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Journal

Caring for Glazed Architectural Terra Cotta

Arthur L. Sanders, AIA and Kara L. Shypula, Assoc. AIA

One of the most prevalent materials found on historic buildings, glazed architectural terra cotta was popularized in the late nineteenth century as a versatile, lightweight, economical, and adaptable alternative to stone. Through the 1930s, the sculptural properties of terra cotta gave rise to diverse architectural styles, including the Chicago School, High Rise, and Beaux Arts styles.

Often finished in imitation of stone, terra cotta can be difficult to recognize and may be mistaken for cast stone, concrete, stone, or brick.

Weighing roughly one-tenth as much as stone, architectural terra cotta is composed of kiln-baked clay called *bisque*—a mixture of clay, previously fired clay products (or *grog*), and water—which is finished with a protective glaze. Terra cotta can be molded and fired at high temperatures to a hardness and compactness comparable to that of brick. Readily shaped into sculptural forms, terra cotta offered designers an extensive color palette and range of textures at a much lower cost than that of quarried stone.

After the 1871 Chicago fire, new building codes prompted specification of terra cotta as a lightweight, fire-resistant structural element in floor framing systems. Hollow structural terra cotta blocks were incorporated into fireproof construction in floors, walls, and ceilings. The 1930s saw the introduction of ceramic terra cotta veneer, in which terra cotta was cast as ceramic tile, attached to a grid of metal ties, and anchored to the building as cladding.

Glazed architectural terra cotta is composed of hollow, hand-cast units, and adorns a number of noteworthy turn-of-the-century buildings, including the Woolworth Building in New York and the Wrigley Building in Chicago. As styles changed over time and production costs increased, terra cotta fell into disuse. In the late 1800s, there were over 100 terra cotta manufacturers in the United States; fewer than a dozen remain. The scarcity of qualified manufacturers and skilled craftspeople can present challenges to the ongoing maintenance and restoration of historic terra cotta.

When properly installed and maintained, terra cotta is a durable, long-lasting material. Most significant

Arthur L. Sanders, AIA, Senior Vice President and Director of Architecture, has over thirty years' experience in the restoration of historic facade systems. Project Coordinator Kara L. Shypula, Assoc. AIA, provides investigation, document preparation, and construction administration services for building envelope projects.

problems are due to inappropriate repairs, lack of maintenance, or both. By following good preservation practices, with attention to detail and workmanship on par with the original design and craftsmanship, building owners and design professionals can achieve lasting restoration solutions to terra cotta deterioration.

Fabrication and Construction

Relatively inexpensive and highly adaptable, terra cotta was often used for ornamental detailing, and many historic buildings feature intricate sculptural terra cotta. Units are cast as hollow blocks, open at the back, with internal compartments, or *webbing*, that augment strength and loadbearing capacity without much added weight. For each type of unit, models are prepared, sized to accommodate shrinkage from drying and firing. A mold is then made from the model, and the clay is pressed against the inside of the mold. Alternatively, terra cotta may be extruded or ram-pressed.

Once the mold is removed, the unit is finished by hand and allowed to dry. The outer face is sprayed or brushed with glaze, typically a slip glaze / clay wash or an aqueous solution of metal salts. Not only does the glaze add color and finish effects, it creates a relatively impervious surface that protects the terra cotta from moisture penetration. Historic glazes tended to be highly fade-resistant and durable. Once the glaze has been applied, the unit is fired in a kiln.

Finished terra cotta units were typically installed with masonry backup and supported by steel lintels and angles. In early applications, bricks and mortar in the terra cotta cavities were sometimes used to provide a connection with the masonry wall behind. After the turn-of-the-century, terra cotta construction typically employed metal anchors or wires set into the masonry backup and placed into preformed holes or slots in the terra cotta units.

Causes of Deterioration

Exposed and free-standing terra cotta detailing, such as balusters and parapets, tends to deteriorate more quickly than other facade elements. Where anchoring is extensive and complex, deterioration and failure likewise tend to be more pronounced. Deterioration to terra cotta used as load-bearing masonry tends to be less severe, owing to its simple or limited anchoring system, which presents fewer opportunities for corrosion-induced cracking and failure.

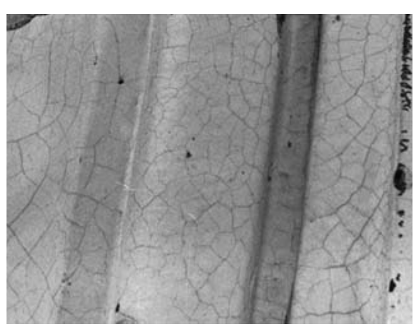
For most architectural terra cotta, deterioration may be traced to some combination of four basic factors: moisture infiltration, the resultant corrosion of embedded steel, structural and thermal movement, and the ill effects of improper repairs.

Moisture Infiltration

Water that penetrates between the clay bisque and finish glaze tends to migrate through the porous clay, leading to disintegration of the terra cotta. One source of water entry might be delamination of the finish glaze, which can occur when the thermal coefficient of expansion between the clay and the glaze don't match. Alternatively, the original design may have supposed exaggerated waterproofing properties of the finish glaze, and systems for water management, such as flashings, weep holes, and drip edges, were never incorporated.

Cyclic wetting/drying and freezing/thawing can lead to glaze deterioration, cracks and spalls in the body of the terra cotta, and fracturing and displacement of the units. *Crazing*, the formation of small random cracks in the glaze, occurs when the terra cotta unit absorbs moisture from the air and expands over many years. When new terra cotta is removed from the kiln, firing has shrunk it to its smallest size; over time, the porous clay grows, and the glaze goes into tension. Once the strength of the glaze has been exceeded, it cracks and shatters, increasing the water absorption of the terra cotta unit and exacerbating water infiltration in a self-perpetuating cycle.

Failed prior repair effort.



Crazed glazing.

Crack and spall caused by corroded steel.

When water enters the wall system through poor detailing, insufficient maintenance, rising damp, a leaking roof, or other sources, the impervious glaze may impede moisture migration and trap water inside the terra cotta unit. As temperature fluctuations increase pressure, sections of glazing or of the terra cotta itself may break off or *spall*. Glaze spalling tends to begin as blistering, when trapped water migrates to the surface and builds up pressure behind the glaze, eventually forcing pieces off the face of the unit. Glaze spalling may also be caused by corrosion of internal metal anchors.

When the terra cotta itself breaks apart or spalls, the result is a loss of visual integrity. With the porous underbody and anchoring exposed to the elements, the potential for water entry and further destructive effects increases.

Corrosion of Embedded Steel

As water penetrates, it comes in contact with embedded steel anchors and reinforcement. In historic applications, steel was often untreated, making it particularly susceptible to corrosion. As it corrodes, the steel expands, exerting pressure on the surrounding terra cotta and causing cracking and displacement. Embedded steel corrosion may be caused by unmaintained roof drainage systems, which admit water into the cladding assembly.

What makes embedded steel corrosion challenging to treat is that it tends to be difficult to diagnose unless it is severe. By the time symptoms are visible at the surface, corrosion is likely already advanced. Initial outward signs of metal anchoring deterioration might include staining and spalling. Total anchoring failure can result in loose terra cotta units, which are in danger of falling from the building.

Structural and Thermal Movement

Large cracks running through multiple units or stories usually indicate problems with embedded structural elements. Rehabilitation often requires removal of pieces to examine and treat defects, such as corroded steel columns.

Most high-rise buildings from the early 1900s had little or no provisions for movement, so unaccommodated thermal expansion and contraction, along with building-frame shortening under load, placed sufficient strain on building materials to cause displacement and cracking. Without proper expansion joints, buildings create their own, in the form of long cracks that admit significant water infiltration and invite further problems.

Improper Repairs

Many repairs fail prematurely because they do not address the root cause of distress or failure. Often, repair materials are not durable and are incompatible with the existing terra cotta, creating a poor visual match and a short-term fix, at best. Where repairs fail, they tend to make deterioration worse.

Poor detailing, including failure to properly anchor the patch to the backup, leads to failure of not only the repair area, but also the surrounding terra cotta. For example, replacement brick and cement stucco are neither watertight nor flexible enough to accommodate movement, so they tend to pull free or crack and spall. Surface-applied sealants are likewise not watertight, and bituminous patches are ineffective and aesthetically unsuited to terra cotta repair. In an effort to keep out water, non-breathable coatings are sometimes applied; these have the effect of trapping water inside the terra cotta, particularly if the source of water entry has not been addressed.

The misuse of sealant in place of mortar for joint repairs serves to trap water within the terra cotta, leading to corrosion of embedded steel and cracking and spalling of terra cotta. Unlike impervious sealants, mortar is porous and allows moisture to escape.

Alterations and additions to the building, such as signs, screens, marquees, and bird proofing, may also cause damage, where anchoring involves boring holes or cutting into the glazed

Cracking at building corners.

Joint deterioration.

Blistering coating.

terra cotta. When the appurtenances deteriorate or are removed, the holes remain, admitting water infiltration.

Investigating Terra Cotta Conditions

Before a comprehensive investigation, it may be helpful to clean terra cotta, as dirt can conceal problems. A unit-by-unit visual inspection should be performed to note surface deterioration, including staining, crazing, cracking, and spalling. Where possible, a hands-on, close-up examination is best.

To identify hidden deterioration, *tapping* may be used, in which each unit is struck with a wooden mallet. To the experienced ear, an undamaged unit will give a pronounced ring, whereas deteriorated units produce a flat, hollow sound. While inexact, tapping provides a measure of the integrity of terra cotta without invasive testing.

Metal detection, by means of an oscilloscope, may be used to confirm the locations of anchors indicated on original drawings. A negative reading where an anchor would be expected may indicate that it is missing or deteriorated.

Together with visual inspection and non-invasive testing, *laboratory analysis* can provide a picture of terra cotta conditions and composition, in order to develop an appropriate program of repair. The evaluation might include glaze absorption, permeability, and adhesion, as well as terra cotta porosity.

Other non-destructive test methods include *infrared scanning,* which uses a thermal camera to measure heat, and *sonic testing / ultrasound,* which emits sound waves and reads the patterns that bounce back. Both methods compare the readings of intact terra cotta with those of damaged units to identify concealed conditions.

Restoration of spalled terra cotta decorative element.

Proper Maintenance and Repair

Before attempting to fix terra cotta damage, causes must be addressed. Eliminating sources of moisture infiltration is critical and may necessitate adding flashings to protect water entry surfaces. For structural problems, including long, vertical cracks at building corners, an engineer may need to evaluate the integrity of the embedded structure before repairs to terra cotta units are made.

Glazed terra cotta was designed to be cleaned cheaply and easily. Typically, all that is required is water, detergent, and a natural or nylon bristle brush for gentle scrubbing. Strong acid solutions may deteriorate mortar, release salts in the terra cotta, and cause efflorescence, and are best avoided. While generally not necessary, some proprietary commercial solutions may be suitable for use on terra cotta; check manufacturers' recommendations. Avoid abrasive cleaning, such as sandblasting, as well as high-pressure water or metal bristle brushes, all of which can damage glazing irreversibly.

Although persistent water infiltration may make a waterproof coating seem like a good idea, indiscriminate coating of the entire wall is generally inadvisable, as it may trap water and make matters worse. Serious crazing may be treated on a limited scale; however, most glaze crazing does not substantially increase the flow of water into the wall. Unless the source of moisture infiltration is addressed, applying an impervious coating will only serve to prevent outward migration of water from within the assembly.

Maintaining mortar joints is very important to the lifespan of the terra cotta. Periodic repointing prevents water entry and inhibits deterioration. It's important to use a mortar with a compressive strength that is lower than that of the adjacent terra cotta, since a hard mortar may prevent the outward migration of water and may cause point loading. Never repoint with sealant, as it impedes moisture movement. Use sealant selectively, such as at joints in horizontal surfaces of copings and sills.

For spalled glazing, coat or seal blistered areas to prevent water infiltration, using color-matched products. At lower stories where visual integrity is critical, the unit may need to be replaced. Patches tend to be aesthetically unappealing and don't bond well over the long term. Cementitious materials, especially, have a coefficient of expansion that differs from that of terra cotta. For major spalls, the only solution is to replace the unit. Partial repairs don't last, and may cause problems later.

As a stop-gap measure to prevent further water infiltration, structural cracks in units not slated for replacement may be sealed with a waterproof material that accommodates movement. For static cracks, butyl sealants or acrylic latex caulk may be recommended, while dynamic cracks are better sealed with polysulfide caulks or other proprietary products. Take care never to use these compounds for repointing; only mortar should be used in mortar joints.

Where the existing steel has corroded, it should be treated, repaired, or replaced, as appropriate. For new anchors, protected stainless steel should be used to prevent future corrosion.

Deteriorated, unstable, or visually incompatible previous repairs, including cementitious stucco, bituminous compounds, and brick infill, should be removed and replaced with appropriate, properly detailed repairs. Rehabilitation should address the root cause of distress, using materials that are compatible with the existing terra cotta, and which do not compromise the breathability and moisture balance of the assembly. In addition, maintaining materials adjoining the terra cotta, including flashing, capping, roofing, and sealant at doors and windows, is vital to averting deterioration.

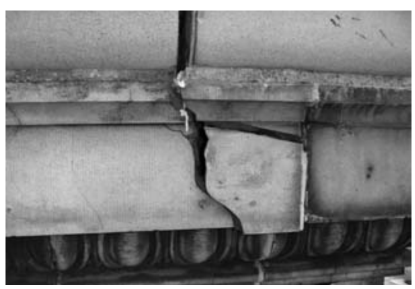
Temporary Stabilization

Where deterioration is so severe that pieces may fall from the building, temporary stabilization or replacement may be necessary to protect public safety. Particularly in urban areas or locations with high seismic activity, code compliance—and civic responsibility—dictate the immediate securing of identified hazards. Until a permanent solution can be implemented, nylon netting and metal strapping are commonly used to secure unstable pieces.

Where hazardous deterioration necessitates removal of units, leaving open gaps can increase the structural load on the remaining pieces and provide an avenue for water infiltration. When fabrication time, budget considerations, or seasonal factors delay restoration, temporary replacement can prevent further deterioration until the long-term repair is completed.

In-kind Replacement

Since glazed architectural terra cotta tends to be a complex, interlocking system, it may be difficult or even impossible to remove damaged units without destroying them. If a terra cotta unit is very loose or severely deteriorated, it may be necessary to replace it, rather than salvage and restore it. It's best to completely remove all of the deteriorated original material, as leaving half-units is not likely to yield a satisfactory repair.



Untreated deterioration can result in hazardous conditions.

Until permenant repairs are made, netting may be used to secure unstable terra cotta.

During production of new terra cotta units, meticulous design, specification, and quality control are imperative. Both structural and visual compatibility are major considerations, and specifications must account for factors that affect strength and durability. Key considerations include:

- Compressive strength
- Absorption (saturation coefficient / cyclic freezing testing)
- Glazing compatibility with the terra cotta and resistance to crazing
- Uniform joint widths and unit dimensions
- Tolerances for face dimensions and warping/chipping of the finished face
- Surface color/texture/shape/size/profile matched to existing units
- Finish defects/imperfections
- Low coefficient of moisture expansion (for new units set into existing terra cotta)

Given the variegation, intricate textures, and sculptural forms of historic terra cotta, most replacement pieces must be custom cast. These handcrafted units are expensive, and they have lengthy delivery times, on the order of eight to ten weeks. Machine-made, standardized terra cotta units may be available for some pieces, such as plain ashlar blocks, and provide a faster, more economical solution. While more uniform than hand-made terra cotta, these factory-produced units tend to be less durable and less dense, having glazing that is thinner and more brittle, with color less rich and varied than its historic counterparts.

For both machine- and hand-fabricated terra cotta, it's important to

Working with Landmarks Agencies

For state or local landmarks or buildings listed as part of a historic district, it may be necessary to submit a permit application prior to undertaking terra cotta restoration. Permits are typically not required for routine maintenance, such as caulking or removing graffiti. For most restoration work, including repairs, repointing, resurfacing, replacement, and cleaning, a permit is usually compulsory.

Landmarks agencies typically require documentation that the restoration program is based on evidence of original conditions and will not alter the historic fabric. For terra cotta replacement, the design professional may need to document deterioration and show that proposed methods and materials replicate the original texture, color, dimensions, and details, and that they are consistent with accepted preservation practice. Substitute materials are typically approved only for limited areas.

For specific guidelines, refer to the local landmarks authority or historic preservation commission. ■

obtain material samples and quality control units from each firing, to test compressive strength and absorption characteristics and to confirm the properties of special glazes. To facilitate correct installation of replacement pieces, a unit numbering system should be used, both in shop drawings and on the units themselves. Prior to installation, the terra cotta pieces should be laid out in configuration, to confirm dimensions and colors. Where possible, replacement units should be anchored similarly to the originals.

Replacement with Substitute Materials

While in-kind replacement is always preferable from a historic preservation standpoint, there are other viable options that may be appropriate where new terra cotta is not feasible.

Stone is durable and may be the best match for terra cotta that was originally cast and glazed to imitate natural stone. However, it weighs significantly more than terra cotta, and the cost may be just as high, especially where ornately detailed carving is involved.

Precast concrete is cost-effective, offers rapid production times, and can usually replicate original detailing. When cast hollow with lightweight aggregate, its weight is comparable to that of terra cotta, and it typically produces good results in color matching. For visual compatibility and waterproofing, a clear masonry coating should be applied to the weather face. On the downside, precast concrete may not be as long-lasting as is terra cotta.

Glass-fiber-reinforced concrete (GFRC) is a precast product composed of Portland cement-based composite with alkali-resistant glass fibers randomly dispersed throughout to add flexural, tensile, and impact strength. Strong and lightweight, GFRC may be formed into complex shapes and offers a range of colors, textures, and surface finishes. While similar to terra cotta in terms of weight and wall thickness, GFRC typically has no structural capacity; some varieties incorporate different glass content and admixtures to gain some structural strength. GFRC is perhaps most appealing for its substantial cost savings over terra cotta, typically upwards of 50 percent. Be aware, however, that it may be difficult to match the finish of existing terra cotta.

Glass-fiber-reinforced plastic (GFRP, FRP, or GRP) or fiberglass can be cast from intact pieces of original terra cotta and has limited use as a replacement material for elements with fine detail, provided the size and scale are not too large. Originating in the boatbuilding industry, GFRP is lighter than terra cotta and may be a viable option for buildings in areas of high seismic activity, or where existing structural supports proved inadequate. Surface gelcoats offer a wide range of colors and patterns; however, ultraviolet light degradation is a consideration, as is fire resistance. Several blends of resin, gelcoat, and glass fibers may need to be tested in order to obtain the requisite strength and finish properties.

Micro-cotta, a polymer-based composite concrete, is a proprietary product developed for terra cotta rehabilitation. Lightweight and capable of reproducing detail with sharp definition, Micro-cotta uses a finer aggregate than does cement-based concrete and has a lower absorption rate. However, there is some evidence that early formulations tended to fade and yellow in sunlight, and may have been susceptible to excessive crazing.

On the whole, substitute materials tend to offer faster manufacture and

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representative projects

Terra Cotta Restoration

To address deterioration in historic glazed architectural terra cotta, Hoffmann Architects' design professionals begin with close-up visual inspection, evaluating terra cotta units for cracks, spalls, crazing, displacement, joint failure, and other signs of distress.

Based on observed conditions, our architects and engineers develop a program of rehabilitation tailored to the needs of the structure and situation, designed to remedy concealed conditions while taking into account budgetary, logistical, aesthetic, and durability considerations.

Broad Exchange Building, 25 Broad Street in New York, New York. *Landmark Terra Cotta Facade Restoration.*

Chauncy House in Boston, Massachusetts. *Facade Investigation & Terra Cotta Repair Design.*

Hoffmann Architects has provided architectural and engineering services for terra cotta rehabilitation at a number of structures, including:

State University of New York Plaza Parking Garage
Albany, New York
Terra Cotta Facade Rehabilitation

Kings County Hospital Center
New York, New York
Historic Terra Cotta Restoration

Carnegie Mellon University
Pittsburgh, Pennsylvania
Building Envelope Restoration Master Plan for Terra Cotta Facades

Taft Apartments
New Haven, Connecticut
Historic Terra Cotta Cornice and Facade Restoration

Barnard College Milbank Hall
New York, New York
Historic Terra Cotta Cornice Stabilization

Four New York Plaza
New York, New York
Terra Cotta Coping Replacement

Congregational Church of Naugatuck
Naugatuck, Connecticut
Landmark Terra Cotta and Brick Masonry Steeple Reconstruction

The Bridal Building 1385 Broadway
New York, New York
Terra Cotta Repair Consultation

Hotel Wales in New York, New York. *Landmark Terra Cotta Repair and Replacement.*

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cost savings over replacement terra cotta. However, even closely matched alternatives may have a slightly different appearance than terra cotta; some are glossier, and concrete products tend to darken when wet. Unlike decorative elements or cladding, structural terra cotta may be difficult to substitute, as an entirely redesigned structural system may then be required.

Toward a Durable Solution

Many architecturally significant buildings from the late 19th and early 20th centuries in the U.S. incorporate terra cotta facade elements, and as these buildings age, they demand ongoing care and maintenance. Restoration of glazed architectural terra cotta should employ the same level of care and attention that went into the design, fabrication, and installation of the original historic material.

When cared for diligently, terra cotta is a resilient and relatively low-maintenance material. By repairing minor cracks, spalls, and other signs of deterioration promptly, building owners and managers can break the cycle of deterioration before damage becomes severe and irreversible. When coordinated among owner, design professional, fabricator, and contractor, terra cotta rehabilitation can revitalize the distinctive facades of historic terra cotta structures, while providing durable repair solutions that stand the test of time. ■

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2321 Whitney Avenue
Hamden, CT 06518
203-239-6660

1040 Avenue of the Americas, Ste. 14C
New York, NY 10018
212-789-9915

2611 Jefferson Davis Highway, Ste. 200
Arlington, VA 22202
703-253-9800

www.hoffarch.com

Editor/Production: Alison Hoffmann