Evaluation of conservation options for decoratively painted wood, Mission San Miguel Arcangel

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Abstract
The adobe church of Mission San Miguel Arcangel (c.1818, San Miguel, California, U.S.A.) is one of California’s cultural treasures; the painted interior has extraordinary integrity and significance. The 2003 San Simeon earthquake caused considerable damage and the church was closed to the public. An extensive project is underway to stabilize the building and conserve the interior decoration. Many structural elements were displaced during the earthquake and all of the painted wood is deteriorated due to termite infestation and decay. Planning for conservation followed two lines of investigation: 1) inspection of the structural woodwork to characterize section losses and evaluate member capacity, and 2) treatment testing of painted wood to characterize period paints and develop materials and techniques for conservation. A multidisciplinary team including an architectural conservator, a wood science firm, a furniture conservator, a wall paintings conservator, and a preservation carpenter completed evaluation and treatment testing of the painted wood.

Keywords
videoscope, resistance drilling, digital radioscopy, wood assessment

History and Significance
Mission San Miguel Arcangel was founded in 1797, the sixteenth of 21 Spanish missions established in Alta California. Construction of the mission took place over two decades, culminating with the church, completed in 1818. The gable-roofed adobe building is laid out roughly on an east-west axis and is 11.5 meters wide by 47.9 meters long. Nave walls are 1.63 meters thick, and the room interior is approximately 8.23 meters wide. The altar on the west includes a wooden retablo, railings, pulpit and canopy. A wood-framed choir loft occupies the east end of the room. The sacristy is an adobe wing located at the northwest corner of the nave (Figure 1).
Nearly all of the church interior is decorated with a polychrome paint scheme applied within a decade of construction and comprised of painted classical architectural elements and stencilled designs, including the mud-plastered walls, the nave, choir, and sacristy ceilings, the retablo, and the pulpit. This paint scheme is typically ascribed to Esteban Munras, a Spanish immigrant, who directed a crew of Native American neophytes. The interior paint scheme is thought to have been completed sometime early in the 1820s. The church interior retains one of the highest levels of integrity and authenticity of any of the California missions (Figure 2). The mission complex was listed on the National Register of Historic Places in 1971, and was later elevated to National Historic Landmark status. In 2006, the National Trust for Historic Preservation included the property on its 11 Most Endangered Sites list.

Figure 1: Most of the interior elements, including walls, ceilings, retablo, and pulpit are incorporated in an early 19th-century decorative paint scheme. Photo: HABS collection.

Figure 2: This composite image of the north nave wall highlights the architectural nature of the painting motifs. Photo: Neil Dixon.
Deterioration Conditions
The church was closed to the public following the San Simeon earthquake of December 22, 2003. However, the building had been badly damaged in previous earthquakes and as the result of decades of neglect. A visual inspection of the woodwork and documentary research provided qualitative information about the building’s condition and stability. Damage to historic wooden elements on the building interior included:

1. Staining and dissolution of historic paints (comprised of inorganic pigments combined with protein and carbohydrate binders);
2. Displacement of structural wood as the result of earthquakes;
3. Section loss associated with wood-boring insects and fungal decay.

The levels of damage associated with water staining varied from mild to severe. Period paints are extremely sensitive to water. In its mildest form, water staining resulted in the dissolution of the painted finish, with pigment loss and the formation of tide lines. In its severest form, water staining resulted in the formation of disfiguring dark crusts on the wood surface, apparently the result of rainwater washing through bat and pigeon manure in the attic spaces and onto painted surfaces.

Several large timber vigas (roof beams) shifted position during the last earthquake, particularly in the sacristy where there were total displacements of 15 cm relative to the adobe walls. Displacements are undoubtedly cumulative, as the result of several earthquakes. Most of the movement resulted from rotation of the north sacristy wall. Displacements in the nave are more modest, totalling no more than 5 cm. Prior to the investigation, embedment depths of vigas and cantilevered beams were unknown. Sacristy vigas were of particular concern because of the amount of displacement at the south sacristy wall, and the unknown condition of the wood remaining in the wall.

The ceiling construction has suffered severe levels of insect damage, with lesser levels of damage in the retablo and pulpit. The inspection of the building produced evidence of infestations by drywood (belonging to the family Kalotermitidae) and subterranean termites (belonging to the family Rhinotermitidae), and probably at least one species of wood-boring beetle. Of these, the damage caused by drywood termites is by far the most extensive, with damage from this insect appearing in virtually every non-structural ceiling element (Figure 3). In the nave and sacristy, damage visible on the upper surfaces of ceiling planks was extensive, perhaps affecting more than 30 percent of the total surface area. Visual inspection of the exposed ends of vigas and corbels on exterior walls revealed severe deterioration on many of the exposed surfaces.

Inspection Technologies and Quantification of Deterioration
Preservation of the painted and structural wood poses interesting challenges. In addition to the structural damage resulting from several earthquakes, wooden ceilings and architectural elements have been exposed to weather and termite attack for decades. The structural and physical integrity of the primary wooden elements and their decorative finishes have been compromised in some areas, yet are remarkably well preserved in others. The question arises: how can structural repairs be made to meet current code and public safety requirements while conserving the historic finishes that give the building its cultural significance? Quite often, public safety takes precedence over the conservation of historic fabric and structural continuity is recovered by simply replacing compromised elements. In this case, however, it is important that structural elements and decoratively painted surfaces be conserved and are durable enough to withstand long-term daily use of the building as a place of worship.
Figure 3: Deterioration conditions include dissolution of period paints, severe staining, and damage resulting from insects and fungal decay. Photo: Douglas Porter.

Historic wooden structural elements in the church include vigas, corbels, and cantilever beams supporting the nave, choir, and sacristy ceilings; columns that support the retablo; and wooden lookouts embedded in adobe walls that support the pulpit and canopy. Exposed portions of most of these elements are integral parts of the early 19th-century painting scheme. Several inspection technologies were used to characterize section loss and to produce quantitative data on wood condition, including resistance drilling of the vigas, cantilevered beams and lookouts, and retablo column bases; remote visual inspection of structural woodwork buried in adobe walls; and grading of the nave, sacristy, and choir vigas based on wood species, knot size and location, and slope of grain in order to determine original and residual structural capacity. Survey results from all sources were combined in assessment summaries for each of the elements.
Resistance drilling

Resistance drilling is a quasi-nondestructive technique for quantifying the loss of material in wood [1]. It is considered quasi-nondestructive because, although there a small needle penetrates into the wood (approximately 1 mm diameter), none of the wood fiber is removed. It is best suited for determining internal problems in timber that does not show obvious signs of deterioration, such as surface decay. Internal voids at the location drilled can be detected by observing the relative density of the wood as it is printed on the resistograph strip (Figure 4).

![Resistance drill in action](image)

*Figure 4: The resistance drill is used to detect internal voids by graphing the relative density of the wood. Photo: Ronald Anthony.*

A complete survey of accessible structural timber was conducted using the IML RESI M300 Resistance Drilling System. Drill sites were located along a grid adopted by the survey team, in consultation with the structural engineer, as well as in obvious areas of deterioration. Where substantial voids were encountered, the drill was used to locate void boundaries so that total section losses could be determined. Resistance drilling of the vigas occasionally quantified
section losses in excess of 50 percent, though damage levels were typically much lower. In general, damage was found to be concentrated along the adobe walls. The distribution of water staining and other surface damage was not a reliable indicator of termite damage on the interior of the larger structural elements.

Remote visual inspection
Remote visual inspection equipment allows imaging of wood that is inaccessible to direct inspection and resistance drilling. Remote visual inspection involves the use of a videoscope, a device with a small, high-resolution camera mounted at the end of a flexible insertion tube, and a monitor that displays the transmitted images from the camera. In use, the camera is inserted into gaps, holes, or crevices too small for other forms of access. This method of inspection was useful for determining the depth of embedment of structural members, as well as for ascertaining their condition.

For examining selected portions of embedded vigas and corbels, 12.7 mm holes were drilled into exposed viga tops in the attic. The holes were angled into the wood embedded within the adobe walls. Drilling locations were chosen so that the data collected provided critical information on the depth of embedment and quality of the bearing area of vigas and corbels, and so that the decorative paint finishes were undisturbed (Figure 5). Additional data was gathered by accessing embedded woodwork through tile chases and pre-existing cracks in the plaster.

Figure 5: Wood embedded in adobe walls was examined using a videoscope. Photo: Ronald Anthony.
Based on photographs taken before 2003, it is clear that the pulpit and canopy were partially dislodged in the San Simeon earthquake. The videoscope was useful for determining the depth of embedment and condition of wooden lookouts installed in adobe walls; investigators were also able to determine that voids around lookouts were enlarged, perhaps due to compaction of the adobe, causing instability in the pulpit and canopy.

**Grading of structural timber**

Structural timbers used in new construction are intended to comply with the relevant building code for that jurisdiction. The design values given in the building code for solid wood products are established by the American Forest & Paper Association and published as the *National Design Specification for Wood Construction* [AF&PA, 2005]. The published design values are based on test data and procedures published by the American Society for Testing and Materials [ASTM, 2008] that demonstrate the engineering performance of the material. For existing buildings, the engineer often relies on current standards to determine the adequacy of the wood members to remain in service. Where species and grade are unknown, an assumed species and grade are often assigned. The result is often an overly conservative estimate of design values resulting in unnecessary replacement, repair, and retrofit decisions.

Measurement of knots and slope of grain provides an indication of the approximate lumber grade for a given wood species. The size and location of the knots determine how the timbers can be classified. The larger the knot, the lower the grade; the highest grade is Select Structural, followed by No. 1, No. 2, and No. 3. Slope of grain relates to the angle of deviation of the wood fibers from the straight edge of the lumber or timber. The angle of deviation can generally be determined from seasoning checks on the wood surface.

Grading was conducted by measuring visible defects on each accessible viga surface; most vigas had three exposed faces. Of the vigas accessible for grading, twenty-six can be considered to have a grade of Select Structural, Western Woods, Beams and Stringers; the remaining seven can be considered to have a grade of No.1, Western Woods, Beams and Stringer (AF&PA, 2005). Slope of grain was the grade-limiting characteristic for several of the wood members.

**Structural assessment findings**

Because the assessment of structural timber involved multiple methods of investigation, a data summary was prepared for each structural element that incorporated data collected from all sources in graphic, tabular, and narrative form. Graphic and tabular presentation of the findings was organized according to moment diagrams provided by the structural engineer. Condition classifications were based on section losses measured at each of the drill sites, the quality of the wood and extent of damage visible directly or by videoscope, and conditions related to grade (Figure 6).

Preliminary estimates of the structural capacity of the nave, choir, and sacristy vigas suggested that most of the structural elements originally had adequate reserve capacity to support required loads. However, termite damage and decay have resulted in capacity reductions for some members. Investigators conducted the comprehensive survey of structural timbers in cooperation with the project structural engineer, who provided estimates of loads imposed on the elements based on Historic American Building Survey (HABS) drawings and field survey data.

Load values were used to produce moment diagrams and accompanying tables showing viga moment capacity based on effective cross-sectional areas of varying widths and depths; surviving cross section was determined by the investigators. In addition, the engineer provided investigators with an embedment evaluation chart indicating the necessary depth of embedment and the
**Condition Assessment**

Conditions within viga 5 range from poor to excellent. The north bearing area and the interior north end of the viga have very minimal incidental damage, and the north bearing area of the corbel appears to be in excellent condition. The south interior end has a concentration of punky wood near the top of the element which may be indicative of decay. In the south bearing area, the viga has an active termite infestation and significant termite damage. The corbel within the south bearing area has significant damage and an overall loss of section greater than 50%. On the exterior, the north and south viga ends are riddled while the corbels are in fair condition with moderate damage.

<table>
<thead>
<tr>
<th>Viga Condition</th>
<th>North Exterior</th>
<th>Bearing Area, North Wall</th>
<th>Interior North End</th>
<th>Mid-span</th>
<th>Interior, South End</th>
<th>Bearing Area, South Wall</th>
<th>South Exterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Corbel Condition</td>
<td>Fair</td>
<td>Excellent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6:** Summaries for each of the structural elements presented data derived from all sources, presented in graphic, tabular, and narrative form. Image: Anthony & Associates, Inc.

Investigators were able to consult these tables in the field and make decisions regarding the level of data to be collected at specific locations. In general, investigators sought more highly detailed information in areas where loads approached estimated capacity (as indicated by resistance drilling and videoscope results), since these are areas where repairs are more likely to be required. A comparison of the values derived from the structural analysis and the findings of the systematic survey of the structural wood allowed designers to identify marginal members and design repairs that conservatively address specific deterioration conditions.
Painted Wood: Treatment Testing and Pilot Treatment

Nearly all of the woodwork in the church is incorporated in the original decorative polychrome paint scheme. Based on the results of finishes analyses [Rainer et al, 2007; Porter et al, 2008], the earliest paints in the church consist largely of inorganic pigments combined with protein (such as animal glue) and carbohydrate (possibly a plant gum) binders. The paints are extremely sensitive to water but are largely unaffected by organic solvents (mineral spirits, xylenes, ethanol, and acetone). The historic paints are generally leanly bound, very porous, and matte in appearance. Nearly all of the woodwork seems to have been coated with a limewash or gesso layer prior to painting.

After decades of exposure to weather resulting from failures of the roof covering, the painted wood exhibits several forms of deterioration including water staining, soiling, termite and other insect damage, paint loss, severe abrasion, the formation of crusts probably associated with the dissolution and re-deposition of manure, and the over-application of paint and other coatings. In some parts of the church, particularly on nave and sacristy ceilings, damage levels are severe and stencilled designs are extremely disfigured.

Treatment testing was designed to address general cleaning; safe removal / encapsulation of encrusted stains; consolidation of friable wood; consolidation of flaking paint; selective removal of over-painting; materials and techniques for filling voids; paint formulation (resins, modifiers, solvent blend); and inpainting and toning techniques. Materials and techniques developed in treatment testing were then used in pilot treatment of representative areas of the nave ceiling, the retablo, and altar woodwork [2].

General cleaning
Dry cleaning techniques were focused on vacuuming and the judicious use of latex sponges to remove grime. Generally, the nave ceiling responded well to dry cleaning, and no other cleaning regimen was necessary. The retablo, however, proved very difficult to clean and dry cleaning was only moderately effective. Aqueous cleaning was impossible due to the water-sensitivity of the paint. A naptha: acetone blend (80:20) was partially effective on oily/waxy dirt and rust-colored stains that may have been associated with a previous application of a wood preservative. Some colors exhibited greater sensitivity to solvents than others and cleaning regimens were adjusted to the behavior of each (Figure 7).

Removal / encapsulation of encrusted stains
The heavy black stains and crusts appearing on many of the ceiling elements seem to be the result of the dissolution and re-deposition of bird and bat manure dissolved in rainwater. The stains and crusts are insoluble in organic solvents, but are softened by water. Poulticing with an aqueous gel was effective in loosening the crusts, but due to the water-soluble nature of the historic paints, resulted in new tide lines. As an alternative to stain removal, conservators opted for encapsulation of the stains using a hand-mixed paint based on a polyoxazoline (Aquazol) resin [3]. White pigment was used to maximize the hiding properties of the paint and to replicate the nearly white color of the limewash or gesso layer.

Consolidation of friable wood
Termite deterioration of the wood has left many elements in a friable and weakened condition, and susceptible to damage resulting from handling and cleaning. In order to prevent further damage and improve strength and functionality, damaged areas were consolidated using a 12:60:40 weight/volume/volume (w/v/v) solution of Butvar B-98 [4] in an ethanol:acetone mixture.
Reattachment of flaking paint
Flaking paint was reattached to the gesso/limewash ground with a 12 percent (w/v) Butvar® B-98 in a 60:40 (v/v) ethanol:acetone mixture. Several areas of partially detached paint included large flakes out-of-plane with the rest of the painted surface. These were fixed out of plane to avoid breakage using the same filler as was developed for loss compensation (see below).

Overpaint removal
Overpainting was concentrated on high-traffic areas at floor level, including railings, pulpit, and the lower level of the retablo, and was the result of more than one repair campaign. The naptha:acetone blend was useful for removing semi-transparent coatings applied to the retablo columns. Multiple layers of overpaint on the altar railings were relatively easily removed using a Carbopol™ based gel of acetone [5], clearing with an acetone:naphtha mixture (1:1). In very
limited instances, overpaint was not responsive to organic solvents or solvent gels and recovery of the original paint surface at these locations appears to be impossible.

**Filling voids / loss compensation**

Termite galleries and other small voids were filled to support the painted surface. The filler consisted of a 3:5 (w/v) Paraloid B72:acetone mixture combined with enough glass microballoons (approximately 50 percent by volume) to form an injectable paste [6]. Using the glass microballoons (3M Glass Bubbles K15), it was possible to add substantial bulk to the filler and still inject it into the smallest termite galleries. The filler is lightweight, and imposes minimal mechanical stresses on the thin paint / wood layers that overlie much of the termite damage.

*Figure 8: Two retablo panels before and after treatment. Treatment of the upper panel included inpainting of losses with the background color. In the lower panel, inpainting of losses included replication of the stencil design. Photo: Douglas Porter*
**Paint formulation**

Paints for inpainting and toning were mixed from resins dissolved in organic solvents to prevent dissolution of historic paints during their application (and removal). Every attempt was made to avoid or limit the use of aromatic, chlorinated, or otherwise dangerous solvents. Alcohol-soluble resins seemed to be desirable in principle as the solvent has low toxicity and good working properties (particularly a suitable evaporation rate). Furthermore, alcohol-soluble resins should be reversible/removable from original paint in the future; during the trial treatment, this was found to be the case.

Aquazol produced somewhat glossy paints at resin concentrations required for adequate binding of pigments. Use of this resin was limited to formulation of undercoats. Topcoats were formulated with Butvar B-98; at a four percent resin concentration, the resulting gloss level was found to be within acceptable limits. The paints mixed in ethanol dried relatively quickly but were workable, did not require frequent re-tempering, and did not dissolve historic paints over which they were applied. Powdered inorganic artists’ pigments were mixed into resin binders to achieve the desired colors.

**Inpainting and toning techniques**

Because of the somewhat transparent quality of the historic paints, inpainting of damaged zones required the application of undercoats to hide the stains and replicate the limewash or gesso layer that shows through the historic paint. This is a two-step process that includes an initial white undercoat applied over tide lines, stains, crusts, and bare wood, followed by a second undercoat layer, bulked with very fine sand, that replicates the nearly white color and coarse texture of the limewash or gesso layer. Topcoats were applied with a stippling brush in such a way as to allow some of the lighter undercoat to show through. A single topcoat color was mixed in bulk and used on all the inpainted surfaces. Toning, to blend the new color with surrounding historic paints, was done from a palette, adding pigment to match variations in tone as necessary (Figure 8).

**Conclusions**

Based on the results of the structural investigation and treatment testing of historic paints, a plan for conservation of the painted wood was developed and implementation is underway. The team assembled to evaluate painted wood at San Miguel represented a broad range of expertise, including architectural conservation, wood science, wall paintings and wooden objects conservation, and preservation carpentry. The broad range of skills resulted in several useful synergies, including:

- Efficient data collection during the assessment phase, because the team was aware of how data would ultimately be used in the design of treatments;
- Team member participation in both assessment and treatment activities allowed for a thorough integration of assessment results into treatment design;
- The involvement of conservation practitioners in each phase of the investigation enabled the effective development and implementation of practical treatments.

In 2009, several of the treatments were implemented in the first phase of stabilization and the church has been reopened for use.
Acknowledgements
The authors would like to acknowledge conservators Arlen Heginbotham, Angelyn Bass Rivera, and Jeffrey Fellinger, and project engineer Nels Roselund for their very substantial contributions to the investigation and treatment testing of painted wood.

Endnotes
[1] The drill inserts a small-diameter needle into the wood, recording the torque required to do so; the drill does not remove wood fiber in the process, but does leave a small hole where the wood fibers have been forced apart, thus the technique is described as “quasi-non-destructive”.
[2] Details concerning the treatment testing and pilot treatment of painted wood can be obtained by contacting the authors.
[3] Aquazol® is a non-ionic polymer [poly (2-ethyl-2-oxazoline)] possessing excellent thermal stability, and is soluble in water and polar organic solvents.
[4] Butvar B-98 is a thermoplastic, polyvinyl butyral resin, soluble in the lower alcohols. The aging characteristics of PVB are considered good. When used as a consolidant, Butvar B-98 satisfactorily strengthens the wood while producing little change in appearance.
[5] The gel was made by combining 2g Carbopol 934, 15ml Ethomeen C-25, 200ml acetone, and 5ml deionized water and shaking vigorously.
[6] Paraloid B72 is an ethyl methacrylate copolymer, a general-purpose conservation resin with excellent flexibility.

References


Biographies

Douglas Porter (Architectural Conservator, author for correspondence) is an architectural conservator who directs grant-funded research and training projects in cooperation with academic, federal and non-profit partners. Recent projects include structural stabilization of the Breeding Barn at Shelburne Farms, investigation of structural and decoratively painted wood at Mission San Miguel, organization of a Colloquium on the Development of Curricula for a Program in Heritage Preservation Engineering, stabilization of the Las Flores Adobe NHL, conservation of architectural redwood at Scotty’s Castle in Death Valley National Park, conservation of built elements in the Formal Garden at Shelburne Farms, and partial restoration of the adobe Post Hospital at Fort Davis National Historic Site. (School of Engineering, University of Vermont / Conservation Associates, 341 Votey Hall, 33 Colchester Avenue, Burlington, VT 05405 U.S.A., http://www.conservationassociates.net/, Douglas.Porter@uvm.edu)

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