ARCHITECTURAL GLASS MUTATES AS BUILDING TEAMS INNOVATE

COURTESY ENCLOS

Project teams are using technologies like digital ceramic printing to incorporate graphic patterns and imagery in glass panels.

LEARNING OBJECTIVES

After reading this article, you should be able to:

- **DISCUSS cold-bent glass versus heat-treated glass forming.**
- **DESCRIBE the challenges of large glass openings.**
- **LIST techniques for silk-screening and spandrel treatments.**
- **DESCRIBE the use of films, coatings, and fritting.**

Novel concepts in glass and glazing are opening new vistas in the buildings world. From massive openings and bent panels to decorative finishes and integrated smart technologies, a cornucopia of glass innovations have been hitting the market in recent years. A review of new projects and recent product introductions gives an idea of the astounding range—and a few key lessons to live by—in today's institutional and commercial sectors.

In many geographies, however, frustrated building teams also face shortages of skilled specialty contractors and glaziers to help build their visions. *The U.S. Glass News Network* has reported on its own studies concluding that a "lack of qualified skilled workers was by far the largest concern for glazing contractors entering 2019."

Product availability has been hampered in a few cases by international trade tariffs. The first step in inventive glass design strategies is to ensure the products, fabricators, and glaziers are available to meet the plan requirements and fulfill the delivery order.

For those touring factories or attending the major glass expos, one answer to the shortages is seen in the increasingly automated operations in float glass plants and finishing operations. At the shows glasstec and GlassBuild, as well as Finland's Glass Performance Days, presenters have demonstrated sealing robots and new automated machines for insulating and laminating panels and air-cushion tempering, as well as systems for faster processing of glass edges.

Advantages for building teams include faster and more reliable processing of bent glass (and curved glass), a fast-growing trend in recent years. “While this technology has been around for some time, recent advancements now enable larger and more complex bent shapes to be created,” according to the fabricator Dillmeier Glass Co. “This has expanded its uses, and driven increased demand, including for glass railings, awnings, and even walls.”

Early examples include Frank Gehry’s Nationale-Nederlanden Building in Prague, with its tower of curved glass, as well as the Kunsthaus Graz museum in Austria. More recently, the 3,000-plus cold-bent and laminated panels made of safety glass for Apple’s headquarters in Cupertino, Calif., were designed by architect Foster and Partners alongside the German maker Seele and its subsidiary fabricator, Sedak. Sedak manufactured 872 cold-bent laminates constructed out of two large-scale panes, including insulated safety glass.

Unlike conventional sag bending or slumping using heat to soften the panels, cold-bent glass turns flat plates into curved shapes at ambient temperatures, and the process can be completed after the glass is tempered. Some manufacturers are even cold-bending insulated glazing units (IGUs) with good results, as used in commercial structures such as the IAC Headquarters in New York, designed by Gehry Partners and built by Turner Construction.

Cold-bending techniques push flat glass into a frame for the desired bending. The heating approaches generally have been more expensive, employing molds and large tempering ovens or kilns to fashion the desired bends and curves, yet the processes are equally reliable. However, experts note that for double curvatures, sharp bends, and right angles, heating is the best specification. Many fabricators have adjustable bending ovens that no longer require molds, instead using moveable sections to customize the bed for the designed shape. Cold bending has limits in terms of shaping glass and may also introduce undesirable optical and reflective qualities in the installed product.

Another approach to shaping panels, called lamination bending, employs a pressurized autoclave to sandwich heat-strengthened panels to ionoplast interlayers, which studies show can improve structural properties and weather resistance as compared

EDMON LEONG

Increased demand for transparency, views, and daylight has led to the fabrication of monolithic glass panels in sizes previously unseen. The new 53W53 project in New York City features a diagrid façade with glass units up to 28.5 feet tall by about 7 feet in width.

to laminated glass using polyvinyl butyral (PVB) interlayers. Using less heat than an oven, the laminated panels help each other hold the designed shape, with the ionomer layer up to 100 times stiffer than PVB. Contractors note the preshaped panels can be easier to install, and some assemblies can be completed at the plant to speed construction, with seals and railings ready for sitework, according to Sedak, which has introduced new lamination bend processes in recent years.

LARGE GLASS OPENINGS

Another obstacle trending in recent years has been increasing end-user demand for larger glass openings requiring expensive monolithic panels in sizes previously unseen. These are being applied to a range of building types and market sectors, including for interior partitions, according to the fabricator Dillmeier, based in Van Buren, Ark. Very large architectural units have been used in recent projects in sizes up to 11 feet wide and 20 feet

An emerging decorative technique is the application of multilayered polymeric films, often called dichroic filters. The polymeric films selectively admit light in a small range of colors while reflecting other colors, appearing to be highly saturated with color that shifts depending on the viewing angle.

high. Total areas of more than 200 sf are now commonly specified for both interior and exterior uses.

Recent examples include the new 53W53 project in New York City, designed by Adamson Associates, Ateliers Jean Nouvel, SLCE Architects, and engineer WSP USA for a Hines subsidiary developer. Located by the Museum of Modern Art, the building's lower floors add 52,000 sf of exhibition space for the cultural institution behind an oversize motorized door measuring 34 feet by 17 feet 8 inches. Above that, a diagrid façade presents unique glass units including trapezoidal modules and large units up to 28.5 feet tall by about 7 feet in width, according to the façade consultant Vidaris and the curtain wall maker Enclos.

"Installing large units in the middle of Manhattan at such great heights in front of a unique structure have required several equipment innovations that continue to aid the field crews in safe installation," according to Enclos. Other challenges for projects like these include "heightened acoustical performance, and combinations of geometric complexity and transparency," says Jeffrey Vaglio, PhD, PE, AIA, LEED AP, Vice President of the Enclos Advanced Technology Studio. "More projects are incorporating curved glass, double-skin façade box-window systems, and more use of terra cotta features integrated into the curtain wall system."

Yet, it's the improving economics of large glass opening that make them feasible today, according to Brian Savage, a Product Manager with Viracon, who concluded in a recent white paper, "The opportunity to incorporate these bigger glass units into the design of buildings with minimal overall investment is driving the trend from the east and

CITIES ADVANCE CODES—AND GLASS SAFETY

In municipalities around the country, building teams are watching carefully as authorities having jurisdiction (AHJs) adopt the latest International Building Code, its 2018 iteration, in major building markets, from Chicago to New York State.

New York is adopting the 2018 I-Codes this fall, according to Josh Breeden of Milrose Consultants, describing its transition period of approximately 90 days and a mandatory effective date after January 2020. Chicago adopted the 2018 IBC in April of this year, which experts describe as a major change for a city where no major code updates have been embraced in 70 years.

What's behind the drive toward the 2018 IBC is an increased focus on safety, including glass systems safety. "These guidelines," according to Milrose, "encompass numerous structural design best practices meant to promote quality commercial and residential development and thereby ensure tenant health and safety."

A study by the National Institute of Building Sciences (NIBS) on natural hazard mitigation looked at the benefits of designing buildings to meet the 2018 IBC and found major advantages: For every dollar invested, localities receive $11 of benefit. "Communities that lag the rest of the country in code adoption will ultimately pay in terms of the health, safety, and welfare of the public, of businesses, of visitors, and of the community's future vitality," NIBS said in a joint statement with other federal agencies.

As an example, the 2018 IBC safety changes include recognition of two types of fire-rated glass referenced in Chapter 7: fire-protection and fire-resistance glass. The IBC also defines where those safety glass types may be used and any related limitations. "Moving forward, there should be less confusion among architects, building officials, and end-users on what types of fire-rated glazing should be used for the application because it is clearly outlined in these tables," said Diana San Diego, Vice President of Marketing at Safti*First*, in a *USGlass Magazine* interview.

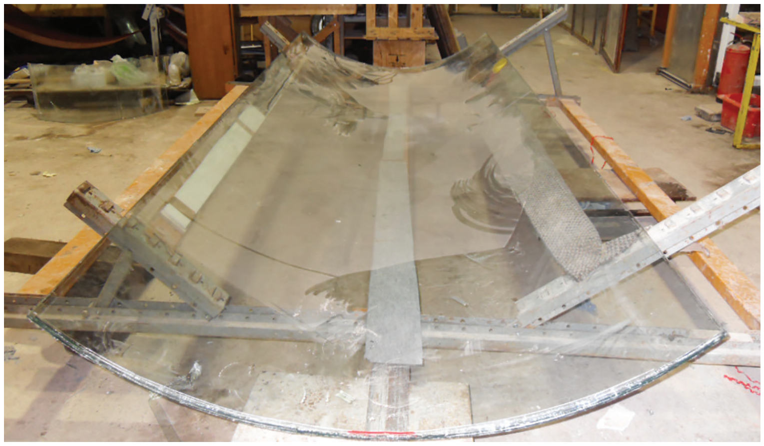
In addition to these safety improvements, the International Code Council (ICC) has shown how I-Code adoptions also make construction more affordable. "The new code represents the first comprehensive revisions to the building code in 70 years and will make construction in Chicago more affordable by expanding options to design and build with a wider range of materials and technologies," the ICC said.

west coasts onto buildings throughout the country." Presenting a representative building example, Savage calculates that 100,000 sf of glass in standard-size glass will account for about 1.7% of the entire project cost. Using large glass sizes for 5,000 sf of the façade, such as for an atrium, increases the glass cost minimally to about 1.8% of the entire project. If all 100,000 sf were made with large-size units, adds Savage, the glass bill would be about 3.2% of the total.

The partial façade areas with large unit sizes is a common approach, according to Saint Gobain Building Glass. For the rebuilt World Trade Center's sculptural subway station building in New York, Spanish architect Santiago Calatrava and the project team selected oversized glass panels for the entrance area, with unit sizes reaching 25 feet 6 inches by 2 feet 8 inches between the structure's girders. Complementing the total area of about 43,000 sf of highly transparent, extra-clear glazing with a custom solar-control coating, the 800 extra-clear glass panes provide an identical visual appearance.

Another example is The Broad Museum in Los Angeles, designed by Diller Scofidio + Renfro and installed by Seele. Color-neutral glass units measuring 7 feet 10 inches wide and more than 25 feet high installed at ground floor locations span from the floor to the ceiling. Detailed without any cross-section and with profileless vertical joints, the glass enclosures are practically invisible, heightening the effect of the voids.

With market demand for large glass exposures, many buildings are using structural glass or frameless assembly systems, which do not encounter the same limits in unit size and weight. They do tend to be costly, however, and require extensive structural engineering work and rigor-



RUNCORN GLASS & GLAZING COMPANY

Recent innovations in glass fabrication include faster and more reliable processing of curved glass. Advancements enable larger and more complex bent shapes to be created for glass railings, awnings, and walls.

COURTESY SAFTI FIRST

An application that makes buildings more adaptable and responsive is fire-resistive glass, which increases the available and code-allowable area of glass enclosures. The adoption of the latest International Building Code (IBC), the 2018 iteration, provides enhanced detail on the limitations of fire-protective glass.

ously made attachment systems. In both cases, the very large glass panels or structural glazings tend to be used in smaller areas and specialized applications for architectural effect. At Apple's headquarters, for example, the largest exterior window panels measure around 47 feet long by 10 feet tall, a precedent for large panel window fabrication. Interior panels along the facility's central courtyard reach 36 feet in length.

MORE COMPLEX AND DECORATIVE

Size is only one dimension driving glass use today. Another is finish and appearance. For the very large monolithic glass products, for example, some building teams are using silk-screening and spandrel treatments, as well as substrates and special coatings for aesthetic variation.

The finishes are becoming more decorative and thus more complicated and expensive, according to Dillmeier: "Along with larger lites, architects and designers are calling for more decorative glass, too. This includes panes with patterns, designs, colors, or textures added, to create a more ornamental finish." Using technologies including digital ceramic printing, building teams are able to easily incorporate graphic patterns and high-resolution imagery in glass panels.

Not unlike inkjet printing on paper, the highly automated digital printing techniques directly depose ceramic inks on glass surfaces, creating abrasion-resistant and colorful patterning. In addition, digital ceramic printing is environmentally benign and the materials can be recycled at the end of its useful life, according to LEED-accredited Cathie Saroka, President and CEO of Goldray Industries, Inc. The highly durable ceramic ink is specified in laminated or monolithic form to create printed designs often in combination with a high-performance, low-emissivity glass, "used as a way of controlling solar heat gain into the building." Ceramic printed glass is often combined with backpainting or laminating, providing greater design flexibility or more customized solutions.

Another decorative technique making headway in the commercial and institutional markets is the application of multilayered polymeric films, often called dichroic or interference filters, such as those made by 3M. Applied to building glazings, typically laminated between two or more glass lites, the polymeric films selectively admit light in a small range of colors while reflecting other colors, appearing to be highly saturated with color that shifts depending on viewing angle. Combining the films, available in both opaque and translucent versions, with textured or acid-etched glass panels can enhance or mute their optical effects. Last, more project teams are employing metallic finishes on glazed surfaces, echoing the use of metallic finishes in other building materials. New laminated metal mesh glass products, for example, are used to give glass an appearance of aluminum, gold, or copper weave, with benefits for controlling daylighting and solar gain.

HIGH-TECH GLASS PERFORMANCE

Treating glass façades as more of a filter is one of the key design trends for today, says Craig Schwitter, PE, Partner at BuroHappold Engineering. "The results are less like structures and more like filters," says Schwitter. "They are balancing the exterior climate and interior climate to make the interior spaces habitable, enjoyable, and inspiring."

The technology that makes this possible is a culmination of advances in modeling technology and computer-aided manufacturing, Schwitter adds, which can result in low-energy and high-performance buildings. Other breakthroughs in glass technology provide for tunable performance based on the needs of the "environmental filter" and changes in weather and other external factors. Switchable privacy glass, an increasingly popular specification, employs

COURTESY EMPIRE HOUSE

Bird-safe glass on skyway.

low-voltage electrical current to arrange liquid crystal molecules into patterns that make glass sheets transparent, according to Guardian Glass, which manufacturers a switchable product. “Turned off, the liquid crystal molecules revert to a random pattern, diffusing the light and causing the glass to become opaque,” the company explains, adding that the glass installations can be controlled with a switch, motion detector, daylight sensor, or another device.

Recent technological improvements have improved the quality of switchable glazings while cutting product costs, according to the blog GlassOnWeb.com. Novel switchable films provide a low-energy alternative, with greater clarity when energized as compared to previous generations of films. Popularized by glass conference rooms and healthcare applications, according to the fabricator Dillmeier, “It can also be incorporated into traditional glass applications, such as room partitions and doors, or less commonly, even countertops and furniture.”

Another application that makes buildings more adaptable and responsive is fire resistive glass, which increases the available and code-allowable area of glass enclosures. The adoption of the latest International Building Code (IBC), the 2018 iteration, provides enhanced detail on the limitations of fire-protective glass, such as wired glass and ceramics, which are rated up to 90 minutes and 180 minutes respectively yet must be limited to 100 square inches in area even when the building is fully sprinklered (see sidebar on page 56).

To exceed that code-maximum area, applications of fire-resistive glass—also known as fire-resistance glass—are specified with IBC’s reference criteria given in the fire-testing standard ASTM E-119, “Standard Methods for Fire Tests of Building Construction and Materials,” as well as UL 263, “Fire Tests of Building Construction and Materials.” Both standards are typically used to test construction assemblies such as floors, enclosures, walls, ceilings and other structural elements.

Similar to fire-protective glass, the resistive type can be used to compartmentalize smoke and flames, yet the fire-resistive glazing additionally can be used to block the transmission of radiant heat. Radiant heat is a significant concern during building fires. It can cause harm to building occupants within 20 feet of a glass partition separating them from the fire source, and can also ignite combustible materials on the non-fire side of the glass. Matched with proper framing, "Fire-resistive glass can save lives without compromising an architect's design vision," according to former fire marshal Robert Davidson, by effectively compartmentalizing smoke, flames and radiant heat to provide safe egres regardless of the size of the glazed area.

GREENER, SAFER GLAZING

Another safety focus for glazing specifications relates not to human occupants but rather to nearby birds. With hundreds of millions of birds lost due to collisions with buildings—and more than half involving low-rise and midrise structures of four to 11 stories tall—building teams are studying the effectiveness of varied solutions. Examples of retrofit products include curtains of fine nylon monofilament lines, adhesive dots and decals, and safety films, as well as an acrylic Plexiglas with embedded polyamide threads for handrails and noise barriers.

For new buildings, a variety of films and fritting as well as architectural enhancements can be used. Georgia Tech's Kendeda Building for Innovative Sustainable Design in Atlanta, designed to meet Living Building Challenge certification, employs bird-safe glass to enclose its education, research, and outreach facilities. Conceived by Lord Aeck Sargent and The Miller Hull Partnership with general contractor Skanska USA, about one-third of the building's 9,500 sf of window glazing from ground level to about 30 feet above grade is treated with a dot matrix of ceramic fritting. The simple frit specification—which added about $32,000 to the cost of the project, according to The Kendeda Fund—employs a silk screening process to create the grey dot patterns. A recent study by Powdermill Nature Reserve employed a specially constructed tunnel to observe how various bird species responded to different kinds of glass intended to reduce collisions from at least 20 glass fabricators. About 94% of the birds tested fly toward conventional glass openings when side-by-side with ceramic fritted glazing. The results showed that dark gray bands of fritting were the most effective at discouraging birds from flying toward the windows. A few cities and states, including San Francisco and Minnesota, have adopted bird-safe building standards, and federal legislation has been proposed. In the meantime, the U.S. Green Building Council has introduced a pilot credit for the design strategy into its LEED certification program, an influential standard. "It is one of the few resources out there that suggests strategies for avoiding bird collisions," according to Georgia Tech's Kendeda Building design team leader, Joshua Gassman, R.A., LEED AP, Director of Sustainable Design for Lord Aeck Sargent.+