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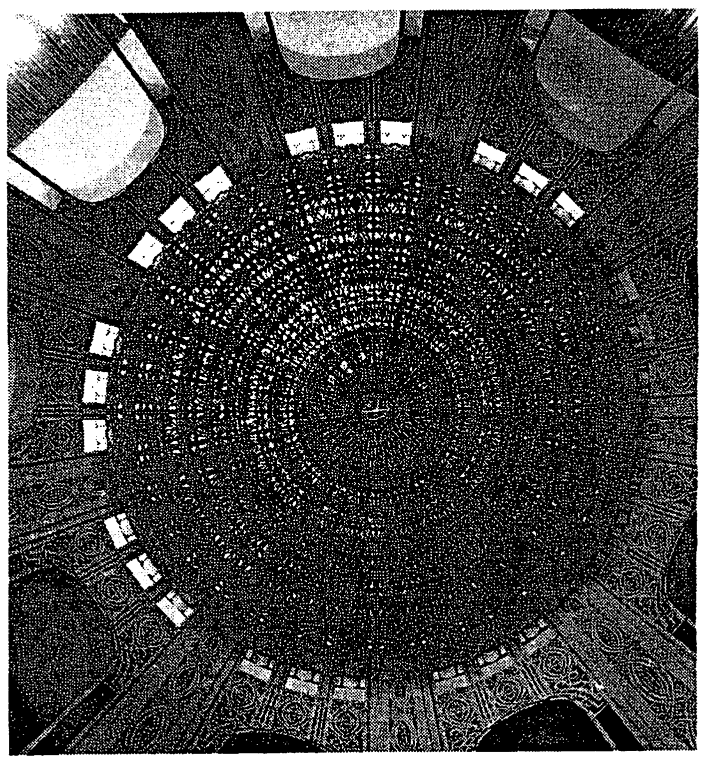
The Fair Face of Concrete

Conservation and Repair of Exposed Concrete



Interior of the dome of the Bahá'i House of Worship.
Photo: R. Armbruster 1991.

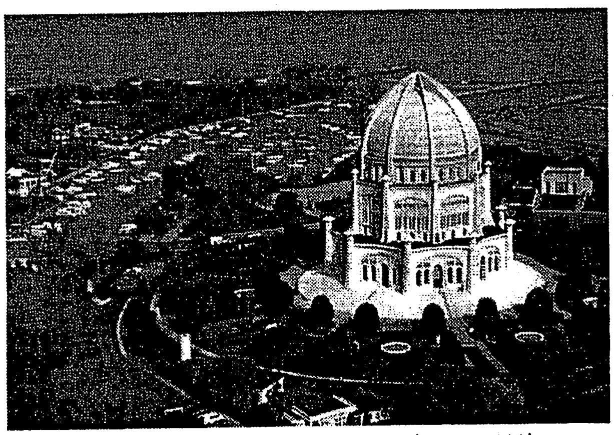
Restoring brilliant ornamentation

The Bahá'í House of Worship (Louis Bourgeois, 1920-53)

Restoration of architectural concrete presents many challenges beyond the production of high quality concrete. The aesthetic qualities of the finished material must be duplicated in the new repair. Restoration requires matching the aggregates, color, pattern, texture and shape of the original components. Correcting the underlying causes of the deterioration calls for attention to the finest details.

by Robert F. Armbruster

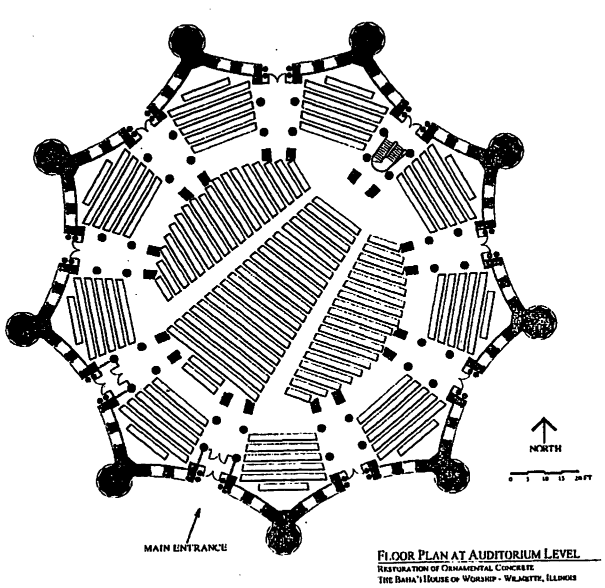
Architectural concrete repairs can be beautiful. Even exceptionally complex, exposed aggregate concrete can be restored to its original appearance.
Restoration of the remarkable ornamental concrete of the Bahá'í House of Worship in Wilmette, Illinois, utilized cast-in-place and precast exposed aggregate concrete of complex geometry to duplicate the existing components. The new work incorporates materials of even greater durability than the original, for the Bahá'ís intend this historic temple to serve for more than one thousand years.
The Bahá'í House of Worship is considered one of the finest examples of architectural concrete. Designed by architect Louis Bourgeois, the House of Worship is notable for its nine-sided symmetry and its mixture of architectural influences. Surrounded by gardens on a bluff overlooking Lake Michigan, the 51 m high Temple features crushed white and crystal clear



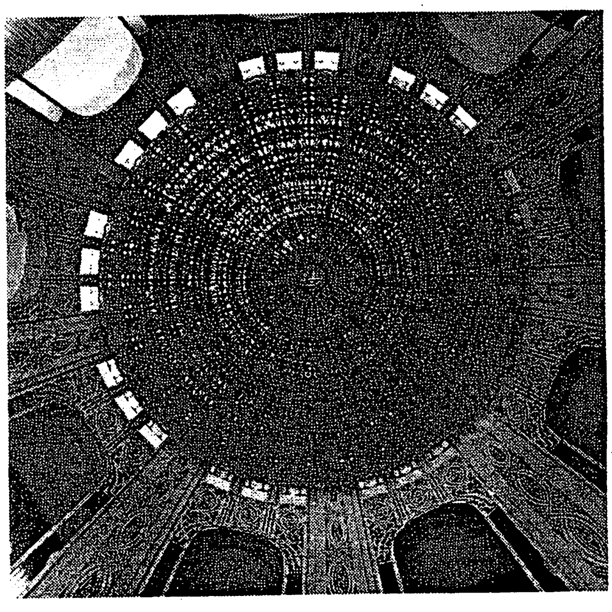
Aerial view of the temple site with Lake Michigan in Wilmette, Illinois. Photo: Bahá'í Media Services.

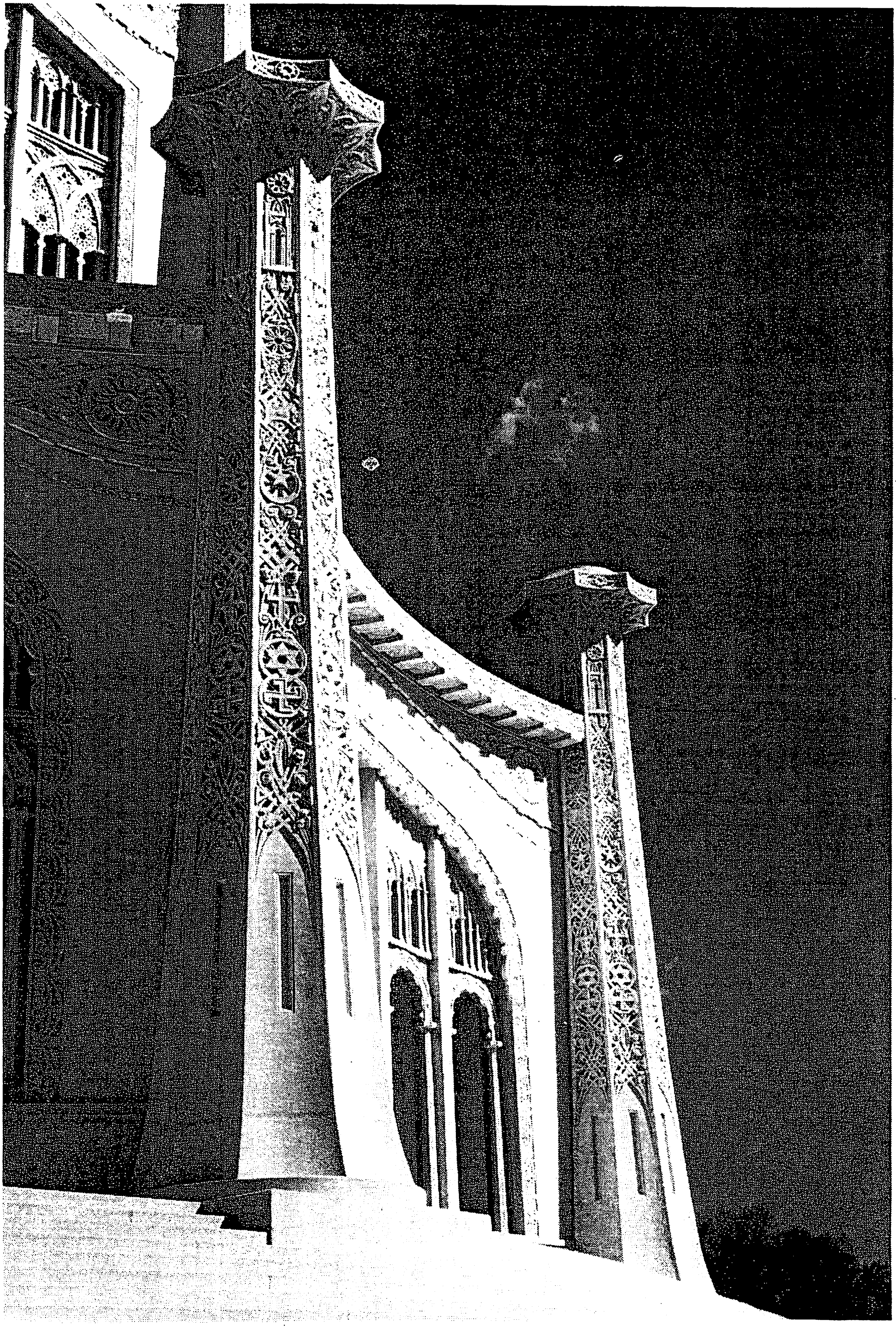
Next page: Detail of the temple, showing the ornamental concrete. Photo: R. Armbruster.

Floor plan at auditorium level showing the nine-sided symmetry.



Interior of the dome. Photo: R. Armbruster.





quartz concrete panels which gleam a vibrant white, sparkling in the sun. A dome of precast concrete panels with more than fifteen thousand perforations scatters light throughout the soaring interior space. Additional sunlight is filtered through filigreed architectural concrete panels screening large expanses of glass within three building levels of highly ornamented, curving walls. Construction began in 1920 and was completed in 1953.

John Early

The ornamental concrete was created by John J. Early who became known in the United States as 'the man who made concrete beautiful'. He championed architectural concrete as offering great visual beauty together with economy, design freedom and flexibility unmatched by other materials. John Early was a pioneer and innovator of exposed aggregate architectural concrete. He expanded the optical sensations of exposed concrete with polychrome color from multi-hued aggregates, cleverly devised construction techniques exploiting precast elements and intricate molds, applied coatings of exposed aggregate concrete, and used thin precast components of architectural concrete as forms for cast-in-place structural elements. Many view Early Studio's greatest accomplishment to be the ornamentation of the Bahá'í House of Worship.

Detail of the Bahá'í House of Worship before restoration. Photo: unknown.

Close-up after restoration. Photo: R. Armbruster, 1993.

Investigation

By 1983, this intricately sculpted concrete was suffering from weathering and the effects of water penetration. Fifty years after their construction, a few areas of the ornamental cladding showed signs of deterioration. Thirty-nine meters above the gardens, a 1 m wide gutter at the base of the dome is encased within the architectural cornice, soffit and dentils of the clerestory. In some of the nine bays, these components exhibited efflorescence, cracking and edge crumbling.

To start the restoration, the project manager formed a team with the structural engineer, contractor and key craftsmen for a unified approach to the investigation and repair. Two years were needed to determine the full extent of the damage. In addition to close-up examinations of the concrete, cores and inspection openings provided the means to explore the interface between the structural concrete and the ornamental concrete and to determine the condition of the original anchors. The source of water infiltration was verified with water testing. Petrographic examination of the cores determined the nature and depth of deterioration within the *in situ* material. Copper-coppersulfate half cell potential measurements and chloride ion analyses assessed possible corrosion activity.

Deterioration

A clear picture of the damage finally emerged. The weather-tight and fully functional superstructure of the

building was completed in 1931. During seventeen years that followed, the exterior and interior architectural concrete was applied as a cladding. The original copper lining in the gutter extended out over the horizontal edge of the structural concrete where it terminated in a drip edge. Years later, a 120 mm thick layer of ornamental concrete was cast directly against the structural concrete face of the cornice and the copper drip edge. The copper was not modified to go over the new lip of the gutter. In addition, the ornamental concrete had a scalloped top edge projecting above the structural concrete and copper lining, thus raising the overflow point of the gutter.
For decades water had entered the interface between the structural and ornamental concrete of the cornice. Trapped, with no means of draining, it saturated both materials. Cyclical freezing and thawing drove deterioration from the interface outward into the white quartz aggregate material and inwards into the plain aggregate structural concrete. Neither concrete material was air entrained. The white quartz concrete proved to be more resistant to the freeze/thaw action. Damage had not yet reached the exterior surface of the architectural concrete in some bays even though deterioration extended deep within that bay's structural concrete. Expansion of freezing water pushed the white concrete away from the structural concrete, creating a gap of up to 30 mm and fracturing the steel anchors tying them together. The building's structural steel frame had not been weakened but the integrity of the concrete cornice was seriously compromised. The condition called for removal and replacement of the architectural and structural concrete.

Versatile repair material

Simultaneous with the engineering investigation, the team developed the exposed aggregate architectural concrete material for the restoration work. Research in the Bahá'í National Archives, laboratory decomposition of material from the building, review of John Early's papers presented to the American Concrete Institute, and discussion with members of Early's original crew were helpful, but it was the knowledge and experience of the craftsmen on the team in particular that led to success through careful experimentation. More than fifty samples were made, many at full size, to refine the concrete mix proportions and the wide range techniques required for forming, casting and finishing different parts of the restoration.
The aggregate in the repair material had to match the original material in color, size, surface density (or packing), exposure and light reflectance. The repair material had to be versatile because it would serve for small patches of existing ornamentation, cast-in-place replacement of large areas, and production of precast panels. The repair concrete need to be air entrained and have a low water-to-cement ratio, yet flow into intricate molds. Materials for the concrete had to be readily available. Production of the finished concrete also had to be economical and of consistently high quality.
The final repair material for the architectural concrete contains white Portland cement, crushed quartz up to 10 mm in size for the large aggregate, finely crushed quartz around 1 mm in size, very fine silica sand, water, a clear water reducing admixture, and a clear air entraining agent. Quality assurance was integrated into every step of the process. Mixing procedures included pre-measurement and independent double checking of quantities. Slump and air content tests were performed on every batch. Cylinder samples were made, cured and tested to verify results.

Fine tuning

All architectural concrete was mixed on the site in 0.4 m^3 batches using portable mixers. A custom formulated retarding agent applied to the surface of the molds gave the desired exposure of the quartz aggregate. All of the new concrete was cured for three weeks within moisture tight plastic wraps.
For architectural components which had to be replaced, a rubber impression of the original was taken from the building. The impression then served as a mold to cast a positive model in plaster. Sculptors further refined this model to renew the original crispness of the ornamentation. The joints, sides and back of the pieces were shaped, additional plaster models cast, and the entire assembly aligned to fit templates of the building before production molds were created in fiberglass, urethane or wood.
The project required sequential replacement of interlocking layers of curving, sculpted elements which had no parallel planes or edges. Dimensional control was transferred between layers as work progressed. For accuracy and production efficiency, a series of templates and jigs were created. Full size mock-ups of complete repair assemblies were built in the shop for testing and fine tuning to the project's exacting tolerances. Specialized hoists and access systems were designed, built and tested.

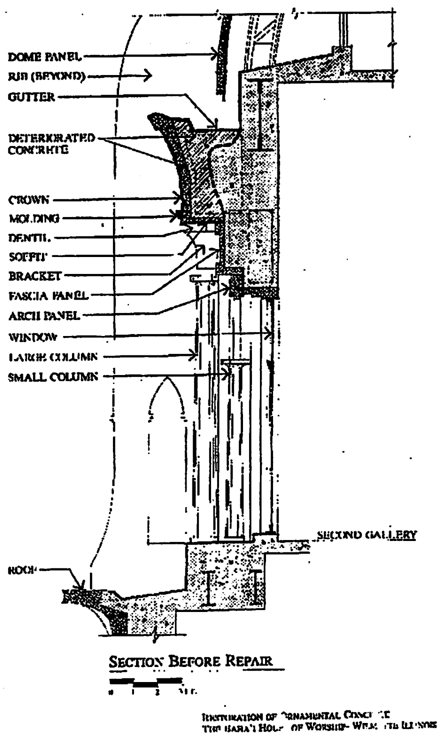
Different designs

Construction began with replacement of the monumental stairs at the entrance of the Temple. Deicing salts had accelerated cyclical freeze/thaw deterioration. The original cast-in-place upper landing and precast stairs were removed. A new waterproofing membrane was applied to the sloping structural concrete deck below the stairs. To melt future snow and ice, a hot water heating system was installed below the new precast stairs. A cast-in-place landing of exposed aggregate quartz concrete completed restoration of the original appearance.
Repairs at the clerestory and crown varied in extent on each of the nine sides or bays. The original concrete in one bay was in excellent condition and the only intervention was the installation of concealed

anchors between the architectural concrete and the underlying structural concrete. Restoration of the remaining eight bays involved the complete removal and replacement of all unsound concrete and the copper gutter. The varied depths of deterioration required three different designs for structural concrete repairs below the same architectural concrete repair scheme.

Seamless repair

Workmen removed the weakened white architectural concrete with seven kilogram jackhammers. Core samples were then taken and analyzed petrographically to determine the depth of deterioration. Meanwhile, the crew continued to remove unsound structural concrete, which sometimes



The ornamental concrete before repair. All drawings: Wiss, Janney, Elstner Associates, Chicago.

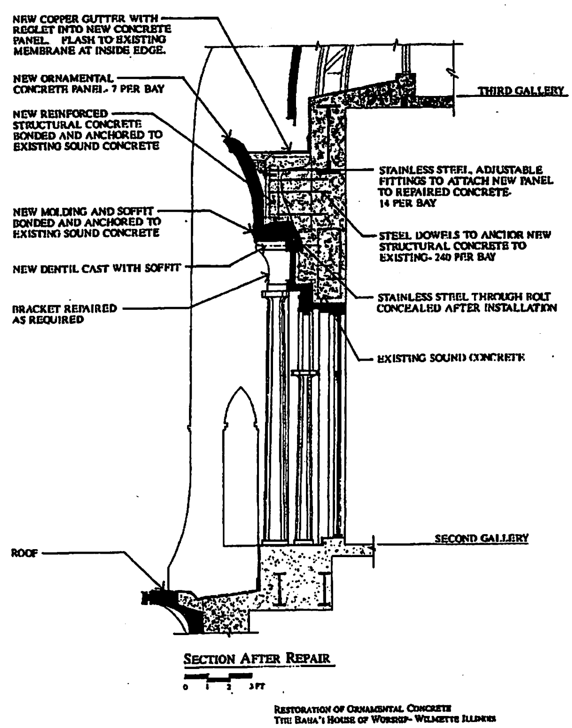
extended 1 m deep. The laboratory results verified the craftsmen's hands-on feeling that sound material had been reached. In some places the petrographic examination also revealed cracks well below the apparently sound surface so the new anchors were extended beyond the cracks.

In each bay, 240 structural anchors were installed approximately 300 mm apart across the remaining *in situ* structural concrete. Epoxy coated steel reinforcing rods were added to follow the curving wooden forms of the structural concrete repair. The craftsmen prepared the existing substrate and then placed ready-mixed structural concrete into the forms. After the forms were removed the concrete cured for three weeks under a plastic wrap.

The crown had rotated outwards due to water freezing within the interface. This movement damaged the projecting ends of the architectural brackets below the soffit. A few fascia panels also suffered deterioration from cyclical freeze/thaw action. The brackets and fascia were patched in place, keeping as much of the historic concrete as possible. After carefully trimming away unsound material, stainless steel reinforcing was added. Flexible urethane molds fit into the remaining ornamental surface to create a smooth transition between the repair and the original concrete. Retarder on the mold exposed the aggregate. The technique created a seamless repair.

Precast panels

To replicate the architectural concrete in the 9 m long

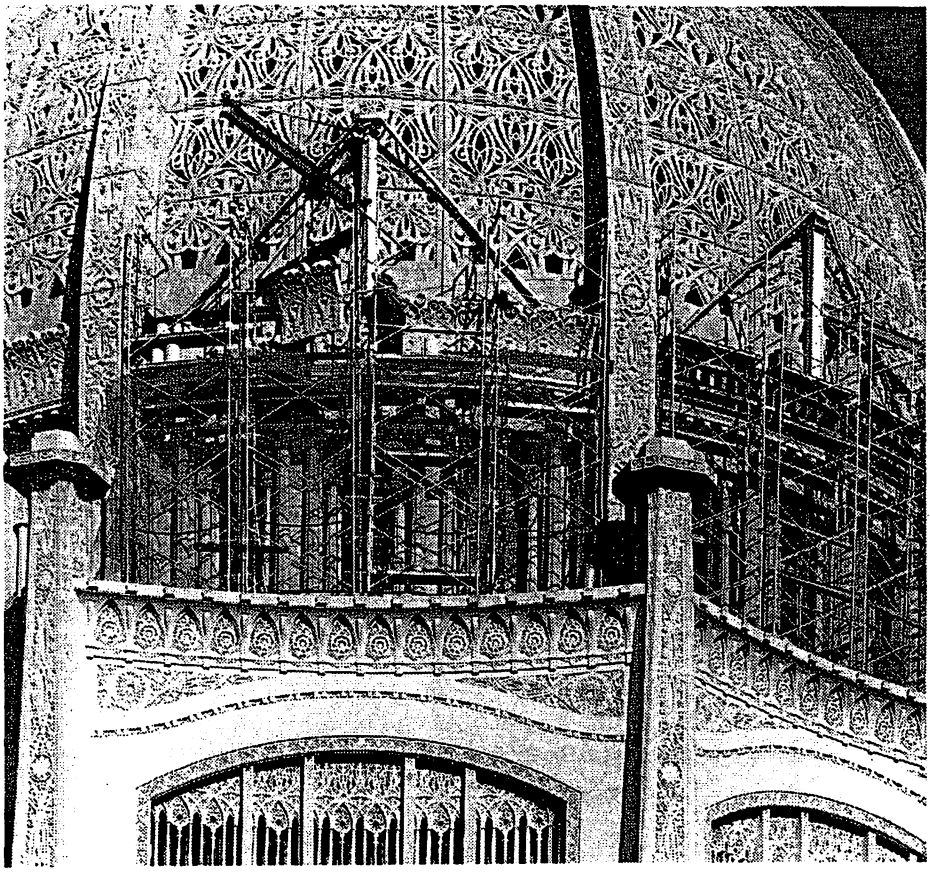


The ornamental concrete at the Bahá'í Temple after repair.

soffit and dentil section, white quartz concrete was cast-in-place using flexible molds carefully fit between the original architectural brackets and fascia panels that remained. The inside surface of the molds was coated with a retarder so that the quartz aggregate could be exposed the next day when the forms were stripped. White quartz concrete was also used for cast-in-place repairs of cracks and freeze/thaw deterioration in the flat architectural panels of the clerestory.

Precast architectural concrete panels were selected to replace the cast-in-place ornamental face of the cornice. By using precast panels the repair could maintain the highest consistency in materials, use an optimum curing environment, provide a free draining internal weep system in the crown, and more easily

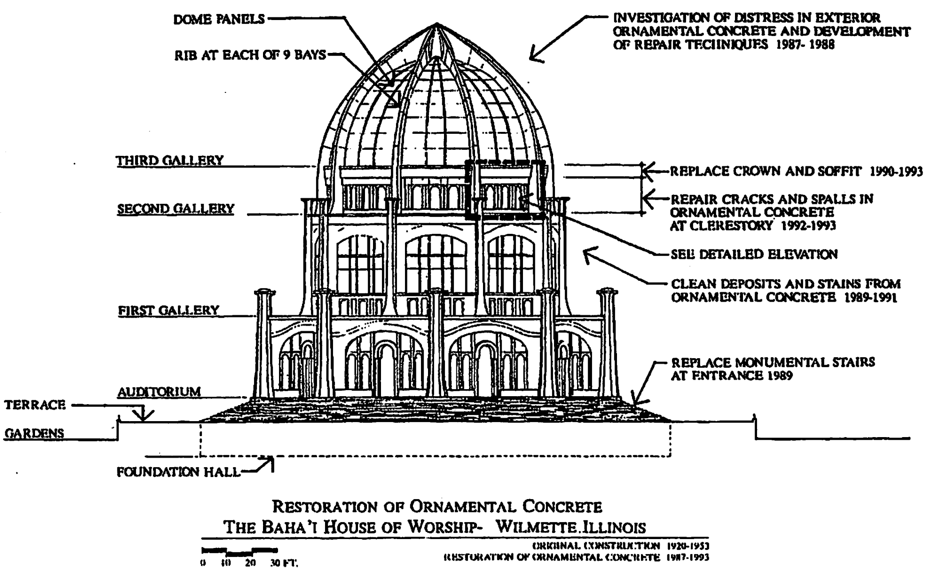
Restoration works in progress. Photo: S. Corrie.



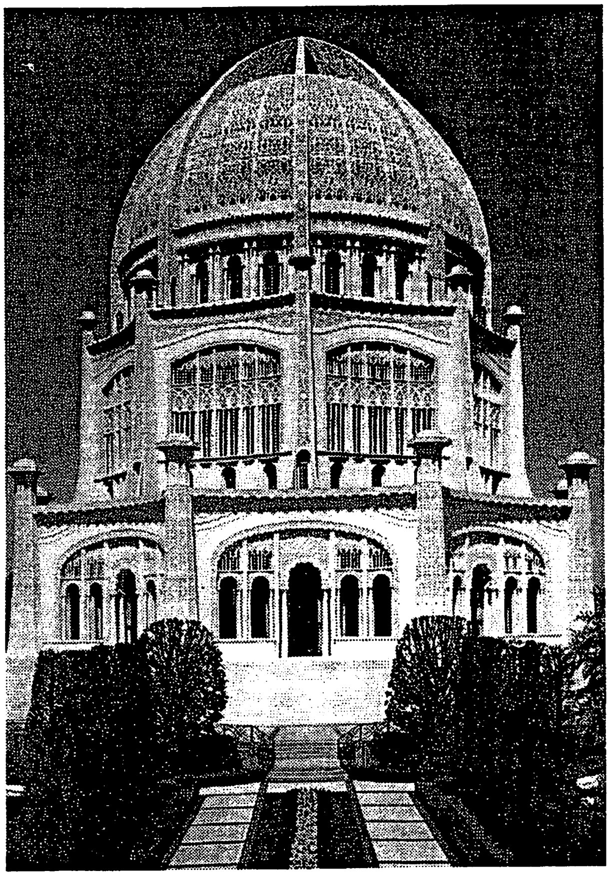
allow for replacement of architectural panels if necessary in the future. Although a cast-in-place repair of the ornamental concrete face would have been simpler to carry out, precast panels offered flexibility in scheduling production, minimized the effects of inclement weather, and reduced material handling high on the building.

The craftsmen produced the precast panels within the Temple's shop with multi-part fiberglass molds. A retarder on the molds let the crew expose the quartz aggregate the next day. The panels were cured before lifting them up to their final position and attaching them to the structural concrete with stainless steel angles and expansion anchors. For the one inaccessible corner of each panel, a concealed, through-panel anchor was invented. The panels were set with 10 mm wide, open joints on the sides and the bottom to provide clear weeping of the cavity behind the panels.

The back of the precast panels included a reglet for tight termination of the new copper lining in the gutter section. Drains were added and the bottom pitched in



Overview of the temple, showing the restoration projects between 1987 and 1993.



Overall view of the temple. Photo: W. Lembke.

every bay of the 95 m long gutter to further improve on the original system.

Future maintenance

The Bahá'í House of Worship always remained open during the seven year project. Having doors on every side of the Temple helped, but a good logistics and staging plan was key. Customized hoisting and access systems provided safety for the hundreds of thousands of visitors to the Temple, efficiency for construction, and protection for the existing fabric of the building. The equipment was designed and built with future maintenance of the Temple in mind. All anchors into the building are stainless steel, recessed and hidden below the surface while remaining permanently available. Equipment is stored at the House of Worship in crates with complete documentation and operating manuals.

From the service driveway and Temple workshops on the ground, a large stationary trolley hoist lifted materials up to the first story roof. Roof platforms permitted the movement of materials around the building on carts to the bay under construction. Small aluminum cranes mounted on the dome then lifted equipment and material between the first roof and the gutter. Curving scaffolding set on the highest roof had adjustable outriggers to give the craftsmen and engineers incremental access to the work. As the crew completed a section they relocated the cranes and scaffolding, leapfrogging equipment around the dome. Another significant part of the architectural concrete restoration consisted of cleaning the exterior and interior surfaces of the House of Worship. Decades of Midwestern climate and urban pollution had darkly weathered the once brilliant ornamentation. The exposed white and crystal clear quartz aggregate lay veiled behind a greasy film with dust, lichen, algae, and calciumsulfate crusts. A three year program of conservation quality cleaning safely removed the deposits without damaging the architectural concrete.

Long term perspective

Early Studios worked for seventeen years creating the beautifully sculpted architectural concrete details on the House of Worship. The Bahá'í National Archives has the architect's full size sketches of the ornamentation and many shop drawings from Early Studios. Yet, the only three dimensional record of the architectural concrete was the Temple itself. So, as an element of the restoration project, a photogrammetric survey was performed so that any point on the surface of the architectural concrete can now be located in three dimensions within 1 mm. If ornamentation needs to be replaced in the centuries ahead, this data could be compiled in a computer-aided design system. Individual architectural components could be defined and a computer-controlled milling machine could create an accurate model for future mold makers.

The restoration of the Bahá'í House of Worship was based on a long term perspective, unified teamwork, and a dedication to excellence. The historic work of Early Studios was respected while developing repair solutions offering economy together with the highest quality. The original architectural concrete has been faithfully reproduced in the finest artistic manner while using advanced technology and refined materials to extend its life far into the future.

Robert F. Armbruster served as director for the House of Worship restoration, for the National Spiritual Assembly of the Bahá'ís of the United States. A licensed professional engineer, he is a consultant from Glencoe, Illinois. Over the last 20 years he has successfully provided project management, design and engineering for a wide range of projects - from Art Deco skyscrapers to New England inns, from shrines in the Holy Land to a home by Tadao Ando.