Fallingwater Part 1: Materials-Conservation Efforts at Frank Lloyd Wright's Masterpiece

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A 13-year-long investigation of deterioration mechanisms, along with prototype treatments, has yielded a better understanding of the nonstructural pathology of materials deterioration at a twentieth-century architectural icon.

Fallingwater is among the world's best-known private residences. Located in Mill Run, Pennsylvania, about 60 miles southeast of Pittsburgh, the house was designed by Frank Lloyd Wright in 1935 and constructed in 1936-39 as a weekend residence for Edgar and Liliane Kaufmann. Mr. Kaufmann was a successful department store owner in Pittsburgh. His son, Edgar Kaufmann jr. [sic], apprenticed to Wright at Taliesin in the fall of 1934, and the parents soon came to visit.[1] Thus began the family's patronage of the architect who designed more than a dozen projects for them, of which only three were executed. These include Fallingwater, its guest house, and Kaufmann's offices on the tenth floor of his store.[2]

The Mill Run property was previously leased by Kaufmann's Summer Club and used for vacationing female employees. By 1932 the Kaufmanns had title to the property where they had built a prefabricated weekend cabin 11 years earlier.[3] The focus of the site is a waterfall in a stream known as Bear Run. Unlike the family's cabin, Fallingwater did not overlook the waterfall but instead sat directly on top of it.

Fallingwater is significant as an embodiment of Wright's organic style of architecture. In his autobiography, Wright states that "it is in the nature of any organic building to grow from its site, come out of the ground into the light . . . ,"[4] and Fallingwater typifies this philosophy. Built of stone and reinforced concrete, it rises from its densely foliated surroundings with enormous drama (Fig. 1).

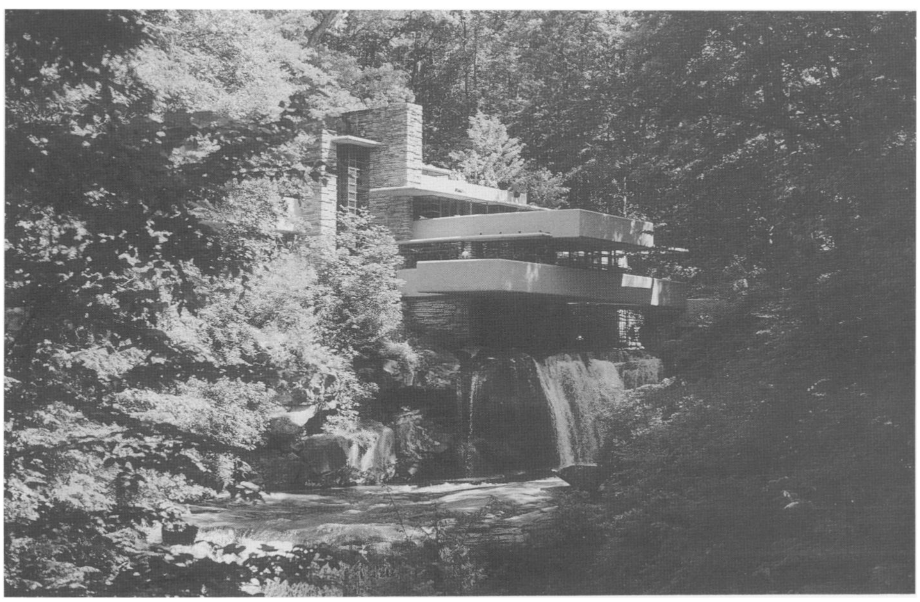

Fig. 1. Fallingwater, which rises dramatically among its densely foliated surroundings and is perched over a waterfall, is the embodiment of Frank Lloyd Wright's organic architecture. This continuously damp environment is largely responsible for materials deterioration. Photograph by WASA. All photographs courtesy of the Western Pennsylvania Conservancy.

The house remained in the family's possession until 1963. It was then deeded, along with 1,700 acres of surrounding land, to the Western Pennsylvania Conservancy. It currently operates as a house museum, accommodating more than 140,000 visitors per year.

Wank Adams Slavin Associates, LLP (WASA), a 112-year old New York City-based architecture and engineering firm with a preservation department,[5] first became involved as architectural conservators in 1988, when two of the authors (Weiss and Gottlieb) were invited to review concrete and stucco conditions at Fallingwater.[6] Since then, WASA has documented and evaluated deterioration, and it has provided recommendations for intervention in the form of reports and construction documents.

As part of the research, a review was undertaken of available drawings and specifications, shop drawings, correspondence, published materials covering the period since construction, and previous consultants' reports and construction documents. Numerous probes were made, selected materials were character-

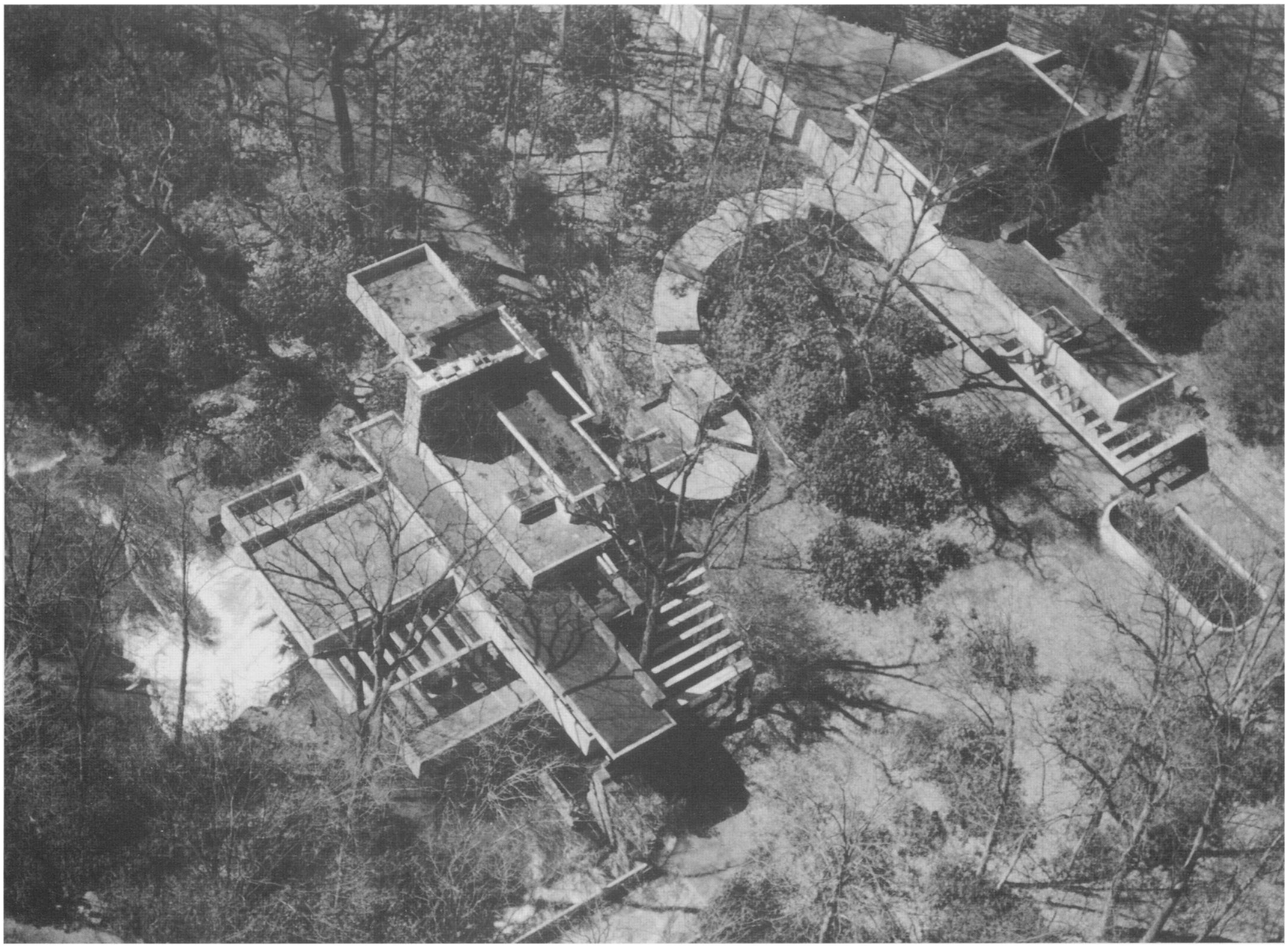

Fig. 2. Aerial view of Fallingwater's main house, with the guest house visible in the upper-right-hand corner. More than half of the approximately 7,000 total square feet is terrace area. Photograph by Paul Wiegman.

ized in the laboratory, and prototype treatments were installed and evaluated. Moisture monitoring was performed in problematic locations. Interviews were conducted with Fallingwater's previous and current maintenance staff,[7] including Earl Friend (who worked on the original construction crew), Bob Mosher and Edgar Tafel (Wright's apprentices who supervised the work), and William Wesley Peters (Wright's apprentice who dealt with structural engineering).

This article describes many of the conditions found at Fallingwater. Some of the solutions have not been finalized because studies are still in progress. However, this paper is intended to give the background information necessary for understanding the design of the materials-restoration program currently in progress. The completed restoration will be the subject of a future article.

Description of the Building

Fallingwater is a large weekend residential complex with approximately 7,000 total square feet, of which almost half is terrace area (Fig. 2). The main house, articulated by massive terraces at each level, stands three stories tall. Additionally, there is a two-story guest house with servants' quarters and carport further uphill. In style, this modernist building acknowledges its De Stijl and Bauhaus predecessors, as well as Richard Neutra's Lovell Heath House of 1929.[8]

Fallingwater's structure consists of cantilevered reinforced-concrete floors and cantilevered reinforced-concrete roofs with integral parapets, supported by natural rock outcroppings, tapered concrete piers ("bolsters"), and stone-bearing walls. The stone (a calcareous sandstone[9]) is of very high quality and was quarried on site. The main house was completed in 1937, and the guest house in 1939. At $155,000, the total cost of the complex, architect's fees included, was well over the estimated budget.[10]

All concrete was originally covered with a white cement stucco to an average thickness of ¼ inch. This stucco was always painted. Initially, Wright proposed that the concrete be covered in

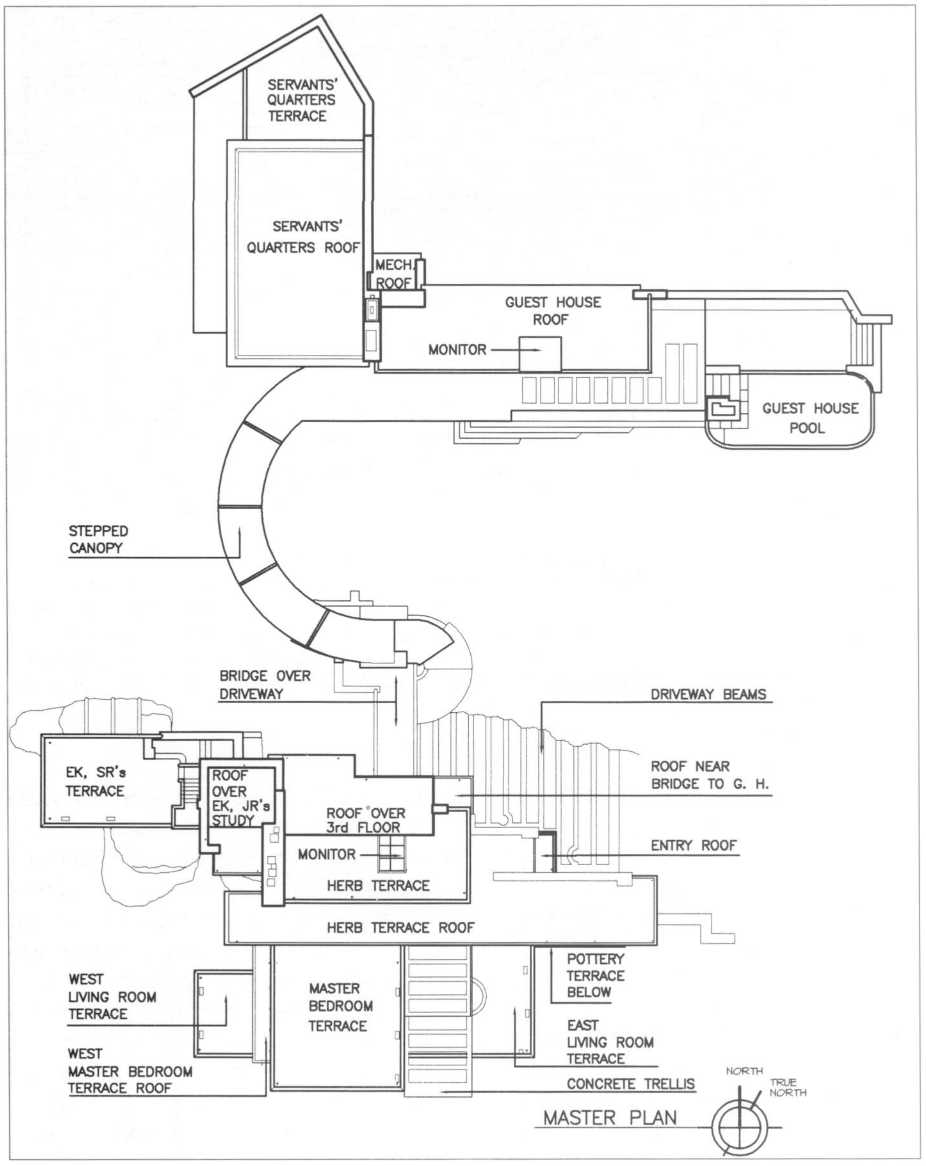

Fig. 3. Plan of Fallingwater. Drawing by WASA. All drawings, except as noted, used courtesy of the Western Pennsylvania Conservancy.

gold leaf, an idea that Kaufmann Sr. thought was both "extravagant, and inappropriate for a mountain lodge"; by March 1937, paint was proposed.[11] There is little surviving historic exterior paint, although sufficient material was discovered in 1989, beneath the living room, to determine the finish color.[12] A can of Cemelith powder paint from the original manufacturer (Super Concrete Emulsions), although not datable to the 1930s, was also found; this suggests that the earliest finish might have been casein based.

Fixed and casement steel windows manufactured by Hope's Windows of Jamestown, N.Y., fill in the horizontal bands between concrete and stone. Originally painted a Venetian red, the windows were changed to Wright's signature Cherokee red in 1976 by Edgar Kaufmann jr, which is the current finish color. Often there is no corner mullion, a technique first used by Wright in the early 1920s.[13]

Design-Based Pathology

After 65 years, Fallingwater is undergoing a major restoration campaign. (Structural failures are significant and are being addressed by the New York City-based engineering firm, Robert Silman Associates, PC).[14] The main materials-conservation issue facing Fallingwater is deterioration caused by moisture penetration. Much of this is inherent to Wright's design. Moreover, the complex is located in a continuously damp environment; it is cantilevered over a stream, surrounded by trees and shrubs, and resting on a hillside from which water seeps almost all year round.

Fallingwater is shaped like a pinwheel in plan, with extensive terrace arms projecting outward (Fig. 3). Exposure of horizontal surfaces to the weather is much greater than for a more traditional house of the 1930s. Penetration of rain and melting snow, associated with waterproofing/roofing systems failures and the lack of through-wall flashing, is a continuing problem in many locations.

Roofs/terraces/skylights. Terraces are surfaced with large irregularly shaped stones quarried on site, varying in thickness from ½ inch to 1½ inches. The cantilevered terraces are largely supported by upturned beams[15] that are concealed beneath the flagstones. With a system of concrete joists placed perpendicular to the beams, the effect is that of coffers. The original terrace substrate was ¾-inch redwood tongue-and-groove decking. A three-ply built-up roof of hot asphalt and building felts was laid over the wood, or on terraces that are not cantilevered, directly onto the slab. Until 1986, there was no flashing on the terraces.[16] Instead, the detailing involved turning up, at the perimeter edge, the waterproofing membrane that lay beneath the 1-inch bedding mortar and the flagstones. Wright was often reluctant to give functional elements significant visibility.

From a probe performed in the living room floor in January 1999, it appears that the original waterproofing of the terraces passed continuously to the interior. This implies that there is no cap or base flashing protection at the exte-

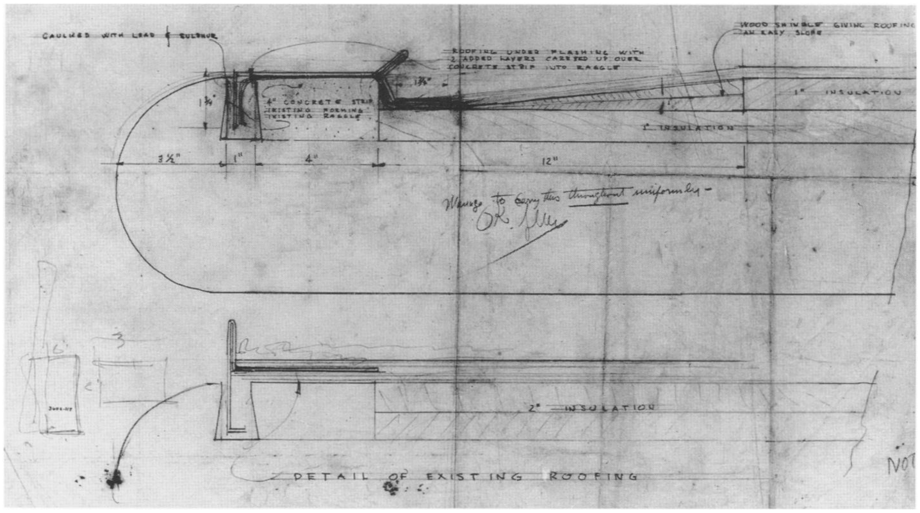

Fig. 4. The flashing, although not original, is similar to a detail shown on this Frank Lloyd Wright drawing, "Detail of Existing Roofing" (undated drawing), referred to as drawing 3602.117 by the Frank Lloyd Wright Foundation. That this drawing uses the word "existing" seems to indicate that the roofing termination on the roof rolls was still being considered even after the roofing was installed. The first detail shows the configuration of the typical gravel stop described by Wright in 1938 in *The Architectural Forum*. The drawings of Frank Lloyd Wright are copyright ©2001 The Frank Lloyd Wright Foundation, Scottsdale, Ariz.

rior walls or stepped-up flashing under the door sills, as would be normal for roof or terrace waterproofing. Terrace doors typically have only a metal channel mounted on top of the flagstones, and there is no difference between the interior- and exterior-floor levels, a deliberate Wright detail.

Roof edges (roof rolls) are rounded, a difficult detail to waterproof. At all roof locations that abut stonework, there was no design provision for the installation of flashing. An added complication comes from Wright's interest in interpenetration of one construction material by another. In some places, the roof passes halfway through the stone wall. Original drawings show a lead gravel stop for the termination of the roofing membrane. It was to be seated in a horizontal reglet and bedded in mastic.[17] According to Wright, "the roof water is caught by a lead strip built into the concrete above near the beginning of the curve."[18] It is unclear, however, from historic photographs whether this detail was ever installed. The only physical evidence for a perimeter reglet exists on the roof over Kaufmann jr.'s sleeping alcove. In addition, the narrow roof to the west of the master-bedroom terrace retains its upright metal flashing at the perimeter (Fig. 4).

Most of the roofs have inadequate depressions for gutters (approximately ¾ inch deep by 4 inches wide) built into the concrete roof slabs at the edge of the roof. Roof and terrace drains are simple sheet-copper tubes that penetrate the slabs and soffits, not tied positively into the waterproofing membranes. Originally, the roofs were built up with asphalt-impregnated felts over 1-inch-thick brown felt insulation board. Wright wanted the roofs to blend with the concrete, so beige-colored gravel was broadcast over the final coat of asphalt.[19]

To the east of the living room there is a concrete trellis. Half of it is glazed, functioning as a skylight for the library. An original waterproofing detail is found in an undated Wright drawing. A double plate of glass is shown, with edges bedded in mastic. Lead strips lap over the glazing edges and are soldered to lead flashing that rests on insulation placed over the trellis beams.[20] The flashing was to create shallow gutters, but there is insufficient slope for drainage. Flashing was not installed where the trellis abuts the parapets, although it is indicated on the drawing.

A series of small skylights, each with a light fixture, punctuates the roof of the enclosed bridge. The tops of the skylights are flush with the flagstones on the terrace above. There is minimal design for waterproofing around the openings.

Concrete and stucco. The original concrete mix consists of cement, sand, and river gravel, averaging 1½ inches in diameter. The concrete is prone to cracking and spalling, as there is poor adhesion of the paste to the rounded gravel.[21]

The parapets appear to be contributing structurally to the cantilevered slabs, but review of structural drawings reveals that they do not fully perform in this manner.[22] In fact, regarding the parapets, Wright wrote, "The cantilever slabs here carry parapets and beams ... But next time, I believe, parapets will carry the floors—or better still we will know enough to make the two work together as one, as I originally intended."[23]

The parapet walls are characterized by a rounded top. The body of the wall was first poured to several inches below the intended height. After several days, the top was installed by piling a stiffer, darker mix of sand and cement on top of the cured wall, creating a cold joint. Probes made in September 1988 revealed that there is no reinforcing connecting the rounded top to the parapet.[24] The lack of mechanical attachment, coupled with the cold joint, led to irregular horizontal cracking and separating of the top from the body of the wall.

Further complicating the system is the stucco coating with which the concrete is finished. The use of stucco over

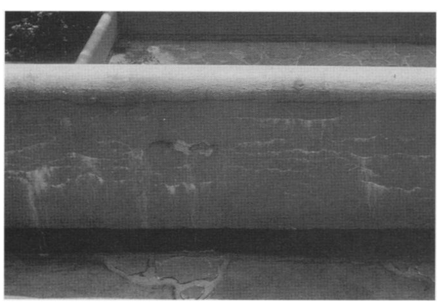

Fig. 5. The cold joint resulting from the construction of the rounded parapet top was clearly visible in the past. These cracks allowed water to flow between the stucco and concrete and exit in horizontal lines lower in the wall, characterized by calcium carbonate deposits. Photograph by WASA.

Fig. 6. Fixed panes of glass sometimes terminate directly into stone walls. These lack waterproofing details of a standard frame. In addition, corrosion occurs at window heads as a result of the rounded edge of the concrete soffits and the lack of metal drips at the main house's fixed windows. Photograph by WASA.

concrete solved some problems for Wright and created others. At the parapet cold joint, surface cracks allowed water to flow down behind the stucco and exit in fine, irregular horizontal lines (with deposits of calcium carbonate) lower in the wall (Fig. 5).

Parapet corners are often cracked, largely due to the absence of expansion joints. Wright stated that he was aware of the need for expansion joints in concrete but felt that they would be inappropriate to the aesthetics of this building.[25] The lower corners of the cantilevers have fractured and been patched numerous times. Probes performed in 1990 also revealed freeze/thaw damage of some corners to be a result of defective drains.[26]

A unique area of concrete failure is the set of stairs to the stream, suspended beneath the living room hatch on thin steel straps. Their failure is in part due to the corrosion of the steel straps embedded in the concrete, resulting in spalls. Because of the seepage of water from the hillside, the driveway beams (another unusual feature) are similarly prone to materials failure (concrete and steel reinforcing bars). Over time, most have been replaced.

Stone. Stone walls are laid up so as to project irregularly beyond the plane of the mortar joints by as much as 4 inches, creating horizontal ledges with numerous depressions. These depressions come from the naturally irregular surface of the local stone, which was split and/or roughly cut. The small ledges encourage the ponding of rainwater and the accumulation of snow, which melts slowly. Water enters the hairline separations that have developed over the years between the stones and the mortar joints. Head joints are not always fully filled with mortar, permitting more water penetration. The irregularity of the stonework makes remedial installation of flashings problematic and repointing difficult.

Windows and doors. Hope's Windows manufactured the steel windows and doors for Fallingwater. Wright wrote, "Steel sash came within reach also for the first time."[27] Windows are constructed of rolled steel sections, usually of **Z** or **T** shape. Operable sash are hinged at the sides. Fixed panes of glass sometimes terminate directly in the stonework at the jambs without benefit of the waterproofing details of a standard frame (Fig. 6).

In the main house, only the operable units have a metal drip built into the head; this oversight was remedied at the guest house. The rounded edge of the roof rolls leads water into the window heads. This is compounded by the differential movement of the concrete, which has created a gap between the head of the frame and the underside of the slab at some locations. There is no flashing between roof slabs and window frames or between sills and walls.

Paints and coatings. The earliest paints soiled easily and continuously, despite Wright's belief that this would be eliminated by the lead strip at the top edge of the roof rolls.[28] A 1937 photograph by Ezra Stoller shows that the soiling of paint occurred almost immediately.[29]

Distinct lines of water movement along the curve of the roof rolls were observed and photographed by WASA during rainstorms. They appear with droplets at the bottom and become soiling lines. Small stalactites sometimes form at the droplets. Organic debris from overhanging trees collects on horizontal surfaces. The constant dampness of the environment, along with the decomposition of this debris, creates prime conditions for biological growth on painted surfaces. Until 1994 peeling of multiple layers of paint was also a problem.

Interiors. One of the wonderful effects of Frank Lloyd Wright's design at Fallingwater is the merging of the interior and exterior spaces. This is best articulated by the flooring material, which provides a continuous walking surface from rooms to terraces. The relationship of the house to the waterfall, the sound the waterfall generates, the introduction of the natural bedrock into certain spaces, and the expansiveness of the terraces all contribute to the "organic" nature of this building.

With a few exceptions, Wright limited the interior finishes to the basic components of the structure. Concrete walls and ceilings are plastered with what appears to be the same stucco material as the exterior. Where stone

Fig. 7. Photograph and detail of drawing from the Existing Conditions Survey, showing the condition of the guest bathroom in the main house. Drawing by WASA.

walls exist, they are exposed and incorporated into the interior. The built-in furnishings and interior doors are wood, with their original shellac finish largely intact.[30] Bathroom walls and floors are finished with cork tile.

Maintenance History and Condition Assessment

Since 1988 WASA staff members have reviewed individual conditions, designed and supervised probes and repairs, and evaluated the results. In 1998 WASA was given the opportunity to assess the entire complex holistically, resulting in a preservation master plan.[31] The field survey was performed from May through September. The buildings were measured, sketched, and photographed, with the CAD drawings serving as the basic graphics for the condition assessment. The two-volume master plan includes 170 sheets of drawings, each with a photograph of the area drawn (Fig. 7). Particular emphasis was given to the stone-by-stone documentation of the living room floor (because of the upcoming structural-reinforcing project), and of the terraces.[32]

Roofs. A 1981 reroofing campaign by a previous consultant consisted of four plies of fiberglass-reinforced felts with hot asphalt in between, over ½-inch-thick insulation board. These roofs were replaced in 1987-88 with a single-ply 60-mil EPDM rubberized membrane, loose laid from 10-foot-wide rolls. Seams were spliced with an adhesive.[33]

Overall, the roofs are in fair-to-poor condition. Many exhibit patches and pinholes. Along roof edges, the membrane is secured with "hit"-fastened termination bars (Fig. 8). The fasteners are spaced 12 inches on center, instead of the recommended 6 inches. Because of the unevenness of the concrete, the connection is not tight. All bars exhibit failed sealant along their edges and failed gaskets at the "hit" anchors (impact-expansion anchors); either failure is a potential source of moisture entry. Drains are often located at the high point, causing ponding. Pea gravel is sparse at most roofs, permitting exposure of the membrane in certain areas to full ultraviolet radiation.

Roof probes performed in November 1999 indicated that moisture penetration could not simply be attributed to defective roofing seams and perimeters, as well as to the absence of through-wall flashing.[34] A probe near the north edge of the guest house roof exposed 3 inches of wet insulation (with a vapor barrier

Fig. 8. The existing EPDM membrane is secured with "hit"-fastened termination bars. Both the sealant along their perimeter and the gaskets at the "hit" anchors have failed. The complicated nature of waterproofing diverse construction materials — stone and concrete — where they abut is self-evident. Photograph by WASA.

Fig. 9. Moisture infiltration in the main house's guest bathroom continues to damage both the plaster and cork-tile finish. Photograph by WASA.

below) beneath the EPDM membrane. The concrete roof slab was also wet. A probe of the roof of the servants' quarters revealed condensation under the membrane. Probes of the herb-terrace roof exposed 2 inches of wet insulation on the west side and a wet slab on the (uninsulated) east side, directly below the waterproofing membrane.

Mechanical-engineering calculations confirmed a relationship between moisture beneath some roof membranes and the lack of a thermal barrier between the exposed concrete roof rolls and interior ceilings.[35] Ceiling leaks in the bathroom of the servants' quarters and in the curator's office, which appear only when the sun heats up the roof, are examples of this. Without insulation on the warm side of the slab (the finished ceiling surface), water vapor condenses at the underside of the waterproofing membrane on the top (cold) side of the slab. Installation of a vapor barrier, in the form of an impermeable coating applied to the ceiling, has been proposed.

Terraces. Where terraces (and roofs) meet parapets, the EPDM membrane extends up the parapet wall approximately 6 inches. Lead counterflashing covers it and terminates in a reglet remedially cut into the concrete.[36] This flashing was installed wherever waterproofing or roofing repairs were performed within the last 15 years. One problem is that the lead, because it is malleable, is easily knocked out of position by the feet of the thousands of tourists who visit Fallingwater every year. WASA staff observed many instances of sealant failure at the reglet, as well as locations where the flashing within the reglet exhibited negative pitch, directing water under the waterproofing membrane.

The east and west living-room and master-bedroom terraces were lifted and reassembled in 1987. This was also done to Kaufmann Sr.'s terrace in 1988. The waterproofing under the flagstones is a single-ply EPDM membrane. There is no protection board or drainage mat, and the copper tube drains do not permit the collection of subsurface water. Freezing within the tubes has split the soldered seams. Since the Kaufmann period, heat tapes have been used in an attempt to alleviate this problem.

The servants' quarters terrace, rebuilt in the late 1950s, has copper cap flashing installed in the remedial reglet. There are active leaks in the servants' quarters members' lounge ceiling (former carport) that seem to originate from this terrace, at the exterior face of the north wall of the director's office. The flagstone mortar joints on the terrace are covered in moss, indicating the presence of considerable moisture.

Several different mortar mixes have been used to point the flagstone joints. On all terraces rebuilt in the 1987-88 campaign, flagstones are bedded in pea gravel for ease of lifting.[37] The original joint mortar was cement and sand, 1:3 (by volume). WASA initially recommended that this mix be lime-modified because of the potential for the mix to be too rigid, leading to mechanical damage of the flagstones.[38] There was also an intent to permit some subsurface evaporation.[39] But lime-modified mortar mixes have shown cracking and some erosion. Joints of the east living room terrace, where regrouting was done with the 1:3 mix, are performing well.

In 1998 WASA designed new waterproofing for the pottery terrace, the only terrace that had never been rebuilt (presumably because there is no enclosed space beneath it and it is fully sheltered by the herb-terrace roof above). The original redwood deck had rotted. (During the Kaufmann period of occupancy, small vents were remedially installed above and below all of the other cantilevered terraces of the main house. At that time weep holes were also added at the soffits.)

Holes were drilled laterally through the upturned concrete beams to permit air circulation between coffers. The new decking was a ½-inch marine-grade plywood over CCA pressure-treated lumber used as upright blocking and discontinuous sleepers placed on the beams. Installed over the plywood was the new terrace underlayment, ¼-inch Hardibacker (a cement-based recovery board by James Hardie Building Products).

The new waterproofing system uses Bituthene 4000, a rubberized-asphalt waterproofing membrane (W. R. Grace). Deck Prep (a low-viscosity, asphalt-modified urethane coating) was applied over the Hardibacker. Two plies of Bituthene 4000 were then installed, the edges sealed with Bituthene Mastic, a rubberized asphalt-based mastic. Copper flashing was seated in a reglet in the concrete parapet. A Hydroduct drainage mat (W. R. Grace) was installed to act both as a protection board for the membrane and as a means to direct moisture toward the two drains. The tube drains were trimmed; J. R. Smith drains, their bronze strainers flush with the flagstones, were installed. These have perforated collars to collect subsurface water. The flagstones were laid in pea gravel and regrouted.[40]

The herb terrace's monitor/planter is a problematic feature in terms of waterproofing. The badly deteriorated steel plant liner was replaced with stainless steel in 1998. At that time, there was extensive sealant failure along termination bars and "hit" anchor gaskets of the EPDM membrane concealed beneath the liner. Sealant at the window-frame perimeter and cap flashing had also failed. In 1998 the waterproofing of the light monitor, under the herb tray, was changed. A new EPDM membrane was installed and the flashing resealed. Repairs were made to the concrete of the southwest corner, where a corroding "hit" anchor had caused the concrete to spall. Despite these efforts, moisture continues to affect the guest bathroom below (Fig. 9). A WASA-designed repair is currently being implemented using a modified-bitumen roofing system manufactured by Siplast.

A monitor also covers part of the guest-house bathroom, where similar problems are occurring. Damage to the plaster and paint is extensive, as is the detaching of the cork-tile finish. Moisture measurement strongly suggests that water is entering where the monitor intersects the roof and the parapet, the latter a particularly awkward detail (Fig. 10). The familiar problem of the termination bars and "hit" anchors is pronounced here.

Fig. 10. The monitors are particularly difficult features to waterproof. This one is located over the guest-house bathroom and is responsible for substantial damage to the interior finishes. Photograph by WASA.

Skylights. Flashing was installed in conjunction with new glazing of the living-room-library area skylights in 1994, although the work was not designed by WASA. Because of the use of termination bars, the entire lead sheet gutter system appears to be compromised. At the enclosed bridge to the guest house, four of the five skylights leak. The southernmost skylight, in particular, exhibits major leaks with snow buildup. In 1991 WASA hose-tested the roof, and water penetrated the interior walls. Open joints in nearby stonework were also judged to be at fault.[41]

Concrete and stucco. The concrete and stucco have suffered numerous cracks over the years. Stalactites and carbonate lines have appeared in soffits below terraces, most especially near drains. Prior to WASA's involvement, most concrete surface patching had been performed using Water Plug (a fast-setting, cement-based repair mortar by Thoro) with poor results. Conventional portland cement mixes were also used. Rounded roof rolls recast during the mid-1980s[42] have held up well, but they exhibit vertical hairline cracks at the positions of the new reinforcing bars (18 inches on center).

From 1989 to 1993 WASA directed and evaluated various patching techniques for the concrete and stucco. Some of these projects were executed by outside contractors and others by Fallingwater's maintenance staff. The southwest corners of the master-bedroom terrace and of Kaufmann Sr.'s terrace were rebuilt. After removal of deteriorated concrete, corroded reinforcing bars were blast-cleaned with Black Beauty (coal-derived slag) and painted with a Nitoprime Zincrich (Thoroc, formerly Fosroc). A cage was constructed by inserting additional steel reinforcing into drilled holes, secured in epoxy and primed. The curved edge of the corner was recreated using a thin sheet-metal form; plywood at the soffit completed the formwork. The pour was recessed ¼ inch to allow for the subsequent application of stucco.[43] This work has performed well.

Masonry Preservation Services worked on some of the concrete beams spanning the driveway in 1990-92. Loose concrete was removed and chipped around the reinforcing bars, which were blast-cleaned and coated with Armatec 110 (an anticorrosion coating by Sika Corporation). Beam ends anchored into the rock ledge were wrapped with Bituthene membrane. Patches were either trowel applied or poured in place.[44] Currently, some other driveway beams exhibit hairline cracks and stalactites.

Some of the concrete-repair techniques were experimental in nature. In 1990 an attempt was made on the herb terrace's south parapet to reattach a loose section of rounded parapet top to the body of the wall using stainless steel anchors.[45] This method would have preserved original concrete, but it proved difficult to implement and was a far greater intervention than needed in most cases. Trowel-applied patches, on the other hand, performed well.

Both trowel-applied and poured patches were tried on the stairs to the stream. Although the affected vertical steel straps were blast-cleaned and primed and the patches reinforced,[46] both techniques failed to prevent further corrosion and concrete deterioration. It appears that these stairs will need to be rebuilt. The suspended stairs to the pottery terrace have similar problems, although less severe; monitoring rather than intervention is planned.

The majority of repairs have worked well. Materials and methods for filling hairline cracks and losses in the stucco were developed in 1993 by one of the authors (Weiss) and Paul Cappelli, a sculpture restorer. Parapet cold joints were cut in a dovetail shape, and they were pointed (about ½ inch in depth) with a fine-grained, low-shrinkage mortar. Exit cracks on the lower half of the parapets were left open (beneath the paint coating) to permit water to escape.[47] Minor work is currently performed by Fallingwater's maintenance staff. Most concrete repairs, including the 1998 patching of three beams that anchor Kaufmann Sr.'s terrace to the north rock, utilize Renderoc HB (a polymer-modified cementitious patching compound by Thoroc, formerly Fosroc).

Stone. With the exception of the walls along the north and east edges of the servants' quarters terrace, there is little deterioration of the stonework, other than soiling from chimney soot and organic growth.[48] The mortar joints, however, often show hairline separations from the stone. Those on the main house chimney mass were repointed in 1992. Several mixes were formulated and tested in 1990.[49] The selected mix is a Type S mortar of 2:1:8 (Type IA gray portland cement, hydrated lime, and an ASTM C 144 sand closely matching the original) conforming to ASTM C 270. Pointing of the stonework is made difficult by the uneven coursing and projecting ledges.

In 1988-89, the uppermost stones were removed on stone walls above the pottery terrace, mainhouse chimney mass, and Kaufmann Sr.'s terrace. This work was ongoing when WASA first visited the site. Lead through-wall flashing was inserted by a local contractor, and the stones were reinstalled in their original locations. This has assisted in reducing moisture penetration into the stone walls but has created an aesthetic problem. Melting snow continues to cause mortar leaching, and the buildup of white carbonate crusts is unsightly.

Several campaigns were made to clean the main-house chimney mass of carbon deposits. In 1989 WASA and Frances Gale (of ProSoCo) cleaned a small test area with good results using ProSoCo's Sure Klean 766 Limestone and Masonry Prewash (an alkaline-based cleaner), followed by Sure Klean Restoration Cleaner (an acid-based cleaner). To permit longer dwell times, Sure Klean Heavy Duty Paint Stripper (an alkaline-based paint remover) was later substituted for the 766 Prewash.[50] The entire chimney mass was cleaned in 1992 with less success; this may have been due to insufficient rinsing between application of the chemicals.[51]

The stone cheek walls of the steps beneath the stepped canopy that connect the main house to the guest house are in fair-to-poor condition. Here the pointing mortar has failed at coping stone transverse joints and on the vertical surfaces. The east wall is in worse condition than the west; this is related to the movement of water from the hillside. An adjacent gutter at grade has not been particularly effective in diverting water from the east wall. The problem is exacerbated by the daylighting[52] of two drain pipes in this area, originating from the guest-house complex. Ponding often occurs on the bottom steps, near the door to the enclosed bridge; the bottom rail of this door is badly corroded. Related to this are leaks that occur through the exposed bedrock and stonework of the north wall of the enclosed bridge. A proposed diversion of the two drainage lines should help alleviate both situations.[53]

Another location where leaks through stone walls are manifested on the interior is Kaufmann Sr.'s dressing room, where the leak occurs through the west wall below the platform at the top of the exterior stairs. There may be no waterproofing at the door threshold, as earlier noted for the living room terrace doors.

Within the servants' quarters former carport, the stone walls of the north and east elevations—which are retaining walls—are often wet. This is probably related to defective below-grade waterproofing, worsened somewhat by the fact that scuppers from the terrace above discharge into the soil.

Windows and doors. Corrosion has been the main issue with the steel windows and doors, along with problems relating to the deflection of the slabs. At WASA's recommendation, John Seekircher and Co. was brought in to work on specific units. In 1992 the living-room hatch over the stairs to the stream was successfully restored and returned to functioning order, as were the corner windows of the living room near the hatch.[54] Seekircher's work involved stripping the units down to bare metal, cutting out and replacing deteriorated sections, priming and painting, and replacing nonfunctioning hardware in kind. Refurbishment of all remaining windows and doors has been incorporated into the ongoing restoration campaign.

The lack of a drip at the underside of the roof rolls continues to be the chief source of moisture penetration into the window heads. Where metal drips exist in the frames, they are inadequate. Water falling from them tends to pond on the stone sills, then penetrates the window frame under the bottom rail. WASA has designed a drip for installation on the soffit of the concrete roof roll to mitigate this problem.

Deflection of the slabs has rendered some windows inoperable, and others no longer tight in their openings. Moisture has caused many of the windows and doors to corrode and expand, in some cases preventing operation. Attempts have been made to seal the enlarged gap between window-frame heads and roof rolls. In the past, terrace deflections have caused glass in some windows to crack. This problem has mostly ceased since the replacement of the single-pane glazing with ultraviolet-protective glazing in 1989.[55]

Paints and coatings. Between 1937 and 1950, Cemelith was used at least twice to paint the concrete at Fallingwater. (Latex paint was used experimentally in the late 1940s.) According to maintenance records, a Pittsburgh Paints oil-based paint was applied in 1951, followed by an alkyd latex through the 1950s. An acrylic latex was used in 1969, and a Tnemec modified epoxy in 1972; neither of these products adhered well.[56] From 1976 until WASA's involvement, an acrylic painting system by Thoro was in use. (Concrete surfaces were sandblasted at the start of this campaign.) The acrylic paint was renewed on a more-or-less yearly basis because of the continuing appearance of calcium carbonate (as surface drips and stalactites) and of organic soiling. One result of the numerous applications was the loss of vapor permeability.[57]

In 1990 WASA began a test program for paint stripping, water-repellent treatment, and finish painting for the exterior. WASA's concept was to design a primer/coating system that would inhibit liquid water from entering the stucco by repelling it at or near the surface, while still permitting vapor transmission. Ideally, the system would require less frequent painting (by reducing leaching), would protect surface repairs, and would be durable enough for periodic cleaning.

Selection of an appropriate paint-stripping method demanded consideration of several issues, including the fact that Bear Run is an environmentally protected stream. Other considerations were ease of handling (stripping was to be done in-house by maintenance staff), dwell time, coverage, cost, and product effectiveness. Testing determined that the paints could only be removed down to the yellow resurfacing layer applied in the late 1970s because removal of this yellow layer damaged the white stucco beneath.[58] Peel Away 2 and 3 (methylene chloride-based paint strippers, by Dumond Chemicals) were used, followed by pressure washing. This approach was unsuccessful on the guest house pool; there, Peel Away 1 (an alkaline-based paint stripper), followed by ProSoCo's Limestone and Masonry Afterwash, was used.

For repainting, WASA specified ProSoCo's BMC 90, a silicone emulsion water-based paint, applied over Sure Klean Weather Seal SL 40, a penetrating silane water repellent acting as the primer.[59] Full exterior painting by the maintenance staff using this system began in 1994. It has worked well for the vertical surfaces (they have not since been repainted), but it is experiencing failures on the horizontal surfaces, including the parapet roll tops.

In the spring of 2001, two of the authors (Weiss and Jerome) began investigating these failures. Several areas were examined and sampled. Delaminated paint, in some areas less than two years old, appeared brittle. Small, irregular tears were observed (at 10× magnification) on the parapet roll tops. Biological contamination was noted in conjunction with adhesion failure. The underside of the film exhibited distinct relief (texture of the underlying substrate), implying that mechanical bonding was not the issue.[60]

Samples were sent to ProSoCo's laboratories for further evaluation. The selected paint, a silicone emulsion, achieves maximum vapor transmission by forming a microporous film. On horizontal surfaces, the pores collect the fine organic debris and microorganisms that are particularly plentiful at Fallingwater. These compromise the paint's ability to repel water. Ponding in the pores eventually wets the substrate, favoring fungal growth. Colonization breaks down the pore structure, promoting further colonization. It appears that in the affected areas, the paint will have to be removed and the surface given an antimicrobial treatment before the finish is reapplied. The antimicrobial product may require reapplication as often as every six months to maintain the coating on horizontal surfaces.[61]

The guest-house pool was stripped and painted in 1996 with Amsterdam Pool Paint, a water-based latex paint, applied over SL 40. This pairing of products proved to be unsuccessful and was removed. A number of pool paints were considered. Epoxies are more durable but are problematic in terms of reversibility. Some synthetic rubbers require yearly renewal. Olympic, a chlorinated rubber paint by Kelley Coatings, was selected and installed in the fall of 1999. This application has been successful to date.

Interiors. Deterioration of interior finishes is mainly related to moisture infiltration from the exterior. Maintenance of interiors has consisted of periodic patching of plaster and repainting. Minor repointing of interior stonework has also been performed. Flagstone floors are waxed once a week (and stripped once a year) and are in good condition. Wood doors tend to be in good condition; their thin frames, being more fragile, are only in fair condition. Some water staining and warping is seen. Thom Gentle, a furniture conservator, has been involved since 1986 with the care of the furnishings and woodwork.

The guest house, with its north wall partially bermed into the hillside, has exhibited high levels of moisture; at times, it smells strongly of mildew. Some reduction of interior moisture was achieved when a trench drain was installed by Fallingwater's maintenance staff along the north elevation in 1990-91. A fan was also installed in the chimney.

Review of original drawings for the guest house indicate that its construction is different from that of the main house. The framing system is steel columns, and the exterior walls are stucco on metal lath. The floor slab was poured on grade. Original plumbing drawings show that the north wall was waterproofed with a three-ply membrane. They also indicate a continuous 4-inch footing drain (for collection of subsurface water), connected centrally to a 10-inch clay sewer pipe that passed beneath the guest house.[62] A test pit was dug by the maintenance staff in April 2000 to verify the existence of the footing drain, but none was found where indicated on the drawings. The waterproofing appeared brittle and compromised.

Recent geotechnical studies have revealed that a farmed field at the crest of the hill significantly contributes to the amount of runoff heading downhill. It is highly unlikely that the slab itself is waterproofed, and the presumed gravel bed beneath has probably silted in over the years. The problems of the north and east walls of the former carport (noted earlier) are related.[63]

Most ceilings and walls in both the main house and guest house have a cement-plaster finish. Where chronic leaks have occurred, there is evidence of staining, blistering, paint and plaster failures, cracking, and loss of cork-tile adhesion. Much of the patching of cracks and superficial spalls has failed.

In preparation for repainting, interior surfaces were studied and sampled during the spring of 2001. The original substrate appears to be a white cement plaster. The last major interior repainting campaign occurred in 1987-88 and used Thorosheen (a water-based acrylic paint). The current appearance of the paint is quite dark and highly textured. Earlier paints were lighter in color and relatively smooth; physical evidence of this is found within built-in cabinets in several locations. The current finish was not introduced until the Thorosheen campaigns began in the mid-1970s.

Samples were mounted in resin by Integrated Conservation Resources and examined in their laboratory. From the photomicrographs, it is apparent that some delamination is occurring. Fourier transform infrared spectroscopy revealed that the original orange-hued paint contains calcium carbonate and quartz as its principal constituents. The plaster itself was not floated smooth and gave a slight texture to the paint. One repainting campaign, still quite early in the history of Fallingwater, used a much lighter peach-colored oil-based paint. Several later campaigns, returning to the darker color, applied alkyd and polystyrene paints.[64]

Today, the successful repainting of the interior will require paint stripping;

because of the built-in furnishings and the difficulties of ventilation, chemical methods are not being considered. Instead, several mechanical methods have been tested. A flat-belt sander with power vacuum attached was tried initially, with mixed results. A braided-wire wheel was also rejected as inappropriate. Hand chipping using a chisel and hammer worked well where the paint was already delaminating, but it was too labor-intensive. The maintenance staff suggested the best device, a small needle scaler, which can be modified with a vacuum attachment. Several paint systems are currently being reviewed, as is the application of a vapor barrier coating on ceiling areas under roofs.

Conclusion

The pathology of deterioration at Fallingwater has proven to be extraordinarily interesting and complex. Years of research and investigation, along with trial-and-error implementation of many treatments, have given WASA a fuller understanding of the synergistic relationships among the many individual construction elements. Design and implementation of the materials aspect of Fallingwater's restoration, in progress, has been a challenging but rewarding endeavor and will be the subject of a future article.

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Notes

1. Edgar Kaufmann jr., *Fallingwater: A Frank Lloyd Wright Country House* (New York: Cross River Press, 1986), 36-39.

2. Richard L. Cleary, *Merchant Prince and Master Builder: Edgar J. Kaufmann and Frank Lloyd Wright* (Pittsburgh: Heinz Architectural Center, Carnegie Museum of Art, 1999), 14 (the office interior is currently the property of London's Victoria and Albert Museum); Franklin Toker, *Pittsburgh: An Urban Portrait* (Pittsburgh: Pennsylvania State University Press, 1986; University of Pittsburgh Press, 1994), 43.

3. Donald Hoffman, *Frank Lloyd Wright's Fallingwater: The House and Its History* (New York: Dover Publications, 1978, 1993), 8-9.

4. Frank Lloyd Wright, *An Autobiography* (New York: Duell, Sloan and Pierce, 1943), 338.

5. WASA's predecessor firms were Reed and Stem (designers of Grand Central Terminal in New York City), Stem and Fellheimer, and Fellheimer and Wagner.

6. Besides Weiss and Gottlieb, WASA staff involved with the early testing and evaluation phases included Bruce Popkin, Karin Reed, and Elaine Unger.

7. Fallingwater's staff have been particularly helpful, including Lynda Waggoner (director); Michele Risdal-Barnes (curator); Jeff Gaul (director of maintenance); Dan Johnson, Cecil Kifer, Albert Ohler (maintenance staff); and Blaney Sproul (former site superintendent).

8. Vincent Scully, Jr., *Frank Lloyd Wright* (New York: George Braziller, 1960, 1996), 23; Robert C. Twombly, *Frank Lloyd Wright: His Life and His Architecture* (New York: John Wiley & Sons, 1979), 277. Neutra worked for Wright for a short period in 1924; Cleary (1999), 48.

9. X-ray diffraction analysis performed in ProSoCo's laboratory revealed that the stone largely consists of quartz (47.1%) and calcite (51.5%) with a minor amount of microcline (1.3%). ProSoCo, Inc. Laboratory Report, "Petrographic and X-Ray Diffraction Analyses for Fallingwater" (unpublished report issued May 5, 2000).

10. Hoffman (1993), 61.

11. Ibid.

12. The finish color is Munsell 8.2 YR 7.2/3.7. This research was performed by Frank Welsh with Ilene Tyler of Quinn Evans, Architects, who also identified the original "Venetian" red color used on all steel as Munsell 8.3 R 3/5. Quinn Evans/Architects with Frank S. Welsh, "Fallingwater: Historic Finishes and Colors" (unpublished report issued February 28, 1990).

13. This technique was first used at the Hollyhock House (1920) and the Freeman House (1924), both in Los Angeles.

14. For structural problems, refer to Robert Silman, "The Plan to Save Fallingwater," *Scientific American* (September 2000): 88-95.

15. The bottoms of the beams align with the slab instead of the tops.

16. Kaufmann jr. (1986), 112.

17. Frank Lloyd Wright Architect, "Roofing and Flashing Details Kaufmann House Bear Run PA" (undated drawing), referred to as drawing 3602.086 by the Frank Lloyd Wright Foundation.

18. Frank Lloyd Wright, "Fallingwater," The *Architectural Forum* (January 1938): 36.

19. Hoffman (1993), 54.

20. Frank Lloyd Wright Architect, "Trellis Flashing Kaufmann House Bear Run PA" (undated drawing), Frank Lloyd Wright Foundation.

21. Wank Adams Slavin Associates, "Volume 1: Fallingwater. Conservation Analysis for Concrete and Stone Masonry" (unpublished report issued January 18, 1989), II/5.

22. Robert Silman Associates, PC, "Analysis of the Master Terrace at Fallingwater" (unpublished report issued May 17, 1996), 31-32.

23. Wright (1938), 36.

24. Wank Adams Slavin Associates (1989), II/5.

25. Hoffman (1993), 36.

26. Wank Adams Slavin Associates, "Volume 3: Fallingwater. Concrete Repairs and Coating Tests. Conservation Tests 1991" (unpublished report issued 1991), 9.

27. Wright (1938), 36.

28. Ibid.

29. Hoffman (1993), 32.

30. The exception is Kaufmann jr.'s study. At this location, a later polyurethane finish was removed and the furnishings were refinished with shellac. Refer to Thom Gentle and Victoria Jefferies, "Conservation of Furniture at Frank Lloyd Wright's Fallingwater," *APT Bulletin* 21 (1989): 55-61.

31. Wank Adams Slavin Associates, "Volume I: Existing Conditions Survey. Volume II: Evaluation and Recommendations" (unpublished reports issued September 30, 1999).

32. WASA master plan team members included Gottlieb and Weiss, with Jerome as project manager. WASA staff members surveying on site included Jerome, Keith Gianakopoulos, Reynaldo Liz, Vasiliki Simpson-Wong, Rodrigo Torres, and Daniel Piselli. Drawings were produced in WASA's New York City office by Felix Fernandez, Gianakopoulos, Luis Herrera, and Simpson-Wong, and on-site by two Fallingwater interns, Piselli and Ian MacDonald. Subsequent construction documents have been generated by WASA staff members Jerome, Gianakopoulos, Fernandez, and René Fan, with Hazel Ephron as partner-in-charge.

33. L. D. Astorino and Associates, "Specifications. Fallingwater: Reroofing, Waterproofing, Concrete Repair" (unpublished project manual issued 1985), 07530/3-07530/4.

34. The importance of through-wall flashing to the integrity of a waterproofing/roofing system

cannot be underestimated. At Fallingwater, any moisture entering the exterior masonry can simply bypass regletted cap flashing and continue into the interior or migrate under the waterproofing/roofing membrane.

35. This work was performed by WASA staff member Walter Bishop, a senior mechanical engineer.

36. P. Fisette, "Tech Talk," *Custom Builder* (February 1998): 25.

37. The exception was the master bedroom terrace, which was bedded in sand. Because sand tended to clog the drain, in 1989 WASA recommended that the flagstones be lifted and re-bedded in pea gravel. At that time, patches were made to the two-year-old membrane.

38. Because of the pea gravel setting bed, the flagstones rock when walked upon. This makes the flagstones vulnerable to damage and subjects the edges to higher stresses. Wank Adams Slavin Associates (1989), II/9.

39. The EPDM terrace waterproofing system does not include drainage mat, so moisture penetrating the joints is nondirected and sits on the membrane until evaporation occurs.

40. This system has worked well with the exception of the pea gravel bedding, which causes the flagstones to rock. The flagstones were relifted in 2000, and a rounded sand setting bed on filter fabric was installed. The filter fabric was also wrapped around the perforated drain collar to prevent clogging. The terraces currently under restoration will receive similar treatment.

41. Wank Adams Slavin Associates (1991), 14.

42 . L. D. Astorino and Associates (1985), 03310/1-03310/12.

43. When the formwork was removed, the sheet metal proved to be insufficiently rigid to maintain the curved form. Power grinding was used to achieve the desired surface profile. The concrete mix used was 1:2:3, portland cement:fine aggregate:coarse aggregate plus a plasticizer (Eucon 37 High Range Water Reducing Agent, Euclid Chemical Company). This worked was performed by Masonry Preservation Services. Wank Adams Slavin Associates (1991), 10-11.

44. Wank Adams Slavin Associates (1991), 5-8.

45. Wank Adams Slavin Associates, "Volume 2: Fallingwater. Conservation Analysis for Concrete and Stone Masonry. Conservation Tests 1990" (unpublished report issued April 8, 1992), 10-11.

46. Wank Adams Slavin Associates (1991), 1-4.

47. Several mixes were tested and evaluated over the years, and two were selected for use. Mix G is used for crack filling and consists of 3:5:2, white portland cement:white plasterer's sand:G-3500 Zeeospheres (ceramic microspheres, manufactured by Zeelan Industries, Inc.). Mix H was found to have superior working characteristics for filling hairline cracks and shallow depressions. It is composed of 2:5, white portland cement:G-3500 Zeeospheres. Wank Adams Slavin Associates, "Volume 5: Fallingwater. Crack Repairs and Coatings. Conservation Tests 1993" (unpublished report issued April 1, 1994), 6-7.

48. Some of the stone on the servants' quarters terrace walls shows evidence of delamination at the bedding planes. Since these walls were some of the last to be built, perhaps the better quality stone had already been removed from the quarry and used in other parts of the complex.

49. Wank Adams Slavin Associates (1992), 17-18.

50. Wank Adams Slavin Associates (1992), 16-17.

51. Wank Adams Slavin Associates, "Volume 4: Fallingwater. Concrete and Stone Masonry. Conservation Tests 1992" (unpublished report issued 1993), 14.

52. "Daylighting" is a term that refers to an underground pipe that appears above grade. In this case, the two pipes also terminate and discharge their contents where they daylight.

53. Pillori Associates, PA, "Report. Geotechnical and Civil Engineering. Fallingwater" (unpublished report issued September 2001), 3-4.

54. Wank Adams Slavin Associates (1993), 2-3.

55. This work was performed under the supervision of L. D. Astorino and Associates and included both the main and guest houses, but not the servants' quarters. The product used was Saflex (a laminated glass), manufactured by Monsanto.

56. Wank Adams Slavin Associates (1989), VI/4-8.

57. The products used were Thorite (a cementitious patching mortar), Acryl 60 (an acrylic admixture), Thoroseal (a cementitious waterproof coating), and Thorosheen (a water-based acrylic paint). When applied in a single coat, Thorosheen is relatively vapor permeable. After multiple applications, however, its vapor permeability is drastically reduced. Wank Adams Slavin Associates (1989), II/6.

58. Wank Adams Slavin Associates (1994), 2.

59. Although this would seem an unlikely paint system, the wetting agents in BMC 90 reduce surface tension between the silicone emulsion coating and the weakly hydophilic silane primer. In addition to the mechanical bond between the coating and the primer, a weak chemical bond is also formed.

60. Wank Adams Slavin Associates, "Exterior and Interior Paint Report" (unpublished draft report issued on March 29, 2001), 1-2.

61. August 3, 2001 correspondence from ProSoCo's David Boyer.

62. Frank Lloyd Wright Architect, "Sheet Numbers 4 and 6" (unpublished drawings issued January 28, 1939 and March 14, 1939), referred to as drawings VIII-21 and VIII-23 by Avery Library Archives.

63. Pillori Associates, PA (September 2001).

64. Integrated Conservation Resources, Inc., "Paint Analysis Services: Fallingwater Bear Run, Pennsylvania" (unpublished report issued May 2001), 7-10.