"Weathering of Architectural Concrete on the Baha'i House of Worship"

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The beautifully elaborate and finely executed design of the Baha'i House of Worship offers some insights into the weathering of architectural concrete. Both precast and cast–in–place, sculpted components of sparkling, white quartz aggregate and white cement have now been exposed to North America's harsh Midwest climate and the pollution of metropolitan Chicago for some sixty years.

The Temple's many faceted surface illustrates deterioration from the movement of water, chemical deposition, atmospheric staining, erosion, organic growths, cyclic freeze/thaw action, trapped moisture, scaling, joint deterioration, effloresence, and metal corrosion. This historic structure also demonstrates the wonderful aesthetic benefits from careful construction and maintenance of architectural concrete.

Original Design

The Baha'i Temple is regarded as one of the finest examples of architectural concrete in the world. The intricate design of architect Louis Bourgeois was selected in an architectural competition in 1920. Bourgeois' concept for a temple of light required tens of thousands of penetrations within highly carved surfaces of luminous ornamentation. John Early, who became known as the man who made concrete beautiful, and his studio of craftsmen ultimately executed the design in brilliant white and crystal clear exposed aggregate concrete.

When his design was chosen, the architect was unsure about which material could adequately give life to this beacon of spiritual unity. The building team evaluated natural stone, terra cotta, cast metals, and, the most recent innovation, reinforced concrete. Although intimately involved with the selection of materials, Mr. Bourgeois passed away in 1930, just two months after exposed aggregate concrete was chosen.

Before he died, Louis Bourgeois had sketched the geometric and naturalistic ornamentation on full size, shaded renderings for every portion of the 167 foot high building. His finely crafted drawings often stretched down the wall and across the floor of his studio. Drawings for the dome's panels, for example, were 139 feet long and 7 feet wide, showing every vein in every leaf which the architect wanted on the finished panels.

Bourgeois's drawings followed traditional detailing for natural stone cladding. The structural drawings and final construction of the superstructure included anchors for the reinforced ornamental concrete skin. John Early and his partner, Basil Taylor, were pioneers in the development of ornamental concrete cladding. The architectural concrete of the Baha'i Temple would be the culmination of their many innovations, a breathtaking achievement both artistically and technically.

Original Construction

Construction occurred in four phases. Initially, the foundation and basement level were built in 1921, then, a structural and weather tight shell was added in 1930. The ten years from 1931 through 1942 were required for Early Studios to create the exterior ornamental cladding, and they completed the interior architectural ornamentation between 1949 and 1951.

John Early developed a luminescent, white, exposed aggregate concrete for the Baha'i Temple. The large aggregate was crushed quartz, approximately 90% white and 10% crystal clear, about 3/8" maximum diameter. The fine aggregate was also crushed quartz. White portland cement and clear water were the remaining ingredients. No air-entraining agent was used. Galvanized reinforcing steel, bent and often spot welded into complex three dimensional networks, and anchors of either galvanized steel loops or stainless steel bolts were cast into the ornamental sections.

Working from Bourgeois' drawings and as–built measurements of the superstructure, Early Studios sculpted clay and plaster models. The studio produced elaborate plaster molds for both precast panels and cast–in–place components. Early's craftsmen often set thin, precast elements into molds on the building before then casting fresh concrete into the mold and producing seamless ornamentation of vibrant relief and complex geometry.

For such intricate sculptural shapes, John Early developed methods to place concrete into the forms with a very high water to cement ratio and then remove excess water from the wet concrete in order to achieve a lower water to cement ratio for hydration. He pulled water out to the surface of the concrete through capillary action by precisely gap-grading his large and fine aggregate. Early was so demanding about the sizing and color of the aggregate that he high-graded railroad car loads of rock at his studio before crushing it there.

To expose the sparkling quartz aggregate which gave such vitality to the finished material, the studio stripped the forms within eighteen hours and scratched the cement paste off the surface. The craftsmen used small wire brushes about one inch in size to scrape every part of the temple's surface. A final rinsing with a wash of acid and water cleaned the panels. All of the precast components were cured in moisture controlled chambers at the studio.

Initial Weathering

The brilliant white cladding suffered significant weathering even before it was finished. Dust storms of 1934 deposited soil onto the newly completed dome and noticeably darkened it. Although an attempt was made in 1942 to clean the dome, the first effective cleaning was thirty years later.

By the early 1970's the luminous quartz concrete was heavily veiled under deposits of dust, calcium sulfate, carbon, lichen, algae, grease and calcium carbonate. A major chemical cleaning removed most of the stains. But the calcium sulfate, commonly referred to as black scab, proved resistant to the chemicals and remained as black deposits.

Sandblasting was then used to remove the calcium sulfate. Sandblasting had been recommended by the Early Studios in their review of the ornamental concrete in 1971. At the time, sandblasting was widely accepted as a viable method for removal of difficult deposits from masonry.

Although one of the workers on the project described it as a selective, finely controlled method, the sandblasting had a very harmful effect on the crushed quartz aggregate. The highly reflective, sharply fractured, jewel–like facets of the quartz aggregate were etched and rounded so that the sparkling finish was irreparably dulled. The quartz surfaces, previously acting like tiny mirrors for the sun, now resembled white, beach–washed stones — bright, but lifeless. Furthermore, the crisp edges of the ornate carvings were also softened so that the clarity of the sculptors' detail was lost.

The monumental stairs encircling the Temple and five of the first story elevations had been sandblasted before a layman on the Baha'i staff pointed out the difference between the original and the sandblasted surfaces. The sandblasting was stopped. The Baha'is decided to wait until a better method was found to remove the black crusts.

Black, Calcium Sulfate Crusts

Calcium sulfate, or gypsum, forms when airborne sulfur pollutants come in contact with a moist masonry or concrete surface offering calcium in a water solution. The chemicals interact and as the water evaporates, the calcium and sulfate crystallize into solid form. Normally white, the gypsum crystallizes on a building around carbon and other pollutants, thus creating a gray–black encrustation.

The crystalline structure was extremely hard and resistant to streams of water, detergent, acidic and alkaline cleaners. At best, the cleaners may produced a bleaching effect. The crystal was also resistant to softer abrasive cleaning methods such as brushing. The crust seemed to breakdown only with grinding or sandblasting.

A closer examination of where the calcium sulfate forms will provide an insight into methods of controlling its growth and removing it from many concrete surfaces. The crystals build up in areas along the boundaries of water flow across the concrete surface. Clear examples are the bottom of window ledges or lintels, below horizontal bands of trim, at the drip edges of cornices or along the underside of column capitals. The growths also build up at the limits of rainwater movement around projecting ornamentation, carved relief, or sloped surfaces.

At the edges of water flow, the surface alternates between wet and dry conditions but there is no beneficial rinsing effect. Where rainwater regularly rinses the surface, the crystals do not build up because they remain in solution and are carried away before the water evaporates. On the other hand, locations that always remain dry lack calcium in solution so the calcium sulfate never forms.

The growth or deposition of calcium sulfate crusts can be controlled through careful detailing of surfaces for water flow. Growth will be reduced by increasingly better air quality, and build–up can be inhibited by periodic rinsing of building surfaces at the boundaries of natural water rinsing. Water resistant sealants that will minimize the movement of calcium into solution may also be effective deterrents.

Removal of calcium sulfate crusts from concrete surfaces can often be accomplished with nebulous water misting techniques. Fogging, as compared to solid streams of water, seems to place the crystals back in solution. Gentle agitation with jets of water may accelerate the removal process. Wetting and drying cycles have also proved effective in the misting process. This cleaning technique is non–abrasive and does not harm the surface of the concrete.

Atmospheric Staining

Black, calcium sulfate crusts covered only a small portion of the Temple's surface. Atmospheric staining was widespread and made the white concrete look a streaky, gray-brown. Wind carries dust and organic material onto the building. Birds love the protective crevices of the ornamentation and bring twigs, leaves and seeds. Bird droppings are highly acidic and don't rinse off in the rain. Spiders are forever weaving webs and spinning cocoons for their eggs. A squirrel was once discovered stashing away acorns at the very top of the dome.

Moisture in the air is a source of life for algae, lichen and moss. Moist concrete surfaces support fungi and bacteria just like natural stone. Some species do not even need sunlight, secreting an acid to break down the masonry for their digestion. Spores are everywhere in the air, dust and organic materials. Colonies of algae and fungi darken the appearance of the concrete surface.

Rain brings pollutants like dust, mineral particles and dissolved chemicals onto the building. Rain also mixes and moves deposits around on the concrete surfaces. This not only rinses some areas clean, but further concentrates soilage at puddles, drips, horizontal and porous areas. While heavy rains generate the greatest scouring and rinsing action, even they do not clean all of the Temple.

In order to maintain a high quality appearance and minimize accumulation of pollutants, we periodically pressure wash areas of the ornamental concrete. Frequency varies by location on the building. The landings, treads and risers of the monumental stairs quickly collect soilage in the coarse surface. They need washed every spring, summer and fall. First story window ornamentation may be rinsed twice a year. Upper story window areas and cornices, farther from view and more difficult to access, are cleaned every two to three years. The dome retains enough dust to warrant water rinsing every four or five years.

The Temple's conservation staff will also clean accumulations of soilage or stains before they reach an advanced state. Gentler cleaning methods can be used when the deposits are small. With the increased custodial rinsing and the reduction of air pollutants, we hope that the Baha'i House of Worship will not need another extensive restoration cleaning for at least twenty–five years.

Surface Erosion

The sculptural quality of the ornamental concrete is threatened by surface erosion from the natural forces of the weather. The original finish was smooth and exposed only the face of the large quartz aggregate within the matrix of fine quartz aggregate and cement. The initially crisp edges which defined every detail are now softened by erosion in many locations.

We have measured up to 3/16 inch in erosion of the cement and sand matrix in areas where rainwater flows are concentrated. The large quartz aggregate almost appears to be above the matrix, precariously attached only by its inward face. In fact, the large aggregate remains well bonded to the panel but more susceptible to dislodgement from mechanical abrasion. The loss of the outer layer of large quartz would diminish the artist's beautifully carved relief in the ornamentation.

Areas protected from routine flow of rainwater and the most direct wind are like new. The inward sides of columns and dentils, the undersides of soffits and arches, the deeply set wall surfaces are all in superb condition. The exposed portions of these same components are eroded. The transition between smooth and eroded occurs at the boundary of water flow.

Although cycles of wet/dry and freeze/thaw may also have an influence, directional flow and concentration of rainwater clearly affects the rate of surface erosion and the weathered appearance of the architectural components. Concretes and natural stones are alike in this regard. Within either category the designer's particular choice in the material's composition, surface shape and finish will greatly influence its durability.

For the Baha'i' Temple we continue to research and test methods to slow the erosion, consolidate or strengthen the existing surface and, potentially, to restore the matrix of fine quartz sand and cement that has been lost. We are preceding with caution as the science of concrete materials is rapidly advancing and we do not want to prevent additional treatment in the future. Maintaining the brilliant, sparkling white qualities of the exposed quartz concrete presents additional challenges to chemical treatments.

Because the architectural concrete surface is truly a work of art, serious erosion of its features may require a future restoration without an accurate model to copy. Even with a duplicate component on another side of the Temple in excellent condition, creating dimensionally accurate molds by hand from the finished surface is extremely complex. As a precautionary measure we conducted a photogrametric survey in 1990 so that we can locate any point on the interior or exterior surface of the Temple's concrete in three dimensions within one–eighth of an inch. We have archived the data and it could be used with computers to create accurate models for sculptors in the future.

Trapped Moisture

An inadequate understanding of the movement of water through concrete can lead to design or maintenance that ultimately generates unsightly conditions or even damage. Eighteen levels of monumental, precast architectural concrete stairs surround the base of the Temple. Each step was cast as a composite of plain concrete with a one inch layer of white, quartz aggregate concrete on the tread and riser.

The stairs lie above occupied basement space. John Early's design cleverly incorporated a full drainage system off the waterproofed, sloping structural concrete deck below the steps. Concrete risers held the precast steps several inches above the deck while creating scuppers below the radial joints between steps. The six inch thick steps were made with overlapping lips at the back of the tread and the face of the riser to minimize water movement through the horizontal joints. All original joints in the stairway were open and free to drain.

The large landing at the top of the stairs was cast directly on top of a coal tar waterproofing membrane. Horizontal joints on the landing itself and where the landing met the wall utilized a flexible sealant.

Years later, when water leaked into the basement space below, the open stairway joints were highly suspected as the cause. All of the joints in the stairway were then caulked. As the basement continued to leak, the joints were caulked repeatedly, sealant on top of sealant. Water moved through failed sealants and into the joint. Water migrated down through the concrete material. Some water also wicked up and out through the concrete. But most of the water was trapped. The areas adjacent to these joints were very slow to dry after a rain or snow melt.

The excess moisture behind the joint and in the concrete riser supported fungus and algae. They flourished in the joints, on the surface and within the tiniest cracks of the concrete. Chemical cleaning and periodic hot water washes removed evidence of the stain from the white surface but could not completely remove the growths from the interior. Within four months the stains would be clearly visible at locations of joint sealant failure. The risers of the stairs would soon be darkened again by overall growth. We found that water resistant, penetrating sealants could not prevent regrowth of the organisms adjacent to the failed joints.

The organisms retained additional moisture as they grew. The saturated concrete deteriorates from cyclic freezing and thawing. As conditions worsen, the white concrete exhibits scaling, spalling at the joints and delamination. Eventually, the white layer of quartz aggregate concrete delaminates from the gray concrete along their interface.

Our detailed inspections show that the advanced stages of this deterioration does relate to compass orientation. Greater damage now exists on the eastern and southern portions of the stairs. These areas are warmed earlier in the day by the sun and, thus, have gone through a higher number of freeze/thaw cycles. In some areas of the stairway, sudden, complete delamination of the white concrete layer has occurred in the early spring when temperatures fluctuated around freezing.

The fifty year old monumental stairs now require removal and resurfacing of the one inch top layer of white concrete. Although deterioration of the risers was accelerated by the improper caulking of the joints, the Midwest's weather ultimately caused the treads to delaminate, too. Early Studios built projects using similar techniques in and near Washington, D.C. where winters are mild. Those structures do not exhibit this type of weather–induced surface failure.

Joint Deterioration

The great majority of details employed by Early Studios have proven to be highly effective during the first sixty years of the Baha'i Temple's life. They still offer excellent models for new construction. Some other details, however, have created difficulties and would not be recommended for similar construction today.

Most of the construction joints in the ornamental concrete cladding system were poured tight with no defined gap and no water stop. Reinforcing steel usually bridged the joint. Remarkably, the great majority of these joints remain tight today or exhibit a fine hairline crack. Very few show any signs of water movement through the joint and those exist only where a serious deficiency of the roofing or flashing systems existed for years.

Where visible construction joints were planned between precast ornamental panels, Early Studios created a surface joint three eighths of an inch wide. The joints were then beautifully pointed with a mortar of white portland cement and fine quartz aggregate. The spacing between joints occurs at far greater intervals than would be used on a unit masonry structure. Unlike softer mortars used in unit masonry, this hard mortar offers no capacity to expand and contract incrementally with the movement of the panels. As a result, the pointed joints are now unbonded along one edge where a hairline crack exists.

Repointing the joints to close the hairline opening or installing a flexible joint material presents considerable difficulty. The mortar is very hard to chip out with traditional tuck pointer's tools. The quartz aggregate is extremely hard and rapidly wears down grinding wheels. The crisp edges of the precast concrete panels are packed with large quartz aggregate that pops out with pressure from grinding at the joint.

The superstructure and ornamental cladding of the Baha'i House of Worship were constructed with no flexible joints for expansion and contraction. The building naturally created some of its own. Most of the cracks which now move follow construction joints in the ornamental cladding. Other places of movement are at cracks across window ledges or flat wall areas. Gaps vary from hairline to one eighth inch wide. Water can move in and out of the cladding system through these cracks. Their small width prohibits the installation of an effective, flexible sealant joint without an unacceptable negative impact on the architectural aesthetics.

Weeping of the Cladding

The exterior dome panels are precast concrete that is effectively open on all sides. The precast panels are set on and anchored to copper bearing steel tees running longitudinally from top to bottom of the dome. An intermediate skylight dome of glass on an aluminum frame provides the watertight closure for the top of the building. A third dome of precast concrete panels creates the interior finished surface.

Many precast components were used for ornamental columns and ornamental window grilles. Although interlocked and held by the wall areas that were cast directly around them, these elements are also open on most sides.

The largest portion of the four to five inch thick architectural concrete, however, is cast directly onto the concrete superstructure. Female anchors cast into the superstructure were used by Early to anchor reinforcing and form ties. Where Early Studios utilized precast panels on the wall itself, the precast component was two and one half inch thick with reinforcing loops projecting from the back. The precast element was set into the wall form and grouted into place as the flat wall surfaces were cast.

There was no provision for an internal cavity to transport water that permeated the cladding system. There was no weep system provided out of the cladding system. Cracks from expansion/contraction movement or from drying shrinkage let water both into and out of the cladding system.

Efflorescence

When water got behind the architectural concrete cladding and traveled downward but had no free access out of the wall, it moved through the concrete itself. Saturating the concrete, the water dissolved mineral components within the concrete, migrated through the material and emerged on the surface. As the water evaporated, the minerals remained in a calcium carbonate encrustation of effloresence. In its mildest form it appears as a white stain. At its worst, it takes the form of hanging stalactites which usually indicates significant internal deterioration of the concrete itself.

A failure of the building's waterproofing system often shows up through effloresence. Effloresence at a joint in precast wall panels below the first story cornice of the House of Worship was the result of a long lasting roofing system failure on the roof two feet above. Effloresence on interior surfaces of the basement coincided with failures at exterior sealant joints on the stairway landings or basement wall waterproofing.

A build-up of extreme effloresence on the soffit below the gutter at the bottom of the dome was due to advanced deterioration of the internal concrete. The water had entered the concrete through a defect in the joint between the flashing and the ornamental concrete. The extensive damage required removal and replacement of the soffits, cornice and gutter.

Quality of the Architectural Concrete Material

The products of Early Studios show a remarkable control of the concretes' manufacture, especially in the precast components. When it started the project, the studio decided that no defects would be acceptable in the dome's panels. Of those 387 pieces, none were rejected. The precast components on the building have almost no shrinkage cracking.

The cast in place areas of the Baha'i Temple presented greater challenges and do have some deficiencies affected by weathering. Shrinkage cracks provide pathways for water movement and hold dirt. Horizontal construction joints at vertical placements cast on the building may be visible because of aggregate alignment, cracks or small voids that retain moisture and soilage. In a few spots on the flat wall surfaces, honeycombing dries slowly and fungus flourishes.

Patches of holes are almost impossible to detect on dry surfaces but are faintly visible when wet. Even trained observers have difficulty finding patches of form tie holes. At one feature of the first story elevation, the underlying plain concrete walls were out of alignment and the architectural concrete is only one–half inch thick. Most of those spots were patched beautifully, but weathering is now making them more distinguishable.

The House of Worship's architectural concrete does have some shallow spalling due to corrosion of the reinforcing steel. Concrete cover over the reinforcing is less than one half of an inch thick where this occurs. The spalls usually show up at the same spot on similar precast components. Yet, the number of spalls is extremely small given the quantity and complexity of the reinforcing. This bears evidence to the consistency and high quality of Early Studios' craftsmanship.

The exceptional workmanship and materials that gave life to the architectural concrete on the Baha'i Temple have also endowed it with durability for the future. Increasing knowledge of the nature of concrete as a material and the effects of weathering provides us with better means for its conservation. Finally, our growing experience in caring for such a sophisticated structure further enhances our ability to meet our goal of preserving this unique Baha'i House of Worship for at least one thousand years.

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