33 PRESERVATION BRIEFS

The Preservation and Repair of Historic Stained and Leaded Glass

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"Stained glass" can mean colored, painted or enameled glass, or glass tinted with true glass "stains." In this Brief the term refers to both colored and painted glass. "Leaded glass" refers generically to all glass assemblies held in place by lead, copper, or zinc cames. Because the construction, protection, and repair techniques of leaded glass units are similar, whether the glass itself is colored or clear, "stained glass" and "leaded glass" are used interchangeably throughout the text.

Glass is a highly versatile medium. In its molten state, it can be spun, blown, rolled, cast in any shape, and given any color. Once cooled, it can be polished, beveled, chipped, etched, engraved, or painted. Of all the decorative effects possible with glass, however, none is more impressive than "stained glass." Since the days of ancient Rome, stained glass in windows and other building elements has shaped and colored light in infinite ways.

Stained and leaded glass can be found throughout America in a dazzling variety of colors, patterns, and textures (Fig. 1). It appears in windows, doors, ceilings, fanlights, sidelights, light fixtures, and other glazed features found in historic buildings (Fig. 2). It appears in all building types and architectural styles—embellishing the light in a great cathedral, or adding a touch of decoration to the smallest row house or bungalow. A number of notable churches, large mansions, civic buildings, and other prominent buildings boast windows or ceilings by LaFarge, Tiffany, Connick, or one of many other, lesser-known, American masters, but stained or leaded glass also appears as a prominent feature in great numbers of modest houses built between the Civil War and the Great Depression.

This Brief gives a short history of stained and leaded glass in America. It also surveys basic preservation and documentation issues facing owners of buildings with leaded glass. It addresses common causes of deterioration and presents repair, restoration, and protection options. It does not offer detailed advice on specific work treatments. Glass is one of the most durable, yet fragile building materials. While stained glass windows can last for centuries, as the great cathedrals of Europe attest, they can be instantly destroyed by vandals or by careless workmen. Extreme care must therefore be exercised, even in the most minor work. For this reason, virtually all repair or restoration work undertaken on stained and leaded glass must be done by professionals, whether the feature is a magnificent stained glass window or a clear, leaded glass storefront transom. Before undertaking any repair work, building owners or project managers should screen studios carefully, check references, inspect other projects, and require duplicate documentation of any work so that full records can be maintained. Consultants should be employed on major projects.

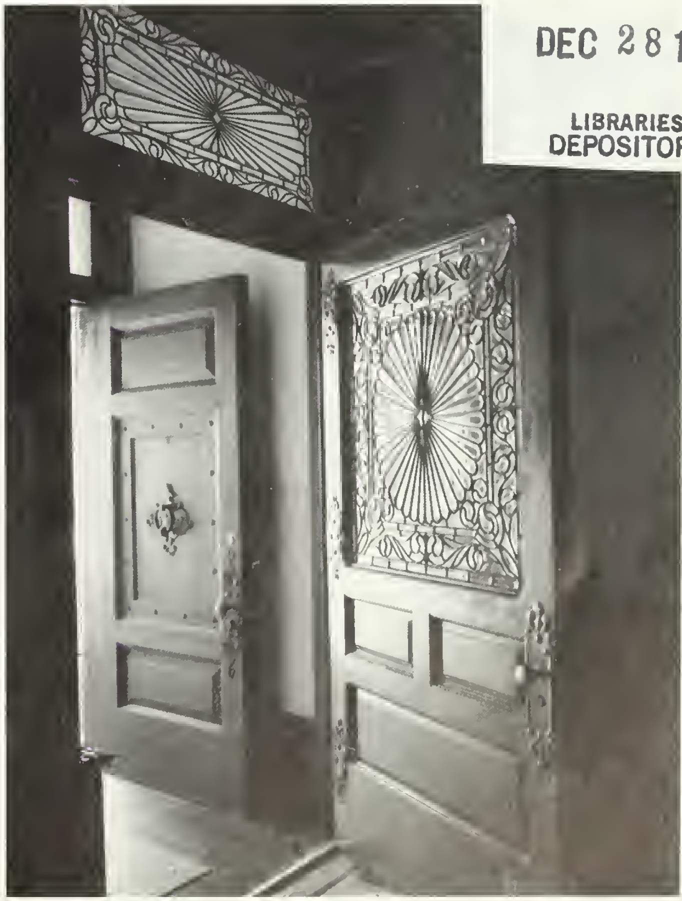

Figure 1. The door and transom of the Edward Hazlett House, Wheeling, West Virginia (1891-1892), suggest the richness of 19th century leaded glass. Photo: Jack E. Boucher, HABS.

Historical Background

Glassblowers were among the founders of Jamestown in 1607, and early glass manufacturing was also attempted in 17th-century Boston and Philadelphia. Dutch colonists in the New Netherlands enjoyed painted oval or circular medallions that bore the family's coat of arms or illustrated Dutch proverbs. German colonists in the mid-Atlantic region also began early glass ventures. Despite the availability of good natural ingredients, each of these early American glassmakers eventually failed due to production and managerial difficulties. As a result, colonists imported most of their glass from England throughout the 17th and 18th centuries.[1]

Social values as well as high costs also restricted the use of stained and other ornamental glass. This was particularly true with regard to churches. The Puritans, who settled New England, rejected the religious imagery of the Church of England, and built simple, unadorned churches with clear glass windows. Consequently, not much glass remains from the colonial and early national periods. Less than 1% of the Nation's stained and leaded glass predates 1700. Considering the enormous loss of 17th-, 18th-, and early 19th-century buildings, *any* window glass surviving from these periods is very significant (Fig. 3). Every effort should be made to document and preserve it.

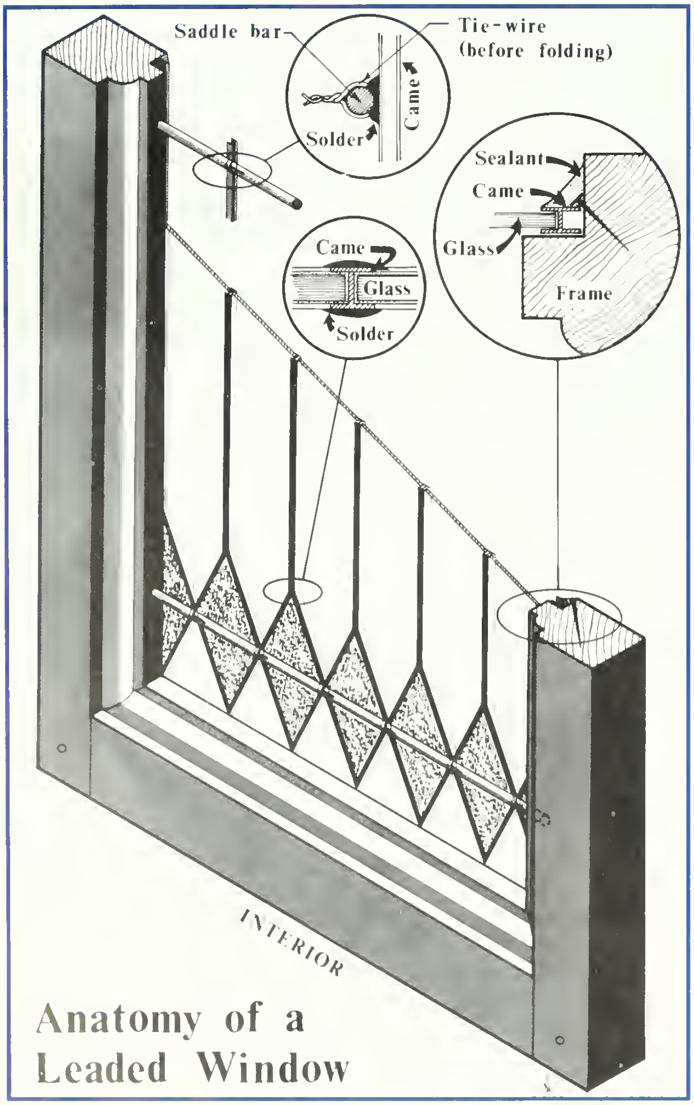

Figure 2. Components of a leaded glass window. Drawing: Neal A. Vogel.

Figure 3. The entrance to the Morris-Jumel Mansion, New York City, is one of the earliest surviving installations of leaded glass in the country. It features a leaded fanlight and sidelights of large clear roundels and small bulls-eyes of red and orange flashed glass from ca. 1810 . Photo: The American Institute of Architects Library and Archives, Washington, D.C.

Despite many failed starts, the War of 1812, and British competition, American glass production increased steadily throughout the 19th century. Stained glass was available on a very limited basis in America during the first quarter of the 19th century, but American stained glass did not really emerge in its own right until the 1840s.[2] The windows at St. Ann and the Holy Trinity Episcopal Church in Brooklyn, New York, made by John and William Jay Bolton between 1843 and 1848, are perhaps the most significant early American stained glass installation (Fig. 4). Other important early stained glass commissions were the glass ceilings produced by the J. & G. H. Gibson Company of Philadelphia for the House and Senate chambers of the United States Capitol in 1859.

America's glass industry boomed during the second half of the 19th century. (And although stained and leaded glass is found nationwide, the manufacturing was based in the Northeast and Midwest, where good natural ingredients for glass, and coal reserves for the kilns were available. Moreover, nearly all of the nationally renowned studios were based in major metropolitan areas of the central and northeastern states—near the manufacturers that supplied their raw materials.) In response to this growth, the industry formed self-regulating associations that established guidelines for business and production. In 1879 the Window Glass Association of America was established, and in 1903 The National Ornamental Glass Manufacturers' Association, precursor of the Stained Glass Association in America, was formed.

The 60 years from about 1870 to 1930 were the high point for stained glass in the U.S. In the early years, American stylistic demands reflected those current in Europe,

Figure 4. The windows at St. Ann and the Holy Trinity Episcopal Church, Brooklyn, New York, were made between 1843-1849 by John and William Jay Bolton. Photo: Leland A. Cook.

including various historic revivals, and aesthetic and geometric patterns. American patterns prevailed thereafter; they tended to be more vivid, brash, and bold (Fig. 5).

After the 1893 Columbia World's Exposition, the Art Nouveau Style became the rage for windows. Sinuous nymphs, leggy maidens, whiplashed curves, lilies, and brambles became standard subjects until World War I. Among the leading proponents of the Art Nouveau Style were glassmakers John LaFarge and Louis Comfort Tiffany. Both men experimented independently throughout the 1870s to develop opalescent glass, which LaFarge was first to incorporate into his windows. Tiffany became the better-known, due in part to his prolific output. He attracted world-class artists and innovative glassmakers to his studio, which produced over 25,000 windows. Today, "Tiffany" remains a household name. His favorite and most popular scenes were naturalistic images of flowers, colorful peacocks and cockatiels, and landscapes at sunrise and sunset (Fig. 6). LaFarge, while appreciated in his own day, gradually slid into relative obscurity, from which he has emerged in recent decades. Tiffany and LaFarge are the greatest names in American stained glass.

In dramatic contrast to the American Art Nouveau style was the Neo-Gothic movement that became so popular for church and university architecture across the country.

Figure 5. Stained glass is an exterior feature as well as an interior one. As part of any preservation project, stained glass should be photographed from the outside as well as the inside. The frame of this Aesthetic Movement window (circa 1880) needs repair. Photo: Neal A. Vogel.

Figure 6. A 1907 window typical of those produced by Tiffany Studios. Characteristics include the use of opalescent glass, intricate leading, copper foil, extensive etching, plating (i.e., several layers of glass), and a scene with perspective that simulates a painting. Hyde Park Union Church, Chicago. Photo: Diana Kincaid.

Charles J. Connick was a leading designer of medieval-style windows characteristic of the style (Fig. 7).

Advocates of the Prairie Style, of whom Frank Lloyd Wright is the best known, rejected Tiffany's naturalistic scenes *and* Connick's Gothic imitations. (Fig. 8). Wright's rectilinear organic abstractions developed simultaneously with the similar aesthetic of the various European Secessionists. The creation of this style was aided by the development of zinc and copper cames in 1893. These cames—much stiffer than lead—made it possible to carry out the linear designs of Prairie School windows with fewer support bars to interfere with the design. At first, these windows had only an elitist following, but they were soon widely accepted and proliferated during the early 20th century.

By 1900, stained and leaded glass was being mass-produced and was available to almost everyone. Leading home journals touted leaded glass windows for domestic use, and a nationwide building boom created an unprecedented demand for stained and leaded art glass windows, door panels, and transoms. Mail order catalogs from sash and blind companies appeared, some offering over 100 low-cost, mass produced designs (although the same catalogs assured buyers that their leaded glass was "made to order") (Fig. 9).

The fading popularity of the ornate Victorian styles, combined with inferior materials used for mass production, and America's entry into World War I (which reduced the availability of lead), essentially eliminated the production of quality leaded glass.[3] The last mail order catalogs featuring stained glass were published in the mid-1920s, and tastes changed to the point that the 1926 *House Beautiful Building Annual* declared: "the crude stained glass windows in many of the Mansard-roof mansions of the 'eighties [1880s] prove how dreadful glass can be when wrongly used." The great age of stained glass was over. However, leaded glass panels have survived in uncounted numbers throughout the country, and are now once again appreciated as major features of historic buildings.

Dating and Documenting Historic Leaded Glass

Before deciding on any treatment for historic leaded glass, every effort should be made to understand—and to record—its history and composition. Documentation is strongly encouraged for significant windows and other elements. Assigning an accurate date, maker, and style to a stained glass window often requires extensive research and professional help. A documentation and recording project, however, is worth the effort and expense, as insurance against accidents, vandalism, fire and other disasters. The better the information available, the better the restoration can be. The following sources offer some guidelines for dating leaded windows.

Building Context. The history of the building can provide ready clues to the history of its leaded windows, doors, and

Figure 7. Charles J. Connick was another American master of stained glass. He worked in a modernized Neo-Gothic style. This window is from 1921. Photo: Diana Kincaid.

other elements. The construction date, and dates of major additions and alterations, should be ascertained. Later building campaigns may have been a time for reglazing. This is especially the case with churches and temples. They were often built with openings glazed with clear leaded glass. Stained glass was added later as finances allowed. Conversely, the windows may be earlier than the building. They may have been removed from one structure and installed in another. Bills, inventories, and other written documents often give clues to the date and composition of leaded glass. Religious congregations, fraternal lodges, and other organizations may have written histories that can aid a researcher.

Inscriptions and Signatures. Many studios and artists affixed signature plates to their work—often at the lower right hand corner. In the case of Tiffany windows, the signature evolved through several distinct phases, and helps date the piece within a few years: *Tiffany Glass Company* (1886-1892), *Tiffany Glass & Decorating Company* (with address, 1892-1902), *Tiffany Studios New York or Louis C. Tiffany* (post 1902). Tiffany Studios, like others, did not always sign pieces and the absence of an inscription cannot be used to rule out a particular studio or artist. Windows may feature dated plaques commemorating a donor. However, these do not always indicate the date of the window, since windows were often installed before a donor was found. Nevertheless, these features help establish a reasonable date range.

Composition and Other Stylistic Elements. These elements are more subjective, and call for a fairly broad knowledge of architecture and art history. Do the windows fit the general style of the building? The style of the window may point to a general stylistic period (e.g., Arts & Crafts, Art Nouveau, Prairie School). The imagery or iconography of the windows may also reveal their overall historical context and establish a general time period (Fig. 10).

Framing and Surround. Framing elements and the window surround can reveal information central to dating the window. Do moldings match other interior trim? Has the opening been altered? Is the window set in an iron frame (post-1850s), a steel frame (generally post-World War I), a cast stone frame (seen as early as the 1880s, but popular

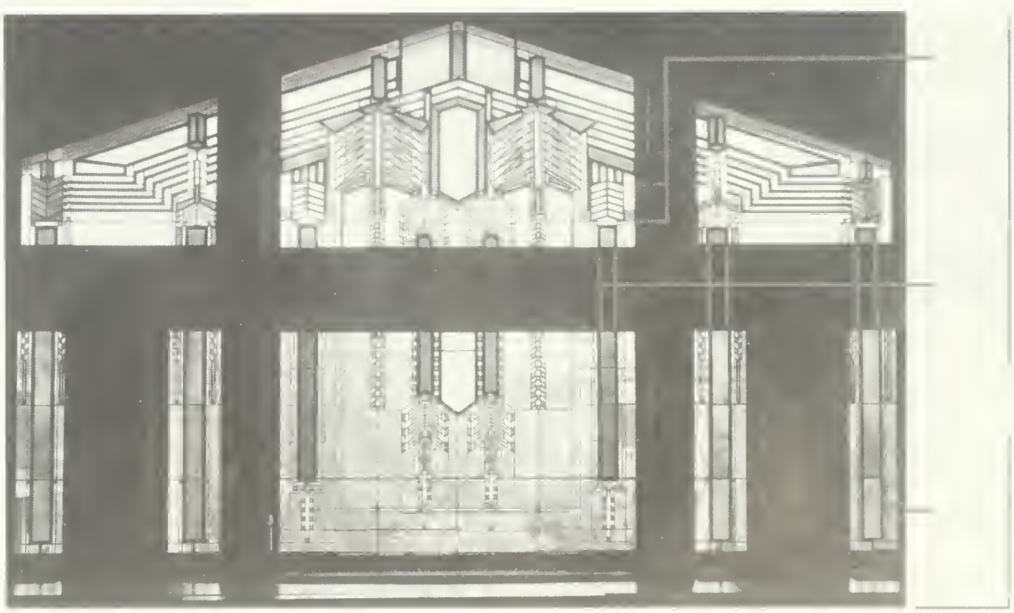

Figure 8. The master bedroom window at Frank Lloyd Wright's Dana House in Springfield, Illinois (1903), reflects the architect's philosophy of providing ornamentation without interfering with the view. Details show profiles of zinc cames. Photo: Leland A. Cook; Courtesy, Chicago Metallic Corporation.

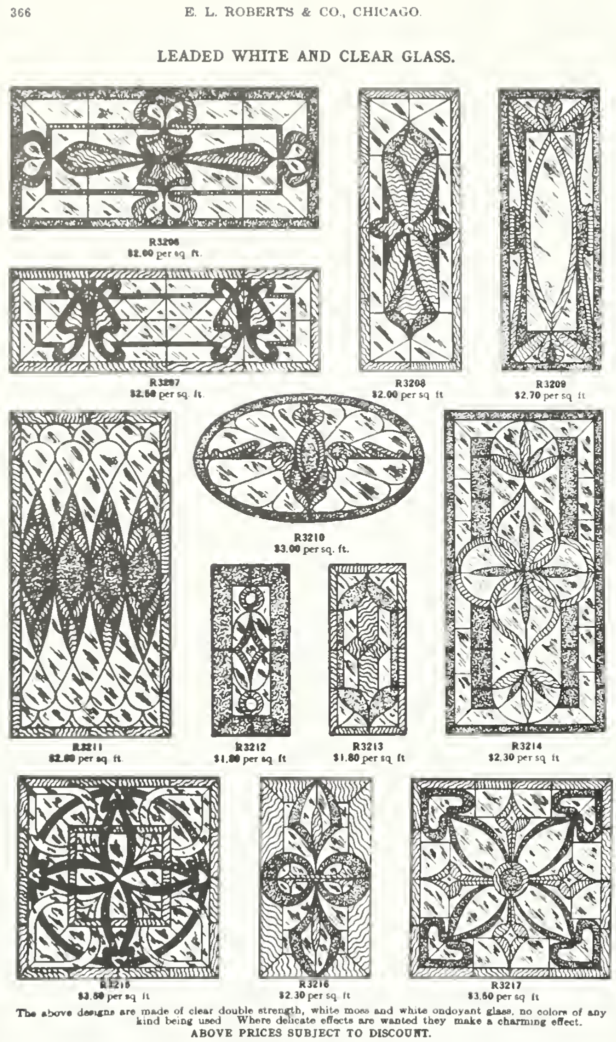

Figure 9. A typical mail-order catalog page of art glass windows available in 1903 from the E. L. Roberts Company, Chicago.

after 1900), or a terra cotta frame (generally after 1900)?

Reinforcement and Leading Details. Does the window or other element have round bars or flat bars? Flat bars began to appear about 1890; round bars, used since the Middle Ages, remained in use until the 1920s, when flat bars supplanted them. Cames can also give dating clues. Zinc cames, for example, developed by a midwestern company in association with Frank Lloyd Wright, first appeared in 1893. In general, however, dating a window by the came alone is difficult. Over one hundred varieties of lead came were available in the early 20th century. Moreover, came was sometimes produced to look old. Henderson's Antique Leading from the 1920s was made "to resemble the old hand wrought lead" and also carried "easy-fix" clip-on Georgian-style ornaments.

Glass. The glass itself can help in dating a window. Opalescent glass, for instance, was patented by John LaFarge in 1880. Tiffany patented two variations on LaFarge's technique in the same year. (Opalescent glass is translucent, with variegated colors resulting from internally refracted light. It features milky colored streaks.) Pre-1880 glass is usually smooth translucent colored glass (painted or not); glass with bold, deep colors is typical of the 1880s and 1890s, along with jewels, drapery glass and rippled glass. But such flamboyance faded out with the rest of Victoriana

Figure 10. This image illustrates Thomas J. "Stonewall" Jackson and J.E.B. Stuart at the Second Battle of Manassas. The window comprises three of nine panels entitled "The Rise and Fall of the Confederacy" at Rhodes Hall in Atlanta. These windows were executed by Von Gerichten Art Glass Company of Columbus, Ohio, 1905 (installed). A.G. Rhodes reportedly returned one scene to the studio to be redone because the Yankees weren't running fast enough. Photo: Tommy Jones; Courtesy, Georgia Trust for Historic Preservation.

by about 1905. However, stained glass styles of the late 19th century continued to appear in ecclesiastical buildings after they passed from general fashion. Leaded beveled plate glass was popular in residential architecture after 1890, and was used profusely until the 1920s.

The level of documentation warranted depends upon the significance of the window, but it is very important to document repair and restoration projects before, during, and after project work. Photographs will normally suffice for most windows (see "Photographing Stained Glass Windows" on page 7). For highly significant windows (generally, those which were not mass produced), rubbings as well as written documentation are recommended. The leading patterns in such windows are complex, particularly in plated windows (which have several layers). Rubbings are therefore encouraged for each layer; they are invaluable if a disaster strikes and reconstruction is required. Annotated rubbings of the leadwork should be done with a wax stone on acid-free vellum.

To document windows properly, inscriptions should be recorded word for word, including misspellings, peculiarities in type style, and other details. Names and inscriptions in or on windows can indicate ethnic heritage, particularly in churches or civic structures where windows often reflect styles and themes from the congregation's or community's origins. Lastly, any conjectural information should be clearly noted as such.

Photographing Stained Glass Windows

Windows should be photographed with daylight color slide film and black & white film in both transmitted and reflected light. Significant windows should be recorded with a positive color film, such as Kodachrome, with a low ISO, since it is more stable, and images should be printed on Resin-Coated paper. Black & white images should be printed on fiber-based paper to be considered archival. Photographing stained glass from the interior is not difficult if a few basic pieces of equipment are used and if a few simple rules are observed. A strong tripod, shutter cable release, light meter, and camera with through-the-lens metering will make the job easier. The key is to photograph windows in even, moderate daylight with the interior dimmed (lights off and, if necessary, with the other windows covered). Although some stained glass is dazzling in sunlight, the camera lens and film react differently from the human eye, which can quickly equalize the high contrast of light and dark glass. Film cannot discriminate this intense contrast, and the result can be a washed-out exposure or "hot spots." A light meter should be used to average out variations within the window, with special consideration for the focal point or most important feature of the window, such as a face. Since there is no precise formula for obtaining a balanced exposure, shots should be bracketed. When photographing on sunny days, shoot away from the sun; shoot eastern windows in the afternoon, western windows in the morning, southern windows at either time, and northern windows at midday. The glass should also be photographed from the inside with reflected light from a flash (positioned away from the camera to provide a raking light and to avoid reflected "hot spots"). Although photographing with a flash will neutralize the transmitted light and black out the glass, interior photography is valuable because it reveals the location and condition of the cames, braces, tie-wires, and other elements. Shoot the windows as centered and straight on as possible to minimize distortion and to keep the window frames from blocking details. Windows should also be photographed from the outside if there is no protective glazing to interfere with the view. This is particularly important with opalescent glass, which was often meant to be read from the exterior as well. As a final note, to photograph glass consistently well, it is essential to limit the variables (by using the same film, camera, and lenses), and to record the camera settings, to compare with the developed pictures and to adjust accordingly next time.

Deterioration of Stained and Leaded Glass

Three elements of leaded glass units are prone to damage and deterioration: the glass itself; the decorative elements (mostly applied paint); and the structural system supporting the glass.

Glass Deterioration

Glass is virtually immune to natural deterioration. Most American glass is quite stable—due to changes in glass composition made in the mid-19th century, particularly the increased silica content and the use of soda lime instead of potash as a source of alkali. Rarely, however, glass impurities or poor processing can cause problems, such as minor *discoloration* or tiny internal fractures (particularly in opalescent glass). And all glass can be darkened by dirt; this can often be removed (see "Cleaning" on page 9). However, while glass does not normally deteriorate, it is susceptible to *scratching* or *etching* by abrasion or chemicals, and to *breakage*.

The greatest cause of breakage or fracture is physical impact. Leaded glass in doors, sidelights, and low windows is particularly susceptible to breakage from accidents or vandalism. When set in operable doors or windows, leaded glass can crack or weaken from excessive force, vibration, and eventually even from normal use. Cracks can also result from improperly set nails or points that hold the window in the frame, or more rarely, by structural movement within the building. Leaded glass that is improperly annealed can crack on its own from internal stress. (Annealing is the process by which the heated glass is slowly cooled; the process is akin to tempering metal.) Glass can also disintegrate from chemical instability or the intense heat of a fire. Finally, windows assembled with long, narrow, angular pieces of glass are inherently prone to cracking. Often the cause of the cracks can be determined by the path they travel: cracks from impact typically radiate straight from the source. Stress cracks caused by heat or improper annealing will travel an irregular path and change direction sharply.

Deterioration of Painted Glass

Painted glass, typically associated with pictorial scenes and figures found in church windows, often presents serious preservation challenges. If fired improperly, or if poor quality mixtures were used, painted glass is especially vulnerable to weathering and condensation. Some studios were notorious for poorly fired paints (particularly those working with opalescent glass), while others had outstanding reputations for durable painted glass. Paints can be applied cold on the glass or fused in a kiln. Since they are produced from ground glass, enamels do not "fade," as often suggested, but rather flake off in particles. Several steps in the painting process can produce fragile paint that is susceptible to flaking. If applied too thick, the paint may not fuse properly to the glass, leaving small bubbles on the surface. This condition, sometimes called "frying," can also result from poor paint mixtures or retouching. Paint failure is more commonly caused by under firing (i.e., baking the glass either at too low a temperature or for too little time). Unfortunately, in American stained glass, the enamels used to simulate flesh tones were typically generated from several layers that were fired at too low a temperature. This means the most difficult features to replicate—faces, hands and feet—are often the first to flake away (Fig. 11).

Structural Deterioration

The greatest and the most common threat to leaded glass is deterioration of the skeletal structure that holds the glass. The structure consists of frame members, and lead or zinc (and occasionally brass or copper) came that secures individual pieces of glass. Frame members include wood sash and muntins that decay, steel t-bars and "saddle bars" that corrode, and terra cotta or stone tracery that can fracture and spall (Fig. 12). When frames fail, leaded glass sags and cracks due to insufficient bracing; it may even fall out from wind pressure or vibration.

Wood sash are nearly always used for residential windows and are common in many institutional windows as well. Left

Figure 11. The face paint has failed substantially in the figure at the left. Ghost images of the feature are barely visible. Window (1903) by Edwin P. Sperry, glass by Tiffany Studios; "Old Main," (1891-1893) Illinois Institute of Technology, Chicago. Photo: Rolf Achilles.

Figure 12. These stained glass angels appear concerned over the cracked terra cotta frames of the rose window they grace. Photo: Neal A. Vogel.

unprotected, wood and glazing compounds decay over time from moisture and exposure to sunlight—with or without protective storm glazing—allowing glass to fall out.

Steel frames and saddle bars (braces) corrode when not maintained, which accelerates the deterioration of the glazing compound and loosens the glass. Moreover, operable steel ventilators and windows are designed to tight tolerances. Neglect can lead to problems. Eventually, they either fail to close snugly, or corrode completely shut. The leaded glass is then frequently reinstalled in aluminum window units, which require wider sections for equal strength and typically trim an inch or more off the glass border. Instead of relocating glass in aluminum frames, historic steel frames should be repaired. Often the corrosion is superficial; frames in this condition need prepping, painting with a good zinc-enriched paint, and realignment in the frame.

Masonry frames typically last a long time with few problems, but removing leaded glass panels set in hardened putty or mortar can be nearly impossible; as a last resort, glass borders may have to be sacrificed to remove the window.

Occasionally, leaded glass was designed or fabricated with inadequate bracing; this results in bulging or bowing panels; leaded panels should generally not exceed 14 linear feet (4.25 m) around the perimeter without support. More often, the placement of bracing is adequate, but the tie-wires that attach the leaded panels to the primary frame may be broken or disconnected at the solder joints.

Lead and zinc cames are the two most common assembly materials used in stained and other "leaded" glass. The strength and durability of the leaded panel assembly depends upon the type of came, the quality of the craftsmanship, and the glazing concept or design, as well as on the metallic composition of the cames, their cross-section strength, how well they are joined and soldered, and the leading pattern within each panel. Came is prone to natural deterioration from weathering and from thermal expansion and contraction, which causes metal fatigue.

The inherent strength of the assembly system is also related to the cross-section, profile and internal construction of the came (Fig. 13). Came can have a flat, rounded, or "colonial" profile, and aside from a few specialty and perimeter cames (U-channel), is based on a variation of the letter "H"and ranges from ⅛" (3.2mm) wide to 1½" (38mm) wide. The cross-section strength of came varies depending on the thickness of the heart and flanges. Occasionally, came with reinforced (double) hearts or a steel core was used for rigidity. Such came added strength at the expense of flexibility and was typically used for rectilinear designs, or for strategically placed reinforcement within a curvilinear design.

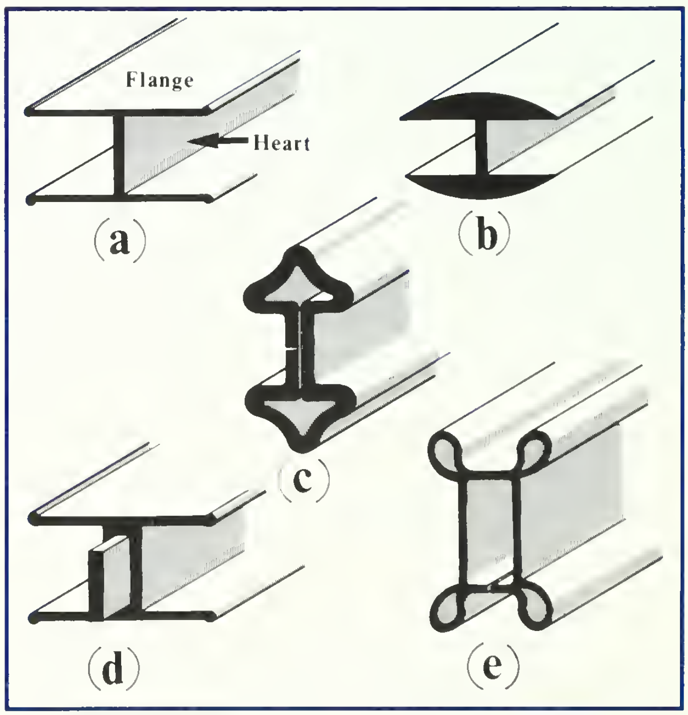

Figure 13. A wide variety of came has been used for ornamental glass in America: (a) flat lead came; (b) round lead came; (c) "Colonial" zinc came; (d) double-heart lead came with a steel core; (e) "Prairie School" zinc came. Drawing: Neal A. Vogel.

Came Types and Properties

Lead Came: Lead is a soft malleable metal (it can be scratched with a fingernail). It naturally produces a protective dark bluish-gray patina. In the mid-19th century, improved smelting processes enabled manufacturers to extract valuable metal impurities from lead, thereby producing 100% pure lead came. The industry reasoned that 100% pure lead came was superior to the less pure variety. Although pure lead came is very workable and contributes to intricate designs, time has proven it to be less durable than medieval came, which contained trace elements of tin, copper, silver, and antimony. Unfortunately, the misconception that pure lead had greater longevity continued throughout the glory years of leaded glass use in America. Most glass conservators use a 100-year rule of thumb for the life expectancy of 19th century came—less for came produced during war times. The demand for lead ammunition and the resulting scarcity of lead required studios to stretch the available lead to its limits, thus resulting in weaker cames. In the 1970s "restoration lead" (ASTM B29-84) was developed based on metallurgic analyses of medieval cames, some of which have lasted for centuries. Restoration lead should always be used when releading historic windows.

Zinc Came: Zinc came is more vulnerable to atmospheric corrosion (particularly from sulfuric acids) than lead, but has proven to be durable in America because it weighs 40% less than lead and its coefficient of expansion is 7% lower. Thus, it is somewhat less susceptible to fatigue from expansion and contraction. Moreover, it is ten times harder than lead, and has three times the tensile strength. Zinc came is strong enough to be self-supporting and requires little bracing to interrupt the window's design. While zinc came is perfect for the geometric designs of Prairie School windows, it is usually too stiff to employ in very curvilinear designs. Zinc can also take several finishes, including a copper or black finish. (As a result, zinc can be mistaken for copper or brass.)

Other Came: Other metals, primarily solid brass and copper, were also occasionally employed as came. They are generally found only in windows between ca. 1890 and ca. 1920.

How the cames are joined in a leaded panel is crucial to their long-term performance. Poor craftsmanship leads to a weak assembly and premature failure, while panels fabricated with interlocking (weaving) cames and lapped leads add strength. Soldered joints often reveal the skill level of the artisan who assembled the window, and can give evidence of past repairs. Solder joints should be neat and contact the heart of the came—wherein lies its greatest strength. Came joints should be examined closely; large globs of solder commonly conceal cames that do not meet. (Lead cames typically crack or break along the outside edge of the solder joint; stronger zinc cames frequently break the solder itself where it bridges junctures.) Weak joints contribute to a loose glass housing, and if glass rattles in the cames when the window is gently tapped, it is an indicator that repair or restoration is needed.

Leading patterns designed with inadequate support also contribute to structural failure. Panels with a series of adjacent parallel lines tend to hinge or "accordion," while lines radiating in concentric circles tend to telescope into a bulge. Stronger leading techniques, support bars, or specialty cames are sometimes required to correct poor original design. Minor sagging and bulging is to be expected in an old window and may not require immediate action. However, when bulges exceed 1½" (38mm) out of plane, they cross into a precarious realm; at that point, glass pieces can crack from severe sagging and pressure. If the bulged area moves when pressed gently, or if surrounding glass is breaking, it is time to address the problem before serious failure results.

Cleaning, Repair, Restoration, and Protection

The level of cleaning, repair, or restoration depends on the condition, quality, and significance of the glass, and, as always, the available budget. Hastily undertaken, overly aggressive, or poorly executed repairs can cause more damage than does prolonged deterioration. Repairs should, therefore, only be undertaken after carefully evaluating the condition of the glass—and only by professionals. Minor cracks, sagging, and oxidation are part of the character of historic leaded glass, and require no treatment. More extensive cracks, major bulges (generally, more than 1½" [38mm]), and other signs of advancing deterioration call for intervention, but caution must always be exercised. And each window must be evaluated separately. In some cases, windows have bulged up to 4" (102mm) out of plane without harming the pieces of glass or risking collapse.

Cleaning

Perhaps the greatest virtue of stained glass is that its appearance is constantly transformed by the ever-changing light. But dirt, soot, and grime can build up on both sides of the glass from pollution, smoke, and oxidation. In churches the traditional burning of incense or candles can eventually deposit carbon layers. These deposits can substantially reduce the transmitted light and make an originally bright window muted and lifeless. Simply cleaning glass will remove harmful deposits, and restore much of its original beauty, while providing the opportunity to inspect its condition closely (Fig. 14). The type of cleaner to use depends on the glass. Water alone should be tried first (soft water is preferable); deionized water should be used for especially significant glass and museum quality restorations. If water alone is insufficient,

Figure 14. The instructor removes one of six etched plates from a ca. 1905 Tiffany window in order to clean the interspaces and provide a rare educational opportunity at a restoration workshop. Cypress Lawn Memorial Park, Colma, California. Photo: Neal A. Vogel.

the next step is to use a non-ionic detergent. Occasionally, windows are covered with a yellowed layer of shellac, lacquer, varnish, or very stubborn grime which requires alcohol, or solvents to remove. Most *unpainted* art glass can be treated with acetone, ethanol, isopropyl alcohol or mineral spirits to remove these coatings if gentler methods have failed. All chemical residue must then be removed with a non-ionic detergent, and the glass rinsed with water. (All workers should take normal protective measures when working with toxic chemicals.)

Painted glass must never be cleaned before the stability of the paint is confirmed, and only then with great caution. If the paint is sound, it can be cleaned with soft sponges and cloth. If the paint was improperly fired or simply applied cold, paint can flake off during cleaning and special measures are required such as delicate cleaning with cotton swabs. Occasionally, paint is so fragile the owner must simply accept the windows in their current state rather than risk losing the original surface.

Acidic, caustic, or abrasive cleaners should **never** be used. They can damage glass. Most common household glass cleaners contain ammonia and should not be used either; ammonia can react with the putty or metallic cames.

Repair

As with all elements in older and historic buildings, maintenance of leaded glass units is necessary to prevent more serious problems. It is essential to keep the frame maintained regardless of the material. Often, this simply entails regular painting and caulking, and periodic replacement of the glazing compound. Wood frames should be kept painted and caulked; new sections should be spliced into deteriorated ones, and epoxy repairs should be made where necessary. Masonry frames must be kept well pointed and caulked to prevent moisture from corroding the steel armature and anchors within.

Windows that leak, are draughty, or rattle in the wind (or when gently tapped) indicate that the waterproofing cement ("waterproofing") and sealants have deteriorated and maintenance or restoration is needed. Waterproofing is a compound rubbed over the window—preferably while flat on a table—and pressed under the came flange to form a watertight bond between the leading and the glass. Traditionally, waterproofing was made of linseed oil and whiting, and a coloring agent. (Hardening agents should not be included in the mixture; solvent-based driers should be used sparingly.) The waterproofing allows leaded glass in a vertical position (i.e., in windows) to be used as a weatherproof barrier. It does not provided adequate protection for leaded glass in a horizontal or arched position; leaded glass ceilings and domes must always be protected by a secondary skylight or diffusing skylight.

Sealants (e.g., putties, caulks, and silicones) are used to seal the leaded panel against the sash, and to seal any open joints around the window frame. Sealants have improved dramatically since the development of silicones from World War II technology. Silicones are not without problems, however. Some release acetic acid as they cure. Acetic acid can harm lead, and should never be used on leaded glass. Instead, "neutral cure" silicones should be used. Developed in the early 1970s, "neutral cure" silicones have an expected lifespan of 50 years. These high-tech construction sealants are not sold in consumer supply stores. The appropriate type of sealant depends on the materials to be bonded and on the desired appearance and longevity. When windows are to be restored, the contractor should explain what types of waterproofing and sealants are to be used, and how long they are expected to last. On large projects, a letter from the product manufacturer should be obtained that approves and warranties the proposed application of their product.

Leaded panels will generally outlast several generations of waterproofing. When the waterproofing has failed, the window should be removed from the opening and waterproofed on a bench. Leaded glass cannot be adequately waterproofed in place. Removing the windows will provide an opportunity to perform maintenance on the window surround and to secure the reinforcement. This is far less expensive than totally releading the window, which is typically required if maintenance is deferred. When waterproofing or sealants break down, many building owners attempt to resolve the problem by installing protective glazing, when the window only needs maintenance. Protective glazing is not an alternative to maintenance; in fact, it impedes maintenance if not installed properly and can accelerate the deterioration of the stained glass (see "Protective Glazing and Screens" on page 12).

A very common—but extremely harmful—practice in the American stained glass industry is performing major window repairs in place. The practice is routine among churches where the cost of restoring large windows can be prohibitive. However, undertaking major repairs in place provides only a quick fix. A window cannot be properly repaired or restored in place if it is bulging or sagging far out of plane, if over 5% to 10% of the glass is broken, or if solder joints are failing. Unscrupulous glazers can introduce a great deal of stress into the glass by forcibly flattening the window in place and tacking on additional bracing. At a comfortable distance the window may look fine, but upon close inspection the stress cracks in the glass and broken solder joints become obvious. Windows subjected to this treatment will deteriorate rapidly, and complete, much more costly restoration will likely be necessary within a few years (while a proper repair can easily last two generations or more).

Major repairs to windows are sometimes part of a larger preservation project. In such cases, the risk of damaging the windows can be very great if their removal and reinstallation have not been carefully planned. When major building repairs are also to take place, the windows should be removed first to prevent damage during other work. Windows should be reinstalled as the next-to-last step in the larger project (followed by the painters or others working on the finishes surrounding the stained glass).

And glass should be protected whenever other work is undertaken on buildings—whether or not the windows are also to be repaired. External scaffolding, for example, erected for repointing or roofing projects may offer vandals and thieves easy access to windows and, through them, to building interiors. Finally, stained and leaded glass should always be well protected whenever chemical cleaners are used on the exterior of the building; some products, such as hydrofluoric-acid cleaners, will cause irreversible damage.

Repairs to Glass

Minor repairs, such as replacing a few isolated pieces of broken glass, can be performed in place as a reasonable stop-gap measure. This work, typically called a "drop-in," "stop-in," or "open-lead" repair, entails cutting the came flange around the broken piece of glass at the solder joints, folding it back to repair or replace the old glass, and resoldering the joints. Repairing a zinc came window is not as easy. Zinc cames are too stiff to open up easily, so they must be cut open with a small hack saw and dismantled until the broken area is reached. The glass is then repaired or replaced and the window is reassembled. New cames can be patinated to harmonize with the originals—but only with difficulty. Repatination should never be attempted in place, since it is impossible to clean off harmful residues trapped under the came.

Original glass should always be retained, even though it may be damaged. Replacement glass that exactly or closely matches the original piece can be very difficult to find, and costly to make. An endless variety of glass colors and textures were produced, and given the delicate chemistry of glassmaking, even samples from the same run can be noticeably different. The traditional secrecy that shrouds the glassmaking trade to this very day, as well as environmental bans of historically popular ingredients such as lead and cobalt for deep blues and greens, further hinders accurate reproductions. Therefore, *it is nearly always better to use an imperfect original piece of glass than to replace it.* If the paint is failing on a prominent feature of a window, a coverplate of thin, clear glass can be painted and placed over the original. (The coverplates must be attached mechanically, rather than laminated, so that they can be removed later if necessary.) A reverse image of the fading feature should be painted on the backside of the coverplate in order to get the two painted images as close together as possible. With repetitive designs, stencils can be created to produce multiple duplicates (Fig. 15).

Sometimes replacement is the only option. Fortunately, custom glass houses still exist, including the company that originally supplied much of the glass for Tiffany commissions. Stained and leaded glass has also experienced a resurgence in popularity, and American glassmakers have revived many types of historic glass.

When missing, shattered, and poorly matched glass from later repairs must be replaced, the new pieces should be scribed on the edge (under the came) with the date to prevent any confusion with original glass in the future.

Glass cracks will enlarge over time as the contacting edges grind against each other whenever the window is subject to vibration, thermal expansion and contraction, and other forces such as building movement. Therefore, it is important to repair cracks across important features as soon as they are detected, and while a clean break remains. Years ago, cracks were typically repaired with a "Dutchman" or "false lead" by simply splicing in a cover lead flange over a crack. Although this conceals the crack, it creates an even larger visual intrusion and provides no bond to the glass. Today there are three primary options for repairing broken glass: copper foil (Fig. 16), epoxy edge-gluing (Fig. 17), and silicone edge-gluing. These techniques differ in strength, reversibility, and visual effect, and the appropriate repair must be selected on a case-by-case basis by a restoration specialist.

Copper Foiling: Copper foil has the longest history and, unless the glass is unstable, is generally the best option when a piece of glass has only one or two cracks. Copper foil is a thin tape which is applied along each side of the break, trimmed to a minimal width on the faces, and soldered. A copper wire can be soldered on where

Figure 15. New stencils are used to produce matching replacement glass for repetitive stenciled patterns in a ca. 1870 window. Photo: Neal A. Vogel.

Figure 16. This stenciled roundel is being repaired by the copper foil technique. The glass cracked because it was not properly annealed. Once it cracks, it relieves the internal stress and stabilizes. Photo: Neal A. Vogel.

Figure 17. A valuable piece of flashed glass is carefully edge-glued with epoxy and a steady hand. Photo: Neal A. Vogel.

additional strength is required. However, copper foil repairs should not be used on unstable glass, since heat is required that can cause further damage. Copper foil produces a strong repair, is totally reversible and has a negligible aesthetic impact (a 1/16" [1.6mm] wide line).

Epoxy Edge-Gluing: This technique produces a nearly invisible line and is often used on painted glass, particularly focal points of a window such as a face, or a portion of sky intended to be one continuous piece. Epoxy can even be tinted to match the glass. It is also used for infusing shattered glass or microscopic cracks caused by intense heat from a fire. Epoxy produces a very strong repair, but will deteriorate in sunlight and requires secondary glazing to protect it from UV degradation. Epoxy is the least reversible of the three techniques, and usually the most expensive.

Silicone Edge-Gluing: This repair method has the lowest strength and should be used when a flexible joint is desirable—if, for instance, the window will be under continuous stress. Silicone repairs are easily reversible, and can be removed with a razor blade—when they are done correctly, that is. Silicone edge-gluing is not the same as smearing silicone all over the glass. This unfortunate practice, seen throughout the country, is useless as a repair technique, and usually causes more damage than if the glass were left alone. Silicone is almost clear, but it refracts light differently from glass and is, thus, easily detectable. Silicone is not affected by temperature, humidity or UV light. Silicone repairs are typically the least expensive repair option.

Repairs to Structural Support Systems

Windows may have detached from the saddle bars and begun to sag, bulge, and bow extensively. This point varies from window to window. Generally, however, a window sagging or bulging more than 1½" (38mm) out of plane has reached the point where it should be removed from the opening to be flattened out. Under these conditions, it is essential to note if the support system or leading pattern has failed so it may be corrected before the window is reinstalled. The window must be allowed to flatten over a few weeks in a horizontal position. This will minimize stress on the solder joints and glass. A moderate weight and controlled heat will help coax the window back into its original plane. The process requires patience. Once the window has flattened, the original support system should be reattached and additional support added as necessary. It is crucial to consider the original design so the new support bars do not intrude on important window features. Sometimes small thin braces or "fins" can be manipulated to follow existing lead lines exactly. These give support, but are almost invisible. Flattening windows also provides a good opportunity to apply new waterproofing to help prevent further deterioration. Today, synthetic compounds are used.

Windows should only be removed when they need to be flattened, waterproofed, reinforced or releaded. Allow plenty of time for careful, thorough work. Large projects can take several months, especially if complete releading is necessary. Owners, consulting professionals, and construction managers must therefore ensure that vacant openings will be weathertight for an extended period—whether the opening is covered by plywood, acrylics, or polymer film.

Rebuilding or releading a window is an expensive and involved process. The releading process requires that a window be "unbuilt" before it can be "rebuilt." The glass pieces must be removed from the cames, the old cement must be cleaned from each piece of glass, and all the pieces must be rejoined precisely. At every step the process involves the risk of damaging the glass. Furthermore, exceptional studios had unique leading techniques, and thus the cames should not be replaced casually. Total releading should only be undertaken when necessary to avoid or slow the loss of historic fabric (Fig. 18). (It is essential to request a copy of all window rubbings if the windows are to be completely releaded.)

Figure 18. A craftsman releads a window. The full hood offers protection from lead fumes. Photo: Neal A. Vogel.

Lead and zinc came, however, is intended to be a sacrificial element of a glass unit assembly, as mortar is to brick and paint is to wood; came will break down long before glass and must be replaced; came lasts 75 to 200 years depending on the window's quality, design and environment. A common preservation conflict arises in releading historic windows constructed of flat came: whether to retain historical accuracy by using new flat came, or to use came with a rounded profile for greater strength and durability. The decision must be carefully weighed depending on the significance of the window, the contribution of the came profile to the overall design, and the severity of the deterioration caused by a weak flat came. In most windows, the came profile is essentially lost in transmitted light, but occasionally shadow lines are important and should be reproduced (Fig. 8). Furthermore, it is important to correct technical problems that arise from flimsy original came. Occasionally, a slightly heftier came may be the best solution to resolve weak panels that have not proven the test of time. Under these circumstances, the thicker lead came (even if only 1/64" [0.4mm]) will cause a leaded panel to swell slightly, and the frame, perimeter leads, or glass may have to be trimmed slightly to fit the opening. (Trimming the glass should be the last resort.) This would not be an appropriate solution in a museum-quality restoration or for a highly significant window.

Protective Glazing and Screens

The use of protective glazing (also known as secondary or storm glazing) is highly controversial. Potential benefits of protective glazing are that it can shield windows from wind pressure; increase energy savings; protect against environmental pollutants and UV light; provide vandalism and security protection, and reduce window maintenance. Potential drawbacks are that it can promote condensation; cause heat to build up in the air space and thereby increase the window's expansion/contraction; eliminate natural ventilation; reduce access for maintenance; offer only minimal energy payback for intermittently heated buildings (such as churches and temples), and mar the appearance. Protective glazing can also be presented as a cheaper alternative to full-scale restoration. And all too often protective glazing is installed as a routine matter when there is little threat of damage from vandalism or other causes. Protective glazing, especially when improperly installed, may hasten deterioration of stained glass windows.

Various types of metal grills or screens are also used. They add security and vandalism protection but often impair the appearance of the window (inside and out) by creating new shadows or diffusing transmitted light.

As a general rule, protective layers should not be added. In most cases the potential drawbacks outweigh the potential benefits.

Under some circumstances, however, protective glazing or screens may be necessary. (This applies to windows. Domes and ceilings present a special case. See "Domes and Ceilings" on page 14). A real vandalism or security threat warrants protective glazing, such as when the windows can be reached easily or are in an isolated location (Fig. 19). Protective glazing is also warranted when employed historically on a particular window as original plating (Tiffany Studios, for example, often used plate glass to keep dirt and moisture out of their multi-plated windows). Unusual circumstances (such as when the windows are painted on the outside) may also dictate the use of protective glazing. Finally, protective glazing is warranted when a UV filter is needed to prevent epoxy glass repairs from breaking down.

A variety of protective glazing materials are available. They include polycarbonates, acrylics, laminated glass,

Figure 19. Stained glass in mausoleums requires protective glazing since vandalism is frequent in cemeteries. This plate glass intentionally softened the light transmitted through the window. This feature should be reproduced in the replacement glazing. It may be possible to repair the plate glass and install another, stronger (clear) layer on the outside. Photo: Neal A. Vogel.

plate glass, and tempered glass. The plastic products are very strong, lightweight, and relatively easy to install, but tend to scratch, haze, and yellow over time, despite UV inhibitors. They also have a high coefficient of expansion and contraction, so the frames must be designed to accommodate change induced by temperature fluctuations. Poor installations in restrictive frames cause distorted reflections from bowing panels. Protective panels of glass are heavier and more difficult to install, making them more expensive than plastic. However, glass will not bow, scratch, or haze and is usually the best option in aesthetic terms; laminated glass provides additional impact resistance.

A common error in installing protective glazing is to create a new window configuration (Fig. 20). Insensitive installations that disregard the original tracery destroy the window's aesthetics—and the building's. When protective glazing is added, it should be ventilated. If a window is not ventilated, heat and condensation may build up in the air space between the ornamental glass and the protective glazing. The surface temperature of unvented glass has been measured up to twice the outdoor ambient temperature. This differential affects the expansion and contraction of the support system, particularly lead cames, thereby accelerating metal fatigue. Protective glazing may also cause condensation on the historic window, depending on the window's orientation, indoor/outdoor humidity, and whether or not the building is air conditioned.

When absolutely necessary, protective glazing should be installed in an independent frame between ⅝" (16mm) and 1" (25mm) from the leaded glass. This allows the protective panel to be removed for periodic maintenance of both the historic window and the new feature. The conditions of the air space between the two elements should be monitored on a regular basis; the glass should not feel hot, and condensation should never collect on the window.

No ideal formulas have been developed for venting the air space between the ornamental glass and the protective glazing, but it is typically vented to the outside (unless the building is air conditioned most of the year). Generally, a gap of several inches is left at the top and bottom when glass is used, or holes are drilled in the protective glazing at the top and bottom when polycarbonates and acrylics are used. Small screens or vents should be added to keep out birds and insects. Finally, it is important to realize that some original plating of glass softened or tinted the transmitted light intentionally, as designed by the original window maker; in this case any new or replacement plating should simulate this effect to respect the artisan's intentions (Fig. 19).

Domes and Ceilings

(b). Before repairs began on the vaulted glass ceiling below, a new diffusing skylight was installed to correct recurring leaks. Catacombs (ca. 1920), Cypress Lawn Memorial Park, Colma, California. Photo: Neal A. Vogel.

Stained glass domes and ceilings were very popular throughout the Victorian and Classical Revival periods. They are often principal interior features of churches, hotels, restaurants, railway stations, and civic buildings (a). The loss or unsympathetic alteration of leaded glass ceilings and domes is a widespread problem. Poorly planned rehabilitation projects sometimes cause the removal or alteration of overhead leaded glass in order to comply with fire codes or to achieve perceived energy savings; occasionally, they are even concealed above suspended ceilings.

Moreover, stained glass in the horizontal position readily collects dust and dirt over the years and is relatively inaccessible for cleaning. It is also more likely to "creep" or slump when the reinforcement is inadequate. Most importantly, leaded glass cannot be sufficiently weatherproofed in a horizontal (or arched) position. It must always be protected by skylights or "diffusers"—rooftop features that diffuse the natural daylight into the attic or light shaft, and protect the leaded glass ceiling or dome from the elements (b).

Due to the inferior quality of glazing sealants of the late 19th and early 20th centuries, and to deferred maintenance, glass ceilings have frequently been removed or covered with roofing materials. Artificial lighting is then required to backlight the ceiling or dome, which robs the stained glass of its life—the vibrant effects created by ever-changing natural light. All types of artificial lighting can be found from floodlamps to fluorescent tubes. Outside sensors are even used to modulate the light level in an attempt to simulate changes in daylight. However, daylight is impossible to emulate. Moreover, it's free. Artificial lighting requires maintenance, introduces an additional fire hazard in the attic, increases the building's electrical load, and is supplied only at a cost.

Stained glass ceilings and domes that have been sealed off from natural light should be investigated for restoration. Once natural light is restored and the stained glass is cleaned, the lighting effect on an interior can be extraordinary. Improved skylight designs and major advances in glazing sealants since World War II (particularly silicones) encourage the restoration of skylights without the fear of inheriting a maintenance nightmare.

(a). Stained glass ceilings and domes are often principal interior features of churches, hotels, restaurants, railway stations, and civic buildings. This one illuminates the Carnegie Free Library in Union, South Carolina. Photo: Jack E. Boucher, HABS.

Figure 20. (a) The aluminum frame grid used for protective glazing totally disregards the original tracery of this Neo-Gothic church. The grid mars the appearance of the window inside and out. It also impairs the overall historic character of the building. (b) Protective glazing in this instance preserves both the appearance of the window and its contribution to the building. The latter building is the Cathedral Basilica of the Assumption (St. Mary's Cathedral), Covington, Kentucky (1895-1910). The window, 67' x 24' (20.4m x 7.3m), is among the largest stained glass windows in the United States. Photos: Neal A. Vogel.

Conclusion

Most of the Nation's stained glass and leaded glass has recently passed, or is quickly approaching, its 100th anniversary—yet much of this glass has not been cleaned or repaired since the day it was installed. With proper care, these important historic features can easily last another hundred years.

Notes

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The rose window at St. John Cantius, Chicago (1906-1908), undergoing restoration (interior view). Photo: Neal A. Vogel.

Cover Photograph: St. Michael's Church, Chicago. Window dates from 1902. Photo: Rolf Achilles.

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