (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

removed from the object using compressed air. Insufficient time was available to attempt solvent cleaning or poulticing of the iron staining. However, given the viewing distance and planned ambient lighting in the gallery, such measures were ultimately not deemed necessary.

The interiors of the cavities of the two largest losses were liberally consolidated with acrylic resin (10% w/v in acetone) to act as a barrier layer between the stone and the fill, and to seal the iron cramp, inhibiting moisture ingress and further oxidation. Two square planks of foam were cut to roughly the same dimensions as the large voids. With a blade, the backs of the foam planks were whittled to shape according to the profile of the interior of the cavity. The exposed surfaces of the planks were trimmed and carved until they were set back approximately 6 mm below the stone. The foam was bonded to the interior of the cavity using acrylic resin (40% w/v in acetone) bulked with glass beads to promote adhesion and to bridge any voids between the foam and the underlying stone. The foam was clamped in position until the resin reached full cure (fig. 8).

After the foam was securely bonded in position, the clamps were removed and the stone immediately surrounding the losses was coated with acrylic resin (10% w/v in acetone) to protect the surface during the subsequent phases of treatment. As much epoxy, pigment, and filler as could be adequately handled, prepared, and matched within the 20-minute curing window was applied over the foam with a spatula. No hard and fast rule governed which combinations of pigments and fillers worked best for any given area. At times, different, contrasting mixtures were deliberately applied in close proximity to one another to mimic veins and faults, enhancing the naturalism. No test coupons were prepared. Instead, these decisions as to texture, density, and color were made on the spot, guided by the author's previous experience.

Fig. 8. Ethafoam core fill bonded in position on the proper right side (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Generally speaking, successful combinations are achieved by first selecting the aggregate or filler that produces the best textural match to the stone. Aluminum oxide and aluminum hydroxide perform particularly well in emulating dense, highly polished stones. Coarser aggregates such as marble powders and sands work well for weathered or sugary stones. The majority of these fillers tend to impart a greenish cast to the resins. This effect is best offset with pigments, with the proviso that many pigments, titanium white in particular, are potent colorants with opacifying properties all their own and a less-is-more approach definitely wins the day.

The missing angel's wing and feathers were not replicated precisely, barb by barb. Instead, the outermost edges of each vane were built up sharply enough to be legible to the viewer, but the material between the resultant hard edges was modeled to be suggestive of the weathered surfaces visible elsewhere on the sculpture (fig. 9).

The square notch at the top proper right corner was left unfilled to accommodate a new mount, but the disfiguring void was camouflaged by a thin skin of the same epoxy-based fill material. To retain the square shape, a plug of polyethylene foam was inserted into the cavity and the fill material was skimmed over the top. Before the resin cured completely, the foam was extracted from the cavity (fig. 10).

Smaller voids and cracks were filled with the same epoxy-based fill material, tinted and bulked to best match the surrounding area. All fills, both major and minor, were smoothed and brought level with the surface using a rotary flex-shaft tool fitted with various silicone-rubber polishing wheels and points. At the close of treatment, the protective acrylic resin barrier layer was removed from the surface using acetone on cotton wool swabs. The fills were further refined using acrylic paints, colored pencils,

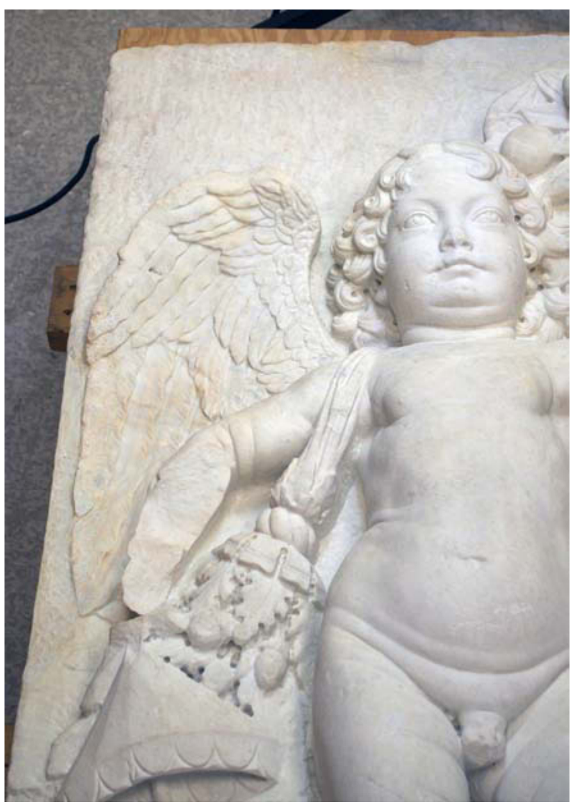

Fig. 9. Detail of the relief after complete loss compensation (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 10. The square notch at the top proper right corner before treatment (left) and after treatment with space left to accommodate a mount (right). (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

and/or pastels. Areas of minor superficial staining were toned out with gouache and refined with colored pencils and/or pastels following the application of a barrier layer of cellulose ether (3% w/v in distilled water; fig. 11). In this particular application, the use of cellulose ether as a barrier layer provides a robust separation between the stone and the overlying retouching media with a minimum of interference. Relative to other classes of materials, it does not rest heavily on the surface; impose a gloss or sheen; or inhibit the retouching media from sitting, feathering, or blending convincingly with the original.

6.1 Cramp Gaps and Texture Pops

To maintain the visual effect of the 3-mm gap around the cramps, strips of blotter board stacked to the correct height were faced with sealing film and secured to the top of the cramp. The epoxy was then applied up to and against the strips. After the epoxy had cured, the blotters could be easily extracted thanks to the sealing film that served as a release agent. Once removed, the gap required only a single pass with a file to round the edge (fig. 12).

To replicate the texture of the marble around the fills, small quantities of vinyl polysiloxane impression material were prepared and placed against the stone following application of a protective coat of acrylic resin. Simultaneously, the impression material was built upwards around wooden stirrers, which served as handles. These so-called “texture pops” were used to impress the texture onto the semi-cured epoxy putty during the latter stage of curing. A light sprinkling of one of the fillers (dependent on the color and morphology of the surrounding crystal matrix) served as a release agent for the mold and as a matting agent for the epoxy, which cured to a relatively high gloss (fig. 13).

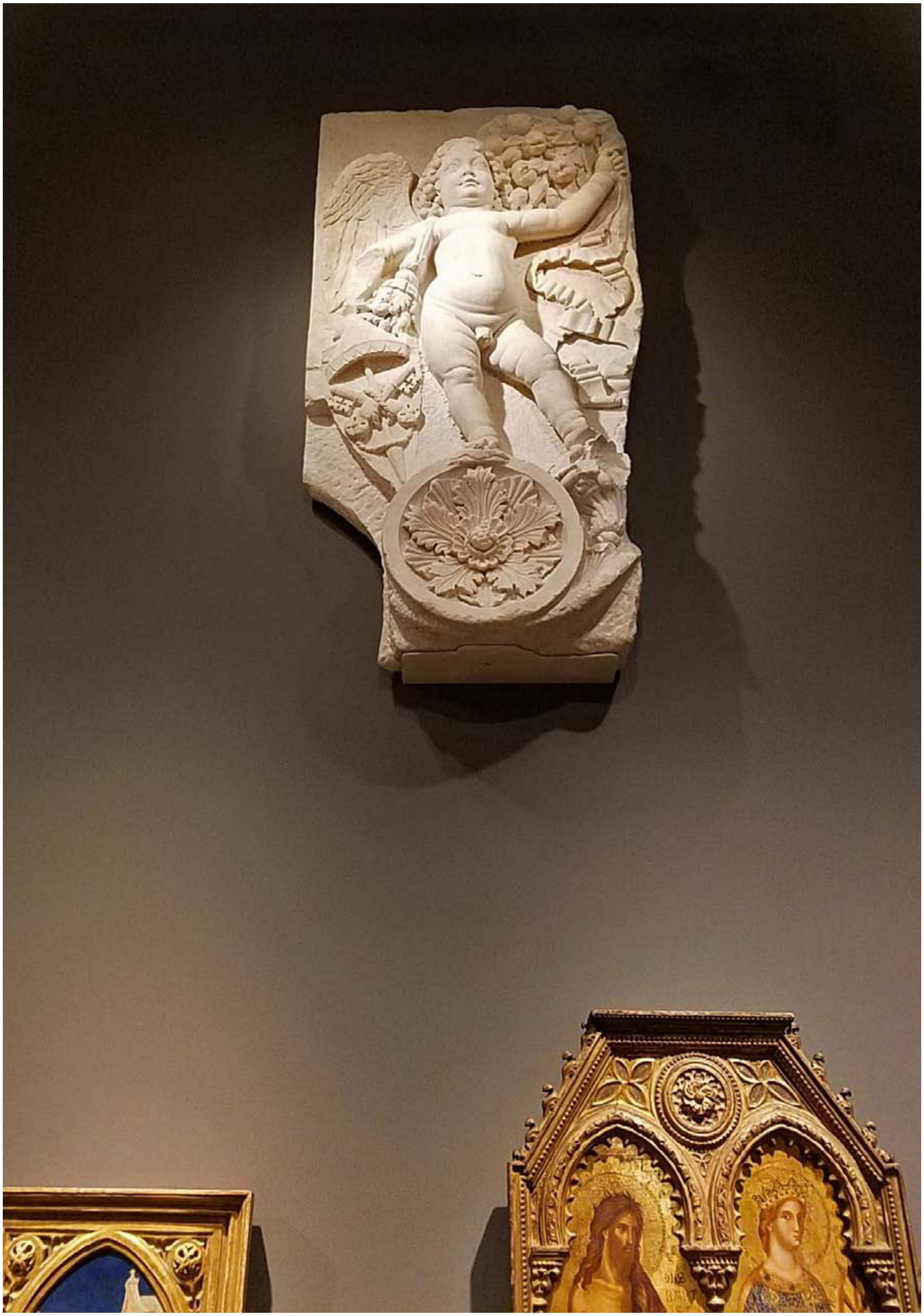

Fig. 11. The relief fragment installed in the gallery at the close of treatment (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

Fig. 12. Side view of the relief after treatment showing the 3-mm gap around the cramp and the mount engaged in the notch (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

7. RETREATABILITY

Should it be necessary to remove the epoxy due to aging, yellowing, and/or failure or to address overarching structural issues that warrant the wholesale removal of the repair, it is easily reversed in stages. The conservator need merely coat the perimeter of the fill with acrylic resin to protect the

Fig. 13. Detail showing the “texture pops” in the foreground and the blotter board spacers in the background (Photograph by Rachel C. Sabino, courtesy of the Art Institute of Chicago)

surrounding stone and apply methylene chloride–based paint stripper to the surface of the epoxy skin. The epoxy covering is sufficiently thin that it will swell rapidly, producing a distinct cleavage plane between it and the underlying foam. Once swelled, the compromised epoxy fill can be levered out with a long, flat implement, such as a palette knife, spatula, or blade introduced through a breach in the epoxy. The exposed underlayer of foam can be cleaned and sanitized with ethanol or acetone, trimmed and consolidated again if necessary, and a new fill, either done in the same material or a different one, can be applied over the top. Alternately, to continue removing the fill, the foam is easily detached from the stone with acetone, as is any residual adhesive and/or glass beads.

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REFERENCES

Riccardelli, Carolyn, Michael Morris, George Wheeler, Jack Soultanian, Lawrence Becker, and Ronald Street. 2014. "The Treatment of Tullio Lombardo's Adam: A New Approach to the Conservation of Monumental Marble Sculpture." *Metropolitan Museum Journal* 49: 49–116.

Wolfe, Julie, and Talitha O'Connor. 2005. "Properties of Fillers in Putties Based on Acryloid B-72." *Objects Specialty Group Postprints, Volume Twelve, 2005.* Washington, DC: American Institute for Conservation (AIC). 12: 91–117.

FURTHER READING

Gänsicke, Susanne and John W. Hirx. 1995. "A Translucent Wax-Resin Fill Material for the Compensation of Losses in Objects." *Objects Specialty Group Postprints, Volume Three, 1995.* Washington, DC: American Institute for Conservation (AIC). 3: 94–116.

Griswold, John, and Sari Uricheck. 1998. "Loss Compensation Methods for Stone." *Journal of the American Institute for Conservation* 37 (1): 89–110.

Kemp, J. 2009. "Fills for the Repair of Marble: A Brief Survey." *Journal of Architectural Conservation* 15 (2): 59–78.

Nagy, Eleonora E. 1998. "Fills for White Marble: Properties of Seven Fillers and Two Thermosetting Resins." *Journal of the American Institute for Conservation* 37 (1): 69–87.

SOURCES OF MATERIALS

Acrylic Paint, Golden Fluid Acrylics
Golden Artist Colors, Inc.
188 Bell Rd.
New Berlin, NY 13411-9527
607-847-6154
https://www.goldenpaints.com/products

Acrylic Resin, Paraloid B-72
Rohm and Haas Company
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http://www.dow.com

Aluminum Hydroxide Powder, Synthetic Onyx Filler (408-040)
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http://www.garreco.com/products/abrasives/aluminum-oxide/

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Cristobalite Sand, 0.1 to 1 mm (58694); Glass Beads, Very Fine #59832; Marble Filler, White Carrara, Fine, 0 to 120 µ (59600); Marble Dust, White (Carrara), 0.6 to 1.2 mm (59613)
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Polishing Points, Kerr Rotary/NTI White Silicone Polishers, Latch, Cone (115-8427); Polishing Wheels, Kerr Rotary/NTI White Silicone Polisher, Unmounted, Knife (115-8070); Polishing Wheels, Kerr Rotary/NTI White Silicone Polisher, Unmounted, Flat Edge (115-8054)

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https://www.net32.com/ec/aquasil-soft-putty-regular-set-standard-includes-d-111697

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