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Protection and relocation of frescoes during construction at the Harvard Art Museums

Teri Hensick, Anthony Sigel, Henry Lie, Narayan Khandekar, Kate Smith, Francesca Bewer, Angela Chang, Louise Orsini and Erin Mysak

Three frescoes painted in the 1930's by social realist artists Lewis Rubenstein and Rico Lebrun needed to be consolidated, protected and moved during major renovations to the Harvard Art Museums between 2009 and 2014. During construction, the frescoes, measuring a total of 22.3 m^2, would be subject to relocation, shock and vibration, climate extremes and structural intervention. Conservators devised a cyclododecane (CDD) facing as part of a multi-layered system of protection designed to remain in place for several years. Two of the fresco walls, weighing many tons, were cut from the existing masonry and moved by crane, while one of the frescos remained in situ on the inside of an exterior wall, protected from the elements by a purpose-built housing.

The project allowed comparison of two techniques for applying molten CDD on a large scale: by spraying through a gun designed for hot-melt glue, and by painting with hog hair brushes. Ultimately, brushes proved quicker and easier to use. Testing at various temperatures revealed new information about CDD's behaviour. Though it reportedly melts at 60–71°C, it was significantly more fluid and easier to apply during testing in the 80–85°C range. Heating the CDD above 85°C using a hot glue gun resulted in samples that became tacky shortly after application. FTIR analysis revealed changes in the aliphatic stretching and bending regions of CDD in these samples. The analysis suggests that CDD can be safely heated to 80°C without causing molecular changes.

The CDD facing successfully preserved the fragile fresco surfaces, remaining intact under a Marvelseal barrier film for over three years. Upon removal of this protective seal the CDD completely sublimated with the help of fans, localised heating and ventilation.

1 Introduction

The painter Lewis Rubenstein created three social realist frescoes in Harvard's Fogg Museum building in the 1930s, one in collaboration with his friend Rico Lebrun. Between 2009 and 2014, as the art museums underwent major construction during renovation, two of the frescoes were moved with their supporting walls, and the third was left in situ on an exterior wall in a purpose-built housing. The goal for conservators was to treat and protect the frescoes that were relocated, as well as the one in situ, from the shock and vibration of transportation and construction, climate extremes and structural intervention. This called for complex engineering, coordination and conservation measures to secure the frescoes in advance of dramatic and potentially dangerous operations. While this paper briefly covers the overall project, we will focus on our choice and use of the volatile binding medium cyclododecane (CDD) to protect the murals during a construction project that was projected to last up to five years. We will describe preliminary testing done to develop CDD application methods, measures taken to prevent premature sublimation, research and analytical findings to assess what happens when it is heated above a certain temperature in preparation for application, and what we learned about encouraging sublimation at the conclusion of the project.

1.1 Harvard Art Museum renovations

Preparations for the frescoes' protection began in 2009, just before the Harvard Art Museums broke ground on a major renovation and expansion project designed by Renzo Piano Building Workshop (RPBW) (Figure 1). The fresco team comprised representatives from RPBW, general contractor Skanska USA, Harvard Capital Planning and Projects Management, the engineering firm LeMessurier, and conservators and facilities staff from the Harvard Art Museums. The RBPW design called for the complete removal of all floors and ceilings adjacent to the murals, demolition of two thirds of the old Fogg Museum building and

Figure 1 The renovated Harvard Art Museums in October 2014: a) front exterior view; b) rear exterior view. Photos: ©Harvard Art Museums, photographer Peter Vanderwarker.

construction of a major extension, including an additional fifth floor and glass roof. The new design called for two of the frescos to be moved to different locations, and for one to stay in place.

1.2 The artists and the murals

A Harvard graduate, Lewis Rubenstein studied painting in Paris and learned traditional Italian true fresco techniques working in the Rome studio of Silvio Galimberti. There he met Italian-born American artist Rico Lebrun (1900–1964), and the two bonded over a shared passion for the age-old process. Their Italian sojourn directly inspired the first of the three murals entitled *End of the World* (Figure 2). In 1932, Museum director Edward Waldo Forbes commissioned Rubenstein to paint the full-size copy of a figure from one of Luca Signorelli's frescos in the Orvieto cathedral to demonstrate the true fresco process to his students. It was painted on the fourth floor of the Fogg, in what was then a studio classroom; this space was transformed into the paintings conservation laboratory in 1940 and remained in use until the 2009 renovation.

Figure 2 *End of the World* (1933.193). Fresco painted on the inside of an exterior wall by Louis Rubenstein after a detail of Signorelli's *End of the World* fresco in Orvieto. Photo: ©President and Fellows of Harvard College, photographed by the Imaging Department.

Rubenstein and Lebrun painted the second Fogg fresco, *Hunger March*, the following year in the same fourth-floor studio space (Figure 3). The subject was a collage of scenes based on their experience of the US Army's forcible removal of an estimated 15,000 destitute and out of work World War I veterans who staged a hunger strike in Washington, DC in 1932 in the hope of forcing the government to pay out a reward bonus they had been promised by Congress in the 1920s. In *Structure* (1935), which filled the

Figure 3 *Hunger March* (1933.192). Fresco painted by Rubenstein and Rico Lebrun on an interior terracotta tile wall, fourth floor of the Fogg building. Photo: ©President and Fellows of Harvard College, photographed by the Imaging Department.

Figure 4 *Structure* (1935.33). Fresco painted by Lewis Rubenstein on the lower level of the Fogg building. Photo: ©President and Fellows of Harvard College, photographed by the Imaging Department.

wall at the end of a basement corridor where staff, students, and museum visitors would have seen it, Rubenstein depicted the stages of constructing the very wall in the basement of the Fogg that he painted upon (Figure 4). It shows workers laying blocks, plastering, and, through a *trompe l'oeil* hole in the upper right, positioning steel girders for the construction of a (then) new wing of the Fogg building. As an added flourish, he depicted himself on scaffolding, seen from the back, in the process of painting the fresco.

Rubenstein went on to paint another fresco cycle for Harvard in Adolphus Busch Hall, then the Germanic Museum. Widely respected for his technical knowledge of fresco, Rubenstein contributed to a written circular on fresco technique distributed by the Works Progress Administration to all artists hired to create public murals. In 1940, he assisted José Orozco on the publicly executed portable fresco panels *Dive Bomber and Tank* at MoMA. Rubenstein went on to a fruitful career teaching and painting. Rico Lebrun became a leading modernist artist, working in California.

1.3 The murals and the engineering project

Few examples of native true fresco, painted in wet lime plaster directly on walls, exist in New England. Boston area museums possess frescoes, but most were removed from European churches by either 'stacco' or 'strappo' techniques in the early- to mid-twentieth century. The fresco project sought to keep these unique works as close to their original condition as possible. To do this, conservators felt strongly that the original wall structures should be retained and the entire walls be moved ('stacco a massello') along with the frescoes.[1]

The three frescoes presented different, but equally extreme, engineering and conservation challenges. The choice of CDD as a facing material was born out of concern for what the frescoes would undergo during the project. After protection was put in place, *End of the World* remained in situ during the demolition and reconstruction of the building, while sheltered in an insulated, heated protective enclosure high on its (now) exterior wall, and exposed to the harsh New England climate for over three years (Figure 5). *Structure* was faced and protected, and specialist contractors cut its three-foot thick masonry wall with an abrasive, water-cooled cable saw. The fresco was enclosed and stored in a plywood structure within the building during construction. It was relocated later in the project with a crane. Together with its steel beam cradle, the package weighed about 32,000 lb (14,515 kg) (Figure 6).

1 'Stacco' is the removal of the paint and render, or 'intonaco' layer; 'strappo' is removal of only the uppermost paint layer of the fresco. 'Stacco a massello' refers to removing as much as possible of the entire wall structure.

Figure 5 *End of the World* in its protective housing after removal of the roof of the building. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

Figure 6 *Structure* being moved by crane, showing the left side cut of the brick supporting wall. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

As many of the conditions and operations for the three frescoes were similar, we will present a more detailed description of the steps taken to protect and move one of them, *Hunger March*. The plan for *Hunger March* was to remove it, along with its entire terracotta box-tile supporting wall from the building. To prepare the painting for facing, the condition of the fresco was assessed and digitally mapped; its surface was cleaned with deionised water rolled over the surface on cotton swabs; and its underbound passages were consolidated with Paraloid B72 (2–2.5% w/v in 3 : 1 acetone : Shell Cyclosol 53).[2]

2 Cyclosol 53 is a slow drying aromatic solvent blend containing a mixture of 70–80% C9 aromatic hydrocarbons (primarily ethyltoluene and trimethylbenzene isomers), with the remainder primarily C8 and C10 aromatic molecules.

2 CDD testing and application

2.1 Choice of CDD for facing

Deciding factors for choosing CDD were the undetermined amount of time during which the murals had to remain protected and the reversibility of the facing material without physical contact after a protracted period. Areas of each fresco contained dry and poorly bound paint, sensitive to rubbing and prone to oversaturation. Some areas were also water-sensitive. Traditional facing techniques, such as adhesives and facing tissue or paper, had drawbacks. A resin facing system such as Paraloid B72 was ruled out due to the need for solvents to remove it. In addition, B72 had already been used as a consolidant, so there was a risk that solvent removal of the facing would also remove some consolidant. Glues, such as sturgeon glue, rabbit skin glue or gelatine, could harden and become difficult to remove. We were concerned that, even though the fresco was consolidated with Paraloid B72, the use of water to remove a glue facing could result in the abrasion and loss of powdery and water-sensitive colours. In addition, the facing material needed to adhere well enough to the surface to stabilise and protect it against impact and vibration and to form a strong and fairly inflexible layer.

Three earlier mural projects using CDD on a large scale encouraged us to consider its use. The first, involving the relocation of Siqueiros' mural *Portrait of Mexico Today* from Los Angeles to the Santa Barbara Museum of Fine Art, took place in 2002 (Emerling 2002). The outdoor mural, painted in synthetic resin on Portland cement, was coated with molten CDD and could start sublimating almost immediately after its move. After about seven months, the CDD was completely gone. In a second project, in 2003, Hangleiter and Saltzmann protected a fresco at the Bronnbach Monastery in Germany with CDD (Hangleiter and Saltzmann 2006). The treatment aimed to prevent sublimation for six months using a vapour seal of polyurethane foam and aluminium foil. The project was considered a success, though the conservators reported difficulty in removing their vapour seal from the CDD. In 2006, Joyce Hill Stoner and a group of student collaborators used CDD to consolidate a Ralph Coleman mural before its move from the Zion Lutheran Church in Wilmington, Delaware (Grow 2007). Our requirements were somewhat more demanding, however, as we wanted the CDD to remain in place for over three years.

2.2 Molten or in solution?

One of the first issues conservators considered was whether to use CDD in a dilute or molten form. We needed the densest film possible, given the amount of vibration anticipated. During our research, we were impressed by the 1999 study by Brückle et al. comparing films formed from a saturated CDD solution and molten CDD. This showed that the latter produced smaller crystals and a denser, compact film (Brückle *et al.* 1999).[3] In addition, we were concerned by reports that the inclusion of solvents creates less dense, weaker films that would be more likely to prematurely (for our needs) sublime (Muros and Hirx 2004). We decided to apply CDD in a molten state rather than using a solvent solution. We could thus also avoid working with quantities of solvents in a large-scale application.

2.3 Testing application methods

Before beginning treatment, we tested methods of applying molten CDD using a fragment of a fresco and 2-ply corrugated blueboard as supports.[4] The characteristics of CDD depend on the application method chosen, the porosity of the substrate, and the rate of film formation. Our fresco surface was fairly porous, no longer friable after consolidation and not heat-sensitive. We tested two options for applying molten CDD: a hog hair brush and spray application. The Champ 10S LCD Hot Spray Gun, a device normally used to spray hot-melt adhesives for furniture construction, box making and other fabrication processes, was used for the spray application (Figure 7). Both methods were tested and refined in a fume hood and spray booth, using respirators and gloves to limit user exposure to the solid and vapour. This was our approach throughout the project because the possible long-term health effects of CDD are not fully understood and various authors have pointed out uncertainties about its safety (Rowe and Rozeik 2008).

Figure 7 The Champ 10S LCD Hot Spray Gun, a device normally used to spray hot-melt adhesives. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

The idea of using a heated spray gun to rapidly apply and build thick coatings of molten CDD on sizeable, vertical surfaces was appealing. In small-scale tests, the spray gun quickly produced a thick, homogenous layer. Most tests were carried out on pieces of blueboard, which does not at all replicate the texture of a fresco; this would have consequences later when working on the actual fresco. We noted that achieving an even layer depended on being able to consistently control temperature, speed of spray, pressure and distance to the surface. Though CDD reportedly melts at 60–71 °C, we found the hot spray gun significantly easier to work with at the 80–85 °C setting. At higher temperatures, CDD clogged the gun less frequently. Curiously, on some of the test panels the CDD applied at the higher temperature settings developed tackiness as it began to sublimate. There was no way of verifying the actual temperature of the CDD inside the gun chamber and the digital readout indicating the 80–85 °C setting may not have represented the actual temperature of the CDD. We were concerned about the tackiness and suspected that it was temperature-related.

2.4 FTIR analysis

In an effort to better understand what was occurring with the tacky test panels at a molecular level, and to identify an ideal practical working temperature, several CDD samples were analysed. These included a reference sample of crystalline

3 See the photomicrographs in Fig. 1 of this paper comparing films formed with CDD in petroleum ether to molten CDD (p. 165).

4 Perma/Cor B-Flute Corrugated Board from University Products is an acid free, lignin-free and alkaline buffered corrugated cardboard tinted a pale blue-grey colour.

CDD (Kremer) at room temperature; samples of CDD heated to 80 °C and 85 °C on a hotplate; and a sample that had been sprayed through the heated spray gun at the 85 °C setting. For analysis by Fourier-transform infrared spectroscopy (FTIR), the samples were flattened between two diamond windows in a diamond micro compression cell. Spectra were measured in transmission while the sample was supported on a single diamond window using a Thermo Continuum infrared microscope coupled to a Nicolet 6700 bench-top spectrometer. The spectra suggested that three of the CDD samples – unheated, heated to 80 °C and heated to 85 °C on the hotplate – appear to be the same (Figure 8). However, the CDD that was (presumably) overheated in the hot spray gun underwent a molecular change, and is different from the unheated molecule in both the aliphatic stretching (Figure 9) and bending (Figure 10) regions of the spectrum. FTIR analysis confirmed that some aspect of the spray gun use, possibly its overheating due to an inaccurate thermostat, caused a molecular change in the CDD. An organised research project that included more samples heated to a range of higher temperatures on a hot plate as well as through a heated spray gun would be necessary to better understand this alteration. Our analysis was in response to a practical problem encountered during preparation for treatment, so it did not proceed any further.

As a practical result of the analysis, we decided to keep the thermometer-measured heated water bath and spray gun setting at or under 80 °C during the project. We did not want to risk creating tacky CDD that could adhere to overlying barrier layers, making them difficult to remove when necessary. The analysis reassured us that CDD could be safely heated to 80 °C degrees on a hotplate, the temperature we found most workable for brushing it onto the fresco surfaces, without degrading the molecular structure.

2.5 Applying molten CDD to the frescoes

The Champ 10S LCD Hot Spray Gun achieved the most rapid, homogenous films on our test panels in the controlled environment of the spray booth. On the actual frescoes, however, we experienced several problems with its use. The spray application allowed some of the material

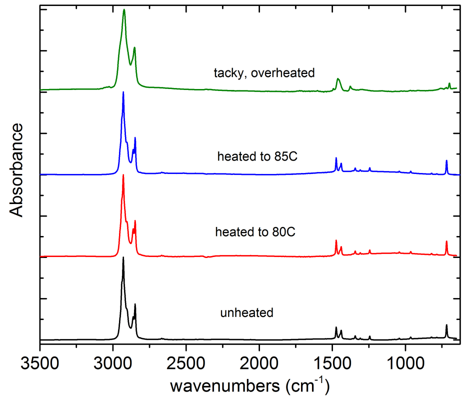

Figure 8 FTIR spectra of unheated CDD (Kremer) (black trace), CDD heated on a hotplate to 80 °C (red trace), CDD heated on a hotplate to 85 °C (blue trace), and CDD heated in a spray gun set to 85 °C, which has become tacky (green trace). The lower three traces of CDD have the same FTIR spectra, whereas the upper tacky sample shows a different FTIR spectrum.

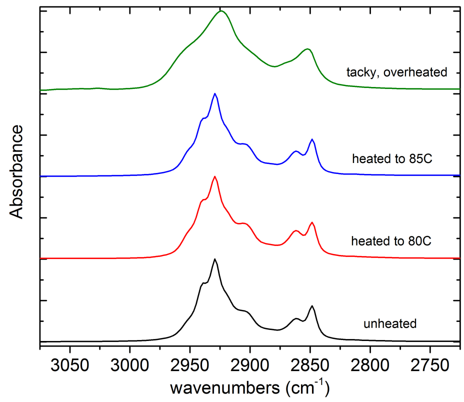

Figure 9 FTIR of the aliphatic stretching region of the four samples of CDD.

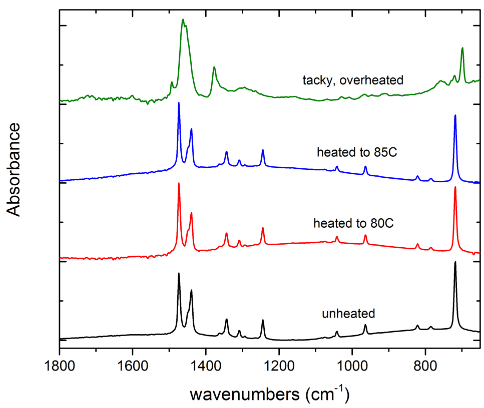

Figure 10 FTIR of the aliphatic bending region of the four samples of CDD.

to dry before reaching the surface of the fresco, trapping air within the coating and creating a dry, pebbly surface that became more pronounced with each subsequent layer. This required re-heating after application with tacking irons or heat guns to smooth out and consolidate the surface, which was time-consuming and only partially effective. The gun's chamber is problematically small and holds relatively little CDD[5]; it was necessary to pre-heat the CDD to avoid a long wait time for it to heat up in small batches in the gun itself. The gun also needed to be cleaned often, at the tip, air vent and elsewhere, to prevent clogging.

Ultimately, brushes proved the most efficient means for applying molten CDD (Figure 11). We chose inexpensive 2-inch wide hog hair 'chip' brushes, which were superior to softer, denser-haired (and more expensive) brushes that held less material and tended to clog up more quickly. We put approximately 300 ml CDD into each of four 500 ml Pyrex beakers in a heated water-filled container. The bath contained a thermometer to ensure that the water did not exceed 80 °C. The beakers were rotated into use as the CDD reached a liquid consistency. When applied, the CDD reverted from a water-thin consistency to a solid almost as the brush met the surface of the fresco, leaving very little working time. With practice, conservators found rapid application controllable, albeit messy. Conservators working in groups of two or three built up the CDD by thin layers into a thick, opaque white coating. It took approximately 90 person hours to apply a 3⁄8-inch (9.5 mm) layer of CDD to *Hunger March*, the surface of which measures 120 inches × 60 inches (50 square feet, or 4.64 m^2). Two layers of cheesecloth were incorporated into the layer of CDD to impart strength and structural support to the face of the fresco. We were concerned by the possibility of interlayer plaster separation, already a problem for *Hunger March*. The thick facing would keep the surface layer together if the underlying plaster failed during the various stages of construction. We also hoped to avoid premature sublimation by applying as thick a layer as we reasonably could.

Figure 11 Jill Hari applying CDD to *Hunger March* with a hog hair brush. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

To ensure a uniform thickness, a simple tool was devised to easily measure the CDD depth at intervals during application. A wire bent into a handle at one end and a 1 cm long indicator at the other was heated briefly with a small flame and melted into the CDD until it touched the fresco. By testing periodically across the surface and marking areas of insufficient CDD thickness with a felt-tipped pen, we could indicate where more applications were needed. Indicators were incorporated within the CDD facing to reveal the degree of sublimation that had occured. Located at eye level on the right and left sides of each fresco, red stickers were placed over the initial third of the CDD depth; orange stickers over the next third (and first layer of cheesecloth), and yellow stickers over the upper layers of CDD (and second layer of cheesecloth).

We carried out the CDD application in less than ideal conditions, as the building was already an active construction site. We were able to set up continuous air extraction, safe scaffolding, and wore personal protective equipment (gloves, safety glasses and respirators).

3 CDD barrier film and sublimation

3.1 Choosing a barrier film

Finding a good barrier film to seal the CDD was crucial to prevent sublimation for over three years after application. The film needed to be to be both

5 Although systems for delivering larger quantities using heated tanks are available, they were deemed uneconomic for such a limited use. We are grateful to Mr Pierce Covert, President of the Glue Machinery Corporation, for his assistance on the project. See `http://www.gluemachinery.com` for further information.

physically durable and airtight. We considered various protective layers: Teflon (Dupont PFA and FEP films), clingfilm (Saran wrap, copolymer of vinylidene chloride and small amounts of vinyl chloride or acrylonitrile), Mylar (polyester film), Dartek (cast nylon film), polyethylene, and Marvelseal. Marvelseal 360, a composite of aluminium foil, nylon film and heat-sealable polyethylene, seemed the clear choice.[6] Marvelseal is >1,000 times less permeable than the next most effective, but less durable, alternative, Saran – and is >10,000 times less permeable to oxygen than plain polyethylene film. 2-inch wide aluminium tape was chosen to seal the Marvelseal to the wall plaster surrounding the frescos. Two different brands were used: Ideal Tape 488[7] and 3M™Aluminum Foil Tape 425.[8]

3.2 Physical support for the frescoes

With the frescoes consolidated, coated in a layer of CDD, and sealed from sublimation, it was time to enclose them in a structural 'package' that would offer physical protection, stabilisation and cushioning, as well as lifting points for transportation. Conservators decided that a layer of foam held in slight compression against the fresco surface under a protective plywood skin would help dampen vibration and provide physical protection. *Hunger March* and *Structure*, both of which needed to be cut away from the building and lifted out by crane, were further contained within two pre-fabricated galvanised steel frames, their design a product of lengthy planning sessions between architects, engineers, riggers and conservators.

The next steps taken to protect *Hunger March* included coating the back of the terracotta box-tile fresco wall with Conproco Structural Skin[9] in order to seal it and equalise the two sides by building in a layer of approximately the same thickness and strength as the fresco and CDD on the opposite side of the wall. The general contractor proposed and carried out this step. Next, 2-inch thick polyethylene foam sheets (with windows cut for indicator sites) were applied to both front and back. Over this, a layer of 0.75-inch (1.9 cm) plywood sheet, with small doors added to allow access to the indicator sites, was installed on both sides.

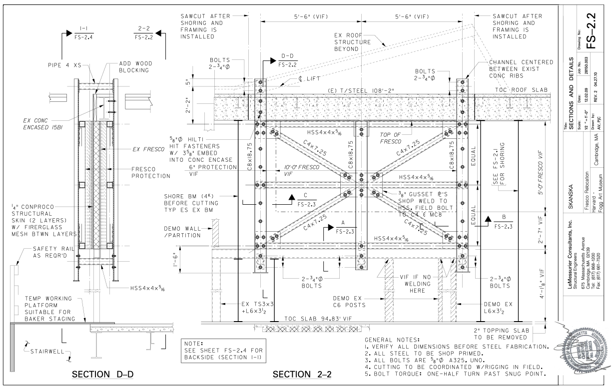

Figure 12 Diagram showing the steel support designed for *Hunger March*. Image: LeMessurier Consultants, Inc / Skanska.

A supporting tubular steel beam under *Hunger March* was incorporated into the new protective structure, designed to help support the fresco during its journey. It comprised two steel frames, designed in a 'Union Jack' configuration, welded in place on both sides of the wall package to the tubular steel beam (Figure 12). Through-bolts were added around the perimeter of the fresco to tie both sides together. A series of vertical rods was welded into the frames to provide support for cedar shingle shims tapped into place against the plywood and secured with screws, which gently pressed the plywood against the foam and the fresco.

At this point the fresco was fully supported and could be freed from the building structure. Contractors using a diamond chain saw had cut the sides of the fresco free previously. The cut on the right side, now left exposed, revealed the sub-plaster layer below the arriccio and intonaco layers, on top

6 Marvelseal is a registered trademark (James Dawson Enterprises, Ltd) for a barrier material made from aluminium foil sandwiched between a transparent nylon film and a layer of heat-sealable polyethylene. The nylon is adhered to the foil with a thin layer of polyethylene. Marvelseal 360 is strong, waterproof, vapour-proof and flexible. Of all the different vapour barriers considered, Marvelseal has the lowest oxygen transmission rate: for a 1 mil film, oxygen transmission is 0.01 ml/m^2/d, and water vapour transmission is 0.01 g/m^2/d (information from the CAMEO database, www.cameo.mfa.org (accessed 16 May 2019).

7 Ideal Tape 488 with paper backing is a pressure-sensitive aluminium foil tape with a rubber adhesive system.

8 Aluminum Foil Tape 425 has a dead-soft aluminium foil substrate and an acrylic adhesive system.

9 A fibreglass-reinforced, Portland cement-based waterproof coating used to plaster exterior and interior above-grade walls.

Figure 13 Crane removing *Hunger March* from the Fogg building, 24 June 2010. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

of the terracotta box-tile. This sub-layer was found to be weakened, crumbling and lifting up to 1 cm away from the tile in areas several centimetres deep. Conservators consolidated these gaps with Paraloid B72 (50% w/v in a mixture of acetone and ethanol). Finally, a wet saw was used to cut through the supporting steel beam overhead. The mural was carefully lifted through the roof of the building by crane and placed on a flat bed truck for transport to a storage facility. Years later, it would be transported back and moved by crane through the front door of the building and to its new location in the Museum's Social Realism Gallery (Figure 13).

3.3 Monitoring depth indicators

During the multi-year period that the frescos were stored, conservators monitored the stability of the CDD periodically. A resealable flap was cut into the Marvelseal barrier layer, and small doors cut into the foam and wood protective layers allowed access to the indicators. For *End of the World*, still attached to its fourth-floor wall, monitoring meant climbing a 70-foot scaffolding; for *Hunger March*, a visit to an off-site storage facility; and for *Structure*, entry into the enclosed plywood protective housing on the Piranese-like basement level of the building under construction. Little to no premature sublimation was observed during the three year period. The only suggestion of early sublimation was a dusting

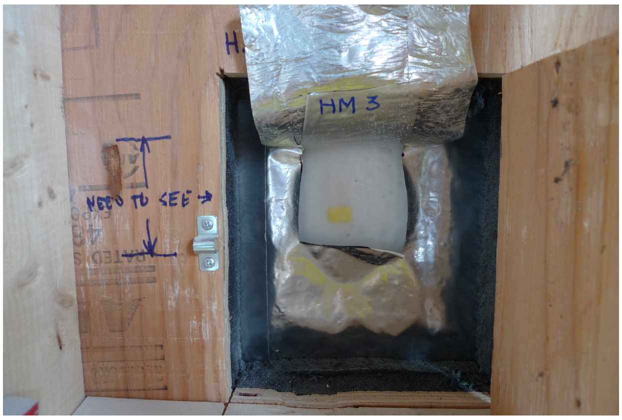

Figure 14 Open access door in the plywood protection on *Hunger March*, showing the foam and Marvelseal layers, the yellow indicator tape, and minor redeposition of CDD on the inside of the Marvelseal. Photo: ©President and Fellows of Harvard College, photographed by the Straus Center for Conservation.

of fine crystals of redeposited CDD on the inner surface of the Marvelseal barrier on one of the indicator windows (Figure 14).

3.4 Sublimation rate testing

To estimate the required sublimation time, we made up blueboard test panels of the same 3/8-inch depth of CDD, with two layers of cheesecloth, and timed their sublimation in different conditions. Though not as porous as the fresco surfaces, the panels provided ballpark time estimates for the sublimation. Weighing the panels initially, and over extended periods, we found that they sublimated at a rate highly dependent on the amount of heat and ventilation provided. A panel placed in a fume hood with a face velocity of 100 feet/minute under a heat lamp, sublimated in three months and eight days. A second panel in the same fume hood without heat took four months and five days. The last panel, kept in a small room with no ventilation, took over 700 days to sublimate.

3.5 Sublimation reality check

In reality, conditions at the time of sublimation of CDD from the frescos were more complicated. The demands of ongoing construction in the new museum and the need to protect the frescoes from adjacent contractors' work slowed the process. Each of the murals had a series of intervening circumstances that had a significant impact on the rate of sublimation. After *Hunger March* was returned to the museum and built into its new gallery wall, the plywood housing erected to protect it from ongoing work in the surrounding gallery delayed adding heat and ventilation to speed sublimation. In addition, the vibration and mechanical stress it underwent while being cut, moved and built back in the new wall weakened the already fragile attachment of the underlying plaster layer along the top and left edges. This necessitated an unexpected step: consolidation and reattachment of the underlying plaster to the tile wall support by injecting 50% Paraloid B72 and bracing the fresco and plaster layers while the adhesive set. While confirming the success of CDD in providing a secure facing for the fresco, this emergency reattachment caused further delays in the sublimation process. From the first day of removing the Marvelseal (4 April 2013) to 99% sublimation (13 November 2013), sublimation took 7 months and 10 days (224 days).

Conservators removed the Marvelseal barrier on *Structure* in January 2013. It remained enclosed in its protective plywood shelter, equipped with fans, a ventilation duct to the outside, and space heaters for nine months. The shallow five-foot depth of the shelter limited options for locating the fans and heaters, creating a pattern of varying rates of sublimation across the fresco. After eight months, sublimation was 95% complete. After the enclosure was removed, small areas of remaining CCD were left to sublimate with the help of a fan.

Although conservators removed the Marvelseal barrier from *End of the World* on 11 July 2013, the fresco was kept enclosed throughout the construction period in its plywood housing, to be replaced later with a glass-fronted vitrine. Beginning in August 2013, the vitrine was opened as the construction schedule allowed, and fans and heaters were set up to speed the sublimation. As conservators were not always at the construction site, an on-site Skanska project engineer monitored the sublimation progress weekly on an Excel log.[10] This speeded the sublimation process by ensuring that fans were running, providing vigilant protection of the murals. Conservators found that weakened plaster interlayers on *End of the World* also required reattachment with Paraloid B72 as above. With the CDD still intact and providing its stabilising function as a facing, the top half and edges of the fresco were reattached without incident. Sublimation of *End of the World* took approximately seven months. At that time, conservators found that preexisting weak underlying plaster had detached further in the centre and lower part of the mural. These areas were reattached by injecting B72 through holes drilled through the front of the fresco, then applying pressure with foam blocks compressed between the fresco and the closed vitrine door. Without the advantage of a stabilising CDD facing, this procedure was considerably more worrisome, but the outcome was successful. The holes were later filled and inpainted.

4 Conclusion

In the cases of both *Hunger March* and *End of the World*, the very solid CDD layer kept them intact despite a poorly bound underlying plaster layer, threatened by the rigours of the construction project. Without the CDD layer, we could have lost parts of the arriccio and intonaco layers due to the interlayer detachments that occurred. The 3/8-inch thick CDD layer held the plaster layers in place during the extreme vibrations caused by transport and demolition and allowed their reattachment afterwards without loss or incident. Marvelseal 360 sealed with aluminium foil tape created a very effective barrier to sublimation, without measureable loss of CDD over the duration of the project. Our project demonstrated that CDD sublimation can be suspended for at least three years, even under the most challenging climate and physical conditions. It is likely that sublimation of a thick molten-applied CDD layer could be stopped indefinitely under such a Marvelseal barrier. Conversely, our project demonstrated that it is possible to speed up the sublimation of even a relatively thick CDD layer by using heat and air movement through extraction blowers ducted to the outside. We observed that CDD heated at the 85 °C setting on our hot spray gun became tacky upon sublimation. This may be due to a

10 The log included date, time, temperature and air flow conditions (location of fans and heaters set up on scaffolding in front of the fresco; whether or not they were in operation). The engineer took digital images of each fresco, whether or not they were covered. The log was continued until February 2014, when project ownership reverted to the Harvard Art Museums.

molecular change, as evidenced by the changes in the aliphatic stretching and bending regions of the overheated CDD samples noted with FTIR analysis.

Our team of museum officials, contractors, engineers, architects and project conservators considered the protection and relocation of these frescoes to have been a complete success. This was attributable to a determination to preserve the frescoes, creative thinking, rigorous testing, and a commitment of necessary time and resources to all phases of the project. It demonstrated the viability of the use of CDD under complex circumstances involving construction and long-term storage, when the structural integrity of a fresco was at issue.

Biographies

Teri Hensick joined the Harvard Art Museums in 1980, and was Conservator of Paintings since 1988, retiring in 2017. She received her BA in Art History from Wellesley College, studied paintings conservation in Florence and Zurich, and interned at the Straus Center for Conservation and Technical Studies, Harvard Art Museums. She also worked at the German National Museum, Nuremberg, and the Detroit Institute of Art. In addition to treating and publishing on paintings in Harvard's collections, she has worked on projects to conserve and study the wall painting cycles by Puvis de Chavannes, Sargent and Abbey at the Boston Public Library.

Email: thensick@gmail.com

Anthony Sigel is Senior Conservator of Objects and Sculpture at the Straus Center for Conservation, Harvard Art Museums, responsible for the treatment and study of three-dimensional art from ancient to contemporary. Receiving a BFA from the School of the Art Institute of Chicago, he was trained as a conservator at the Art Institute of Chicago museum. He has worked for five summers at the Harvard/Cornell archaeological excavations at Sardis, Turkey, most recently as supervising conservator. He has published, lectured and taught widely on conservation practice and technical art history topics. His early training as a sculptor led to his technical study and publication of Baroque terracotta models in collections worldwide. In 2004, he was awarded the Rome Prize, spending a year as a fellow at the American Academy in Rome studying works by Bernini and others. Most recently he co-curated the comprehensive exhibition of Bernini's terracotta sculpture *Bernini: Sculpting in Clay*, which opened in 2012 at the Metropolitan Museum of Art, and in 2013 at the Kimbell Museum of Art, and was also a co-author of the exhibition catalogue. Appointed Robert Lehman visiting professor at Villa I Tatti, Florence, he spent September 2016 studying the techniques of Renaissance sculptural models.

Email: tony_sigel@harvard.edu

Henry Lie was Director of the Straus Center for Conservation and Technical Studies at the Harvard Art Museums and Head of the objects and sculpture laboratory from 1990 to 2015. After studying art history at Harvard College as an undergraduate, he was introduced to conservation by Norman Weiss, helping to develop silane-base stone consolidants. He earned his MS degree in conservation at the Winterthur/University of Delaware program. As an objects conservator, he has concentrated in recent years on the study of ancient bronzes. His most significant work in this area was a collaboration with archeologist Carol Mattusch, *The Villa dei Papiri at Herculaneum* (Getty, 2005).

Narayan Khandekar is the Director and the Senior Conservation Scientist of the Straus Center for Conservation and Technical Studies at the Harvard Art Museums and Lecturer in the History of Art and Architecture, Harvard University. He received a PhD in organic chemistry from the University of Melbourne and a Postgraduate Diploma in the Conservation of Easel Paintings from the Courtauld Institute of Art. His major interest is the materials and techniques of artists and he is an author on over 60 publications.

Kate Smith is Conservator of Paintings and Head of the paintings lab at the Straus Center for Conservation and Technical Studies, Harvard Art Museums. Kate received her BA in Art History from Smith College in 1994 and her Master of Arts in paintings conservation from Buffalo State College in 2001. She held assistant conservator positions at the Harvard Art Museums, Isabella Stewart Gardner Museum, Gianfranco Pocobene Studio, and at the Museum of Fine Arts, Boston, before returning to the Harvard Art Museums in 2012, where she specialises in the technical examination of paintings. With her Straus Center colleagues, Smith teaches conservation-focused courses at Harvard, including HAA 101: The Making of Art and Artifacts: History, Material and Technique; HAA 206: Science and the Practice of Art History; and the Summer Institute for Technical Studies in Art (SITSA).

Francesca G. Brewer is Research Curator for Conservation and Technical Studies Programs and Director of the Summer Institute for Technical Studies in Art at the Harvard Art Museums. She serves as liaison between the Division of Academic and Public Programs and the Straus Center for Conservation and Technical Studies. She has an MPhil from the Warburg Institute, London, and a PhD from the Institute of Archaeology, London. She is the author of *A Laboratory for Art: Harvard's Fogg Museum and the Emergence of Conservation in America (ca. 1900–1950)* (Harvard, 2010) among other publications on the history of conservation, and on the technology of bronze sculpture. She is also the recipient of the 2012 College Art Association/Heritage Preservation Award for Distinction in Scholarship and Conservation.

Angela Chang is the Assistant Director and Conservator of Objects and Sculpture at the Straus Center for Conservation and Technical Studies. She earned an MS degree from the Winterthur/University Delaware Program for Art Conservation and a BA in Art History from Northwestern University. Previously, she worked and trained at the National Gallery of Art, the Brooklyn Museum of Art, the Gordian Excavation, and the National Museums of Scotland. Her recent research interests include medieval Japanese sculpture, ancient Chinese jades, and ancient silver-working.

Louise Orsini is Assistant Conservator of Paintings at the Museum of Fine Arts, Boston, and is a past Board Member and Treasurer for the New England Conservation Association. After completing internships at the Walters Art Museum, the Royal Picture Gallery Mauritshuis, the Doris Duke Foundation for Islamic Art, Shangri La, and the Worcester Art Museum, Louise received an MS and Certificate in Paintings Conservation from Winterthur/University of Delaware. She completed two Postgraduate Fellowships at the Straus Center for Conservation and Technical Studies, Harvard Art Museums. Louise also worked at the Straus as an Assistant Paintings Conservator for the Adolphus Busch Hall Fresco Project.

Erin Mysak received a BS in French and Chemistry from Dickinson College and a PhD in Chemistry from the University of North Carolina at Chapel Hill. She worked in atmospheric chemistry at Lawrence Berkeley National Laboratory prior to entering the field of conservation science. She has worked at the Harvard Art Museums and the Institute for the Preservation of Cultural Heritage at Yale University, and is currently an independent conservation scientist in the New England area.

References

Brückle, I., Thornton, J., Nichols, K. and Strickler, G. (1999), 'Cyclododecane: technical note on some uses in paper and objects conservation', *Journal of the American Institute for Conservation* **38**(2), pp. 162–175.

Emerling, S. (2002), 'A wall on the fly: the only Siqueiros mural left intact in L.A. completes four-year trek to a Santa Barbara museum', *Los Angeles Times* (6 October 2002). Available from http://www.wpamurals.com/Siqueiros.htm (accessed 11 February 2015).

Grow, S.L. (2007), 'Conservation of coleman mural', URL http://web.archive.org/web/20100612081048/http://www.artcons.udel.edu/news/2007/02/16/conservation-of-coleman-mural.

Hangleiter, H.M. and Saltzmann, L.F. (2006), 'Konservierung und Restaurierung des Orangeriegemäldes', in R. Frank, ed., *Kloster Bronnbach: Sanierung und Umbau des Bursariats und der Orangerie zum Bildungszentrum*, Landratsamt Main-Tauber-Kreis, Tauberbischofsheim, Germany, pp. 82–99. [in German]. Available from http://www.hangleiter.com/publikationen/Kloster%20Bronnbach%20-%20Konservierung%20und%20Restaurierung%20des%20Orangeriegemaeldes.pdf; another version is available from http://www.hangleiter.com/html_e/f_vor_br.htm (accessed 30 January 2018).

Muros, V. and Hirx, J. (2004), 'The use of cyclododecane as a temporary barrier for water-sensitive ink on archaeological ceramics during desalination', *Journal of the American Institute for Conservation* **43**(1), pp. 75–89.

Rowe, S. and Rozeik, C. (2008), 'The uses of cyclododecane in conservation', *Reviews in Conservation* **9**, pp. 17–31.