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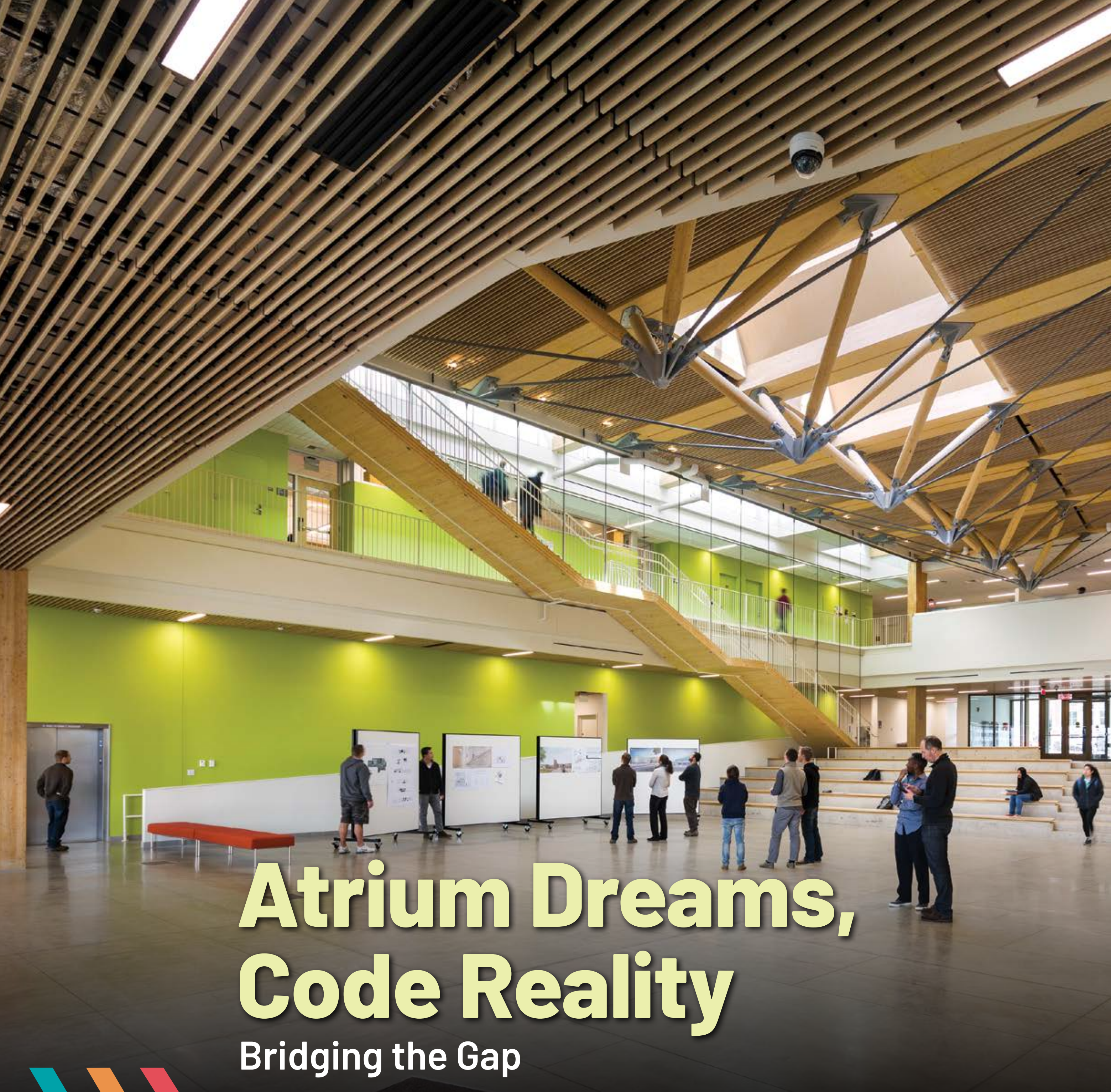


Atrium Dreams, Code Reality

Bridging the Gap

By Madison L. Di Vico
and Kevin M. Black, P.E.

PHOTO © ALBERT VECERKA/ESTO

Atriums are among the most compelling architectural elements in modern design. They invite daylight into buildings, connect levels with openness, and create a sense of spaciousness that is hard to match. Whether it is a soaring lobby, a central gathering space, or a featured staircase linking floors together, atriums have become a preferred design solution.

However, they come with some of the most complex and impactful building code requirements that can reshape projects in ways many architects do not anticipate. Atriums have increased exposure to occupants from heat, smoke, and toxic gases, requiring additional life-safety systems. This is why they often require systems such as smoke exhaust fans, fire-rated shutters, additional sprinklers, and sometimes even a generator. Understanding what triggers atrium classification, what systems it requires, and how it affects fire protection, egress, and cost is essential for preserving the integrity of the design and avoiding compromises.

What is an atrium?

When walking into a building for the first time, it can feel a little claustrophobic. Doors in every direction lead to other spaces within the building, but which door is the correct one?

Walking into an atrium is an entirely different experience: the space is open, airy, and well-lit by natural light streaming in from ceilings that can be 9.1 m (30 ft) or more above the floor. There are often art or architectural features, places to sit, and a welcoming environment for people to collect their thoughts before continuing further to conduct business or enjoy a day of leisure.

Architects use atriums to create seamless connections between related spaces. Common in airports, hotels, concert halls, convention centers, and office buildings, they allow occupants to experience interconnected environments supporting ultimate flexibility.

An atrium can enhance building performance, occupant comfort, and spatial quality, serving both functional and aesthetic purposes. The large open volume introduces abundant daylight into the building core, reducing reliance on artificial lighting and lowering energy demand. When integrated with thoughtful facade and vertical circulation design, atriums can support stack-effect ventilation, improve airflow, and use passive cooling strategies. They strengthen visual connections between floors, improve wayfinding and orientation, establish spatial hierarchy, and act as architectural focal points. In addition, atriums serve as communal spaces that encourage social interaction and collaboration, making them a valuable element in contemporary building design.

When asking fire protection engineers what an atrium is, they are likely to give a strict definition rather than the feeling or design that an architect might describe. According to the *2024 International Building Code* (*IBC*), an atrium is defined as any vertical space that is closed at the top and connects three or more stories—or two stories in hospitals (Group I-2) or detention centers (Group I-3). Atriums are not permitted in high-hazard (Group H) occupancies. Three connected stories may sound like a shaft, but the atrium provisions come from special, detailed requirements in Section 404 of the *IBC* that allow spaces to be interconnected.

However, every time stories are connected, an atrium is not necessarily required. The *IBC* does provide allowances for vertical openings for escalators, parking garages, and two-story openings (including exit access stairways). These can preserve interconnected stories without triggering full atrium requirements. As a reminder, a mezzanine is not a story, and mezzanines are often open to the story they are part of, but are allowed to be closed in certain cases. Other examples of vertical openings where atriums are not required include:

Walking into an atrium is an entirely different experience from other parts of a building; the space is open, airy, and well-lit by natural light streaming in.
PHOTO © HUFTON+CROW

Escalators (712.1.3)
Escalators are commonly featured in the centers of malls and large shopping centers to facilitate smooth movement between levels, make navigation easier, and encourage more interaction and engagement among visitors. A horizontal assembly is not required between the floor and openings for escalators complying with one of the following from *IBC* Section 712.1.3:

- Protection by a draft curtain and closely spaced sprinklers. The vertical opening cannot be more than twice the area of the escalator in the opening.
- Protection of the vertical opening by listed or approved shutters.

Two-story openings (712.1.9)
Upon entering a hotel, guests are often greeted with breathtaking high ceilings that convey a sense of openness and grandeur. The two-story opening provides a welcoming atmosphere that sets the tone for an elevated experience. In occupancies other than Group I-2 and I-3, a two-story vertical opening is allowed when it does not penetrate horizontal assemblies that separate fire areas, is not concealed within structural elements, is not open to corridors in Group I or R occupancies, and is properly separated from other floor openings.

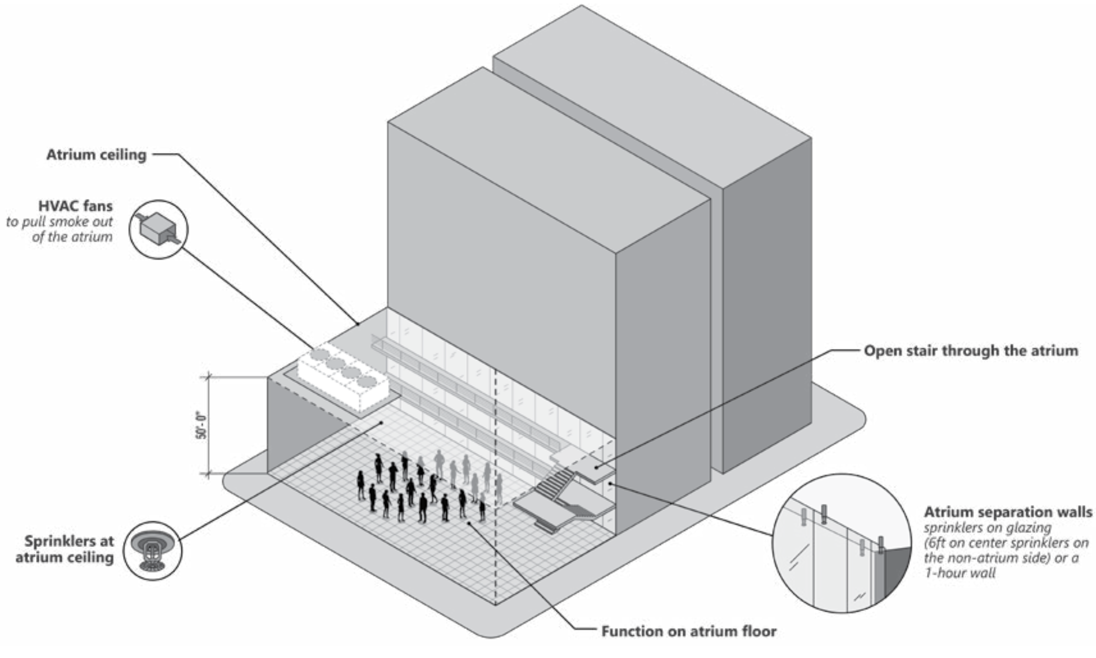
Exit access stairways and ramps (1019.3)
A grand, open stairway rises through the middle of the space, inviting movement, daylight, and visual connection between floors while serving as a primary circulation path. The stairs share some qualities with an atrium, but they meet a special condition and are not classified as one. Vertical openings for exit access stairways and ramps are limited to a maximum area that does not exceed twice the stair's or ramp's projected horizontal area. The number of stories connected in buildings classified as Group B or Group M occupancies (office buildings or retail stores) is not limited. In other occupancies, openings may connect to no more than four stories and are not permitted in Group I-2 or Group I-3 occupancies.

Parking garages (712.1.10)
While driving up parking garage levels looking for a place to park, drivers may wonder how these levels interact so seamlessly, what special systems are in place to allow this fluidity, and how much it costs to design. The truth is, vertical openings in parking garages for automobile ramps, elevators, and duct systems dedicated to the parking garage are permitted if they are constructed in accordance with the requirements for parking garages (406.5, 406.6).

Use and function

Airports, university buildings, and hotels frequently incorporate atriums into their designs to create open, visually appealing spaces. However, the use and function of atrium spaces are restricted by the requirements outlined in the *IBC*. Specifically, atriums are generally limited to low-hazard uses, unless sprinklered.

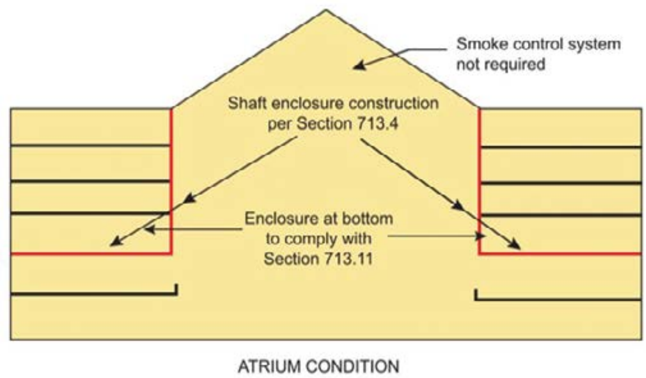
Figure 1



This diagram shows the function and use of atriums.

Low-hazard uses include areas where the contents and activities present a minimal risk of fire, such as churches, museums, educational facilities, restaurant seating areas, and auditoriums (as noted in National Fire Protection Association (NFPA) 13 Annex A.4.3.2). Atrium areas are often prohibited from uses such as fabrication spaces, storage areas, and office areas because they introduce a greater fire risk. In some cases, certain uses may be allowed within an atrium if sprinklered and approved by the authority having jurisdiction (AHJ).

Figure 2



In the traditional approach (not the top-hat method), up to three floors can open directly into the atrium, provided the smoke control system is designed to control the smoke in the occupied spaces open to the atrium.

IMAGES COURTESY SIMPSON GUMPERTZ & HEGER

Atrium separation

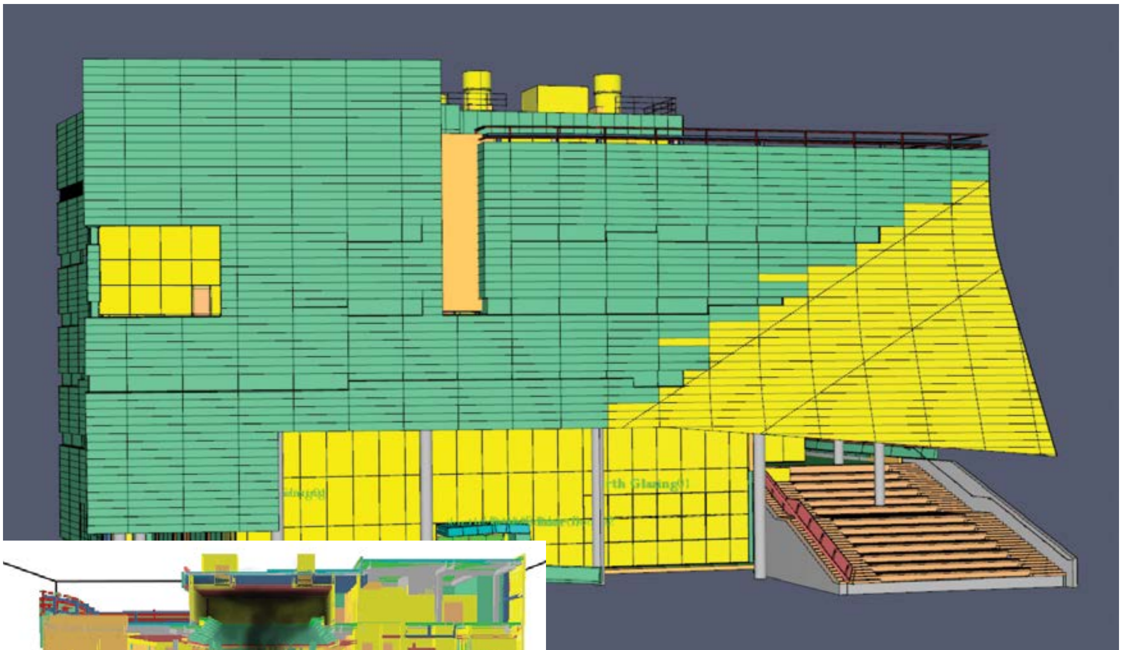
Atriums must be separated from the rest of the building by one-hour fire barriers or horizontal assemblies. There is some flexibility in preserving the openness of the space: design teams can use fire-rated glazing or opt for non-rated glass protected by automatic sprinklers (a water curtain). This involves closely spaced sprinkler heads installed on one or both sides of the glass. Note that this type of application is not a universal substitute for a one-hour-rated fire barrier.

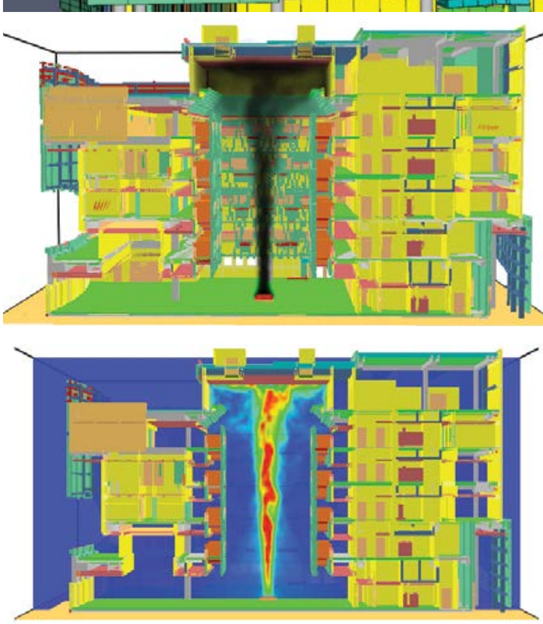
A top-hat strategy can be used to preserve grandeur at lower levels of a building while enclosing the upper floors to better manage fire and smoke risks. This design strategy allows atriums that appear to connect three or more stories (but only connect two) to omit a smoke control system when only the two lowest stories are open to the atrium and all stories above are separated as a vertical shaft. This configuration resembles a top hat sitting above the open atrium with the upper levels effectively capped and isolated, as shown in Figure 2.

In the traditional approach, rather than the top-hat method, up to three floors can open directly into the atrium, provided the smoke control system is designed to control smoke in the occupied spaces within the atrium. Some teams also explore deployable fire/smoke curtains to maintain openness while satisfying separation requirements. These solutions require careful planning, integration into smoke control modeling, and early approval from the AHJ.

Table 1: EXAMPLE OF OCCUPANT TENABILITY CRITERIA

Criteria	Limits	Location and specifications	Reference
Temperature	60 C (140 F) maximum	1.8 m (6 ft) above highest walking surface outside of plume	NFPA 92
Visibility	10 m (33 ft) minimum	At any occupied surface within 1.8 m (6 ft) of the floor outside of the plume	Yamada and Akizuk[2]
Carbon Monoxide	380 ppm maximum	At any occupied surface within 1.8 m (6 ft) of the floor outside of the plume	NFPA 92 Annex M3





University of South Florida, Judy Genshaft Honors College Building, Tampa, Fla., smoke modeling.

IMAGES COURTESY SIMPSON GUMPERTZ & HEGER (SGH)

Walls

Atrium walls are generally required to be constructed as fire barriers in accordance with *IBC* Section 707, which mandates that walls extend continuously from the top of the foundation or floor/ceiling assembly below to the underside of the floor or roof sheathing, slab, or deck above, and that they be securely attached (Section 404.6B). Additionally, supporting construction for a fire barrier must be protected to the same fire-resistance rating as the barrier itself, unless an exception permits otherwise.

Atrium fire barriers must be tested in accordance with ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials,* or UL 263, *Fire Tests of Building Construction and Materials,* the standard fire tests for building construction and materials. These tests evaluate the barrier's ability to resist the passage of fire and maintain structural integrity for a prescribed duration. Testing includes exposure to a standard time–temperature fire curve, followed by a hose-stream test to assess durability under both thermal and mechanical stress.

Openings

An open concept allows spaces to interact with each other, lets light flow through, and enables better interaction between the spaces and their

Atriums should be treated as central hubs.

IMAGE COURTESY STUDIO LIBESKIND

users. Flowing the atrium into the rest of the building can seem challenging when a fire barrier is required to separate the spaces. However, openings in fire barriers are still permitted when protected in accordance with Section 716 of the *IBC*. Fire doors, horizontal shutters, and fire windows (opening protectives) must be tested to ensure they remain intact when subjected to a fire department hose stream, in accordance with NFPA 252, UL 10B, or UL 10C. Typically, these openings are limited to a single opening of 14.4 m^2 (156 sf) and a maximum aggregate width of 25 percent of the wall length. However, single opening size does not apply when adjoining floor areas are fully sprinklered and neither apply when opening protectives tested to ASTM E119.

Smoke control

Once a space qualifies as an atrium under building codes, one of the most significant code requirements is the installation of a smoke control system. This system is critical for maintaining safe conditions during a fire event. Most atriums require mechanical exhaust fans, which must be strategically located so smoke can flow freely to the fans without obstruction. These fans must be connected to standby or backup power sources to provide operation during a power outage.

In addition to exhaust, makeup air provisions are necessary to replace the air being removed and to maintain pressure balance. This can involve installing automatic door openers on exterior doors to allow air into the building or installing mechanical makeup air units—or both. Smoke or heat detection and control systems are also essential. Beam smoke detectors, which span long distances across the atrium space, are commonly used to detect smoke early and at high elevations. Some designs may incorporate UV/IR flame detectors for quicker response in certain environments. The fire alarm system plays a central role in this setup by detecting smoke, managing the sequence of operations, activating control systems, closing fire doors, shutting down elevators, and notifying occupants.

To evaluate smoke control performance, criteria are established to keep conditions safe long enough for people to get out and can still see where to go. Key factors, including temperature, visibility, and carbon monoxide concentration (Table 1), are measured within 1.8 m (6 ft) of the walking surface. Thresholds are selected using applicable standards, building occupancy, and

The central atrium at Kresge College in Santa Cruz, Calif., connects classrooms, offices, and lecture halls across all three levels of the building.
PHOTO COURTESY SIMPSON GUMPERTZ & HEGER

the agreed-upon design fire scenarios. Tenability criteria and the design fire scenarios are typically developed by the fire protection engineer, agreed to by the design team/owner, and approved by the AHJ. They serve as pass/fail metrics for computational fluid dynamics (CFD) or zone modeling and directly drive major design decisions, such as exhaust rates, makeup air paths, and detector and control strategies.

Determining the performance of a smoke control system typically involves detailed modeling. Engineers often use CFD or zone models to simulate how smoke will behave in the 3D atrium space. This includes building a full 3D model of the atrium and running complex simulations that can take days or even weeks to complete, depending on the project's size and complexity. The final design must demonstrate that smoke can be effectively controlled under various fire scenarios.

These systems demand early coordination between the architect, fire protection engineer, mechanical engineer, electrical engineer, and building owner. Waiting too long to address smoke control often results in late reworking, lost ceiling space, or costly redesigns of fan sizes, ductwork locations, or atrium walls.

Egress

Atriums are often treated as central hubs, and it is tempting to rely on them heavily for egress. But there are limits. Exit access travel distance through an atrium is restricted; if the egress path passes through the atrium at the level of exit discharge, it must still comply with the general exit access travel distance requirements laid out in *IBC* Section 1017.2. However, when egress through the atrium occurs on levels other than the level of exit discharge, the travel distance within the atrium is limited to 61 m (200 ft).

IBC 1023.2 requires interior exit stairways to be enclosed in fire reistance-rated construction with an exception for interior exit stairways in atriums to be unenclosed. *IBC* 404 outlines criteria for interior exit stairways located within the atrium, requiring each stairway to be accessible from at least two directions and base code criteria to be followed for stairways.

Whether occupants are exiting from the atrium or another part of the building, they must have access to a stair outside the atrium because no more than half of the required interior exit stairways are allowed within the atrium. The discharge from those interior stairways must comply with *IBC* Section 1028.1. This requires exits to discharge directly to the exterior of the building, or, for up to 50 percent of the required capacity, to discharge through interior areas, including atriums, at the level of exit discharge when specific criteria are met. The stairs must lead to an unobstructed area where an exterior door is readily visible and accessible. The area must be separated from areas below with fire-resistant construction equivalent to the stair enclosure and must be sprinklered. If both an interior stairway and an open exit access stairway serve the same floor and discharge at the same level, they must be located at least 9.1 m (30 ft) or one-quarter of the building's diagonal apart (whichever is less).

Sprinklers

Since residential and institutional buildings must be sprinklered in all cases, and most other occupancies require sprinklers when the building is larger than 1,110 m² (12,000 sf), buildings large enough to feature an atrium will likely require sprinklers regardless. However, even if sprinklers would not otherwise be required, any building with an atrium must be fully sprinklered unless the area of the building adjacent to the atrium is separated by at least a two-hour fire barrier or a horizontal assembly.

Where the ceiling of the atrium is more than 16.8 m (55 ft) above the floor, sprinkler protection at the atrium ceiling is not required. Instead, the code relies on smoke control systems and only requires sprinklers at lower levels or balconies to control fire hazard.

Standpipes

The *IBC* does not have specific requirements for standpipes in atriums. However, standpipe requirements depend on a building's height and occupancy, so a building with an atrium is likely to require coverage by standpipes.

A sufficiently large atrium may require a hose valve, as standpipe hose connections must be located so that all portions of the building are within 61 m (200 ft) of a hose connection, measured along the path of travel.

Conclusion

Atriums are not something to avoid–they are something to plan for. Clear planning for code-compliant smoke control, barriers, and egress can unlock the full potential of an atrium while staying within budget. The real challenge is not the code itself, but realizing too late that open exit access stairs or a grand lobby qualify as an atrium. At that point, retrofitting complex systems into a fully coordinated design can derail the budget and timeline.

NOTES

[1] National Fire Protection Association. NFPA 92: Standard for Smoke Control Systems, Annex M3.6, NFPA, 2018.

[2] Yamada T., and Y. Akizuki, *"Visibility and Human Behavior in Fire Smoke,"* SFPE Handbook of Fire Protection Engineering, 5th Ed., Table 61.3, P2198.e.

[3] NFPA 92 (2018 version) – Standard for Smoke Control Systems, NFPA, Quincy, Mass.

additional **information**

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KEY TAKEAWAYS

Atriums offer significant aesthetic and daylighting benefits but introduces rigorous fire- and life-safety code requirements. Architects must engage code consultants early to manage complex systems, such as smoke control, fire-rated barriers, and standby power, ensuring open designs remain safe and cost-effective without disruptive late-stage design modifications.

MASTERFORMAT NO.

08 44 13–Glazed Aluminum Curtain Walls
21 13 13–Wet-Pipe Sprinkler Systems
23 09 33–Smoke Control Sequence of Operations

UNIFORMAT NO.

B10–Superstructure
B2010–Exterior Walls
D30–Fire Protection

KEYWORDS

Division 08, 21, 23
Atrium code requirements
Egress and travel distance
Fire-rated barriers
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Beyond the Single-Family Home

Building Community-wide Fire Resilience with Concrete

By Tom Tietz

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In the aftermath of the 2025 Eaton and Palisades wildfires, California has a pivotal opportunity to redefine fire resilience, not just for single-family homes, but for the full spectrum of community structures. Construction specifiers can prioritize selecting fire-resistant products and materials, including concrete systems, which offer a proven, cost-effective path to holistic resilience and support density, affordability, and sustainability.

A new era of wildfire risk

In California and in communities around the nation, Americans are living in a new era of wildfire risk. Most dramatic recent examples are the Los Angeles-area Palisades and Eaton fires, which destroyed more than 16,000 structures in January 2025 and prompted projected insurance payouts of $35 to $45 billion. These incidents are hardly isolated in an era when extreme weather is increasingly the norm.[1]

In the aftermath of the Palisades and Eaton fires, most of the rebuilding discussion has focused on single-family homes. But while the loss of homes is deeply personal, commercial, multifamily, mixed-use buildings, and other infrastructure are also critical to the fabric and recovery of communities. People need schools, places to work, worship, shop, and gather. The destruction of those fires not only destroyed people's homes—it disrupted schools, workplaces, healthcare facilities, retail centers, and essential services. This type of infrastructure accounted for 28 percent of structures lost in the blazes, and they must also be rebuilt with resiliency in mind. If the same level of care and foresight is not applied, it risks repeating the same disasters again.[2]

Community-wide fire resilience is not just about protecting individual homes; it is about ensuring the continuity of entire neighborhoods, economies, and social networks. Care must be taken to ensure buildings and their contents do not add additional fuel to these ravaging firestorms.

As the Greater Los Angeles Area continues to rebuild more than a year after the fires, California Senate Resolution 61 and recent executive orders explicitly support rebuilding with more resilient materials, recognizing the long-term benefits for

The 681 Florida Street Affordable Family Housing in San Francisco project highlights that concrete construction simultaneously advances California's building priorities of resilience, affordability, and urban density.
PHOTO © ANDREW CAMPBELL NELSON

communities.[3] The imperative is clear: fire resilience must extend beyond the home, encompassing every building type that sustains community life.

As building codes evolve and communities rebuild, specifiers play a role in ensuring resiliency. The design and material choices made today affect the affordability, sustainability, and resiliency of projects in areas affected by disasters such as the Palisades and Eaton fires.

The technical benefits of concrete-based systems

Southern California's residential landscape and other structures have historically been built with wood-frame and stucco construction, which are more vulnerable to wildfires. In recent years, the regulatory landscape has evolved toward stronger fire-resilience requirements, often through local overlays onto the *California Building Code* (*CBC*).[4]

These regulations prioritize fire-resilient construction by addressing materials, including roofing and exterior walls, vents and eaves, and defensible space and vegetation management, to ensure the use of noncombustible or ignition-resistant materials.[5] Since cement and concrete masonry are classified as noncombustible materials under both the *CBC* and *International Building Code* (*IBC*), they are foundational for fire resilience. Rebuilding in the wake of the 2025 fires presents an opportunity to reconsider large-scale choices of building materials.

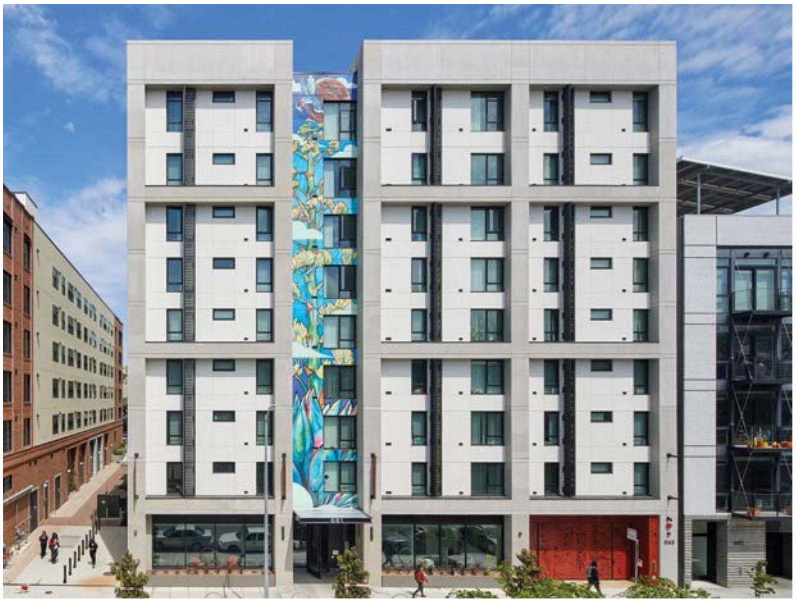
But as many rebuilding experts point out, while regulation updates are significant for improving future resiliency, minimum compliance should not be the goal. In many ways, the most dangerous buildings constructed are those that meet minimum code requirements, which often reflect the same construction practices that did not survive intense fire events.

"It's a habit, people build with wood because that's how it's always been done," says Kit Miyamoto, CEO of Miyamoto International, a global structural engineering and disaster risk reduction organization. "For single-family homes especially, cast-in-place concrete or panelized systems just are not part of the cultural norm, even though they perform better and, in many cases, don't cost significantly more."[6]

Concrete solutions not only meet but exceed code requirements for fire-resilience. The thermal mass of concrete delays heat transmission, protecting structural integrity and providing critical time for evacuation and fire response.[7] For example, concrete masonry walls (*e.g.* 203 mm [8 in.] solid CMU) can achieve up to four-hour fire resistance ratings per American Concrete Institute (ACI) 216.1/TMS 216, *Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies* and ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*.[8,9]

Resilience is the obvious benefit of building with concrete, but long-term sustainability should not be overlooked. The use of concrete in rebuilding supports density to enable taller, slimmer structures, mitigates embodied carbon, and offers compatibility with green certifications and sustainability requirements.[10] Properly

Community-wide fire resilience is not just about protecting individual homes; it is about ensuring the continuity of entire neighborhoods, economies, and social networks.



In San Diego, The Continental is an award-winning building that proves safety benefits and maintenance benefits for the tenants and developers alike.

PHOTOS COURTESY NATIONAL READY MIXED CONCRETE ASSOCIATION (NRMCA)

during earthquakes and seismic events and require far less intervention over time.[11]

The sustainability and financial case for resilience investments

Increasingly, architects are taking a longer view of sustainability, particularly in high-fire risk areas such as Southern California. One such architect, Janek Dombrowa of JTD Architects, is supporting a community rebuilding project in Malibu's Sunset Mesa that prioritizes concrete construction.

"There is also what I call 'survival sustainability.' It is not sustainable for places like Malibu to rebuild every five years after fires," says Dombrowa. "If you assume a 30-year mortgage, you should not be rebuilding the same home two or three times during that period."[12]

Dombrow adds that while concrete has historically suffered from misperceptions about affordability, concrete systems are not inherently more expensive than traditional materials such as wood framing, especially when reduced delays, increased durability, and insurance implications are considered.[13] He also notes concrete is often produced locally, further reducing transportation and supply chain costs.[14]

"The longer reconstruction takes, the more expensive it becomes, and the harder it is for people and businesses to return," Miyamoto adds. "Many residents desperately want to come back to places like Altadena or Topanga [communities impacted by the 2025 fires] because of the strong cultural and community ties. If rebuilding is delayed too long, those ties begin to unravel."[15]

Recent testimonials from homeowners rebuilding with concrete systems have highlighted both the simplicity and speed of construction.

Each dollar not invested in disaster resilience today could cost up to $33 in lost future economic activity.[16] Investing in resilient construction is not just a safety imperative; it is a cost-effective strategy for communities rebuilding or preparing for natural disasters. Concrete construction allows specifiers to build back more resiliently and more affordably, without sacrificing one for the other.

Multifamily case studies

The Continental (San Diego)

In San Diego's Little Italy neighborhood, The Continental demonstrates what affordable, fire-resilient construction can look like in practice. This mixed-use development, named "Project of the Year" by Builder's Choice & Custom Home Design Awards, comprises 42 studio units averaging roughly 35 m^2 (377 sf) across 2,508 m^2 (26,996 sf), offering workforce housing priced below competing properties in the area.

The project's post-tensioned concrete structure simultaneously delivers on multiple priorities. In an earthquake-prone area, post-tensioning lightens the building, improving lateral stability and reducing foundation demands, which is less likely with wood or steel.[17] The structure provides inherent fire resistance

This home in Groveland, Calif., designed and built by PHNX Development, was able to achieve dramatic fire insurance savings from the use of non-combustible materials throughout the home.

PHOTO COURTESY PHNX DEVELOPMENT

This home, designed by Hubbell & Hubbell Architects in San Diego County, is built with non-combustible walls and a roof system in a CalFire Fire Hazard Severity Zone.

PHOTO COURTESY HUBBELL & HUBBELL ARCHITECTS

and durability with minimal long-term maintenance, lifecycle advantages that benefit both the developer and tenants.

Florida Street Affordable Family Housing (San Francisco)

In the heart of San Francisco, the 681 Florida Street Affordable Family Housing project demonstrates how concrete construction can simultaneously advance resilience, affordability, and sustainability. The nine-story development provides 130 units for low-income families and has earned recognition as a new benchmark for affordable housing in the Bay Area. The project highlights that concrete construction simultaneously advances California's building priorities of resilience, affordability, and urban density. The project also achieved a 36 percent reduction in concrete's embodied carbon by strategically optimizing the use of Supplementary Cementitious Materials (SCMs).

The project's post-tensioned concrete structure achieved its cost and design goals. Slim 203-mm (8-in.) post-tensioned floor slabs allowed the building to be under 23 m (75 ft), avoiding the costly high-rise classification that would have significantly increased project costs. This awareness of density, a significant consideration for multistory structures in fire-prone areas, allowed the project to maximize residential space while remaining cost-efficient. Other structural systems would not have achieved this level of cost efficiency, critical for affordable housing projects, where minimizing the cost per unit is essential to market competition.

Equally notable is the project's sustainability performance. Achieving a 36 percent reduction in the embodied carbon of the concrete and a 23 percent reduction overall, the building operates without fossil fuels and meets the 2030 Challenge energy use intensity standards. It has earned Platinum GreenPoint Rated certification, Fitwel certification, and recognition under the International Living Future Institute's (Living Future) Living Building Challenge.[18]

Fire-resilient concrete techniques for single-family construction

The fire-resilient construction techniques discussed in this article are also pertinent to single-family homes, which account for 70 percent of the losses in last year's Palisades and Eaton fires.[19] Incorporating fire-resistant concrete systems into single-family homes offers a transformative opportunity to rebuild for long-term safety, durability, and sustainability.

Concrete systems such as insulated concrete forms (ICFs) and insulated composite concrete forms (ICCFs) are ideal for single-family homes in wildfire-prone areas. Unlike traditional wood-frame construction, which ignites quickly under wildfire exposure, concrete's non-combustible properties allow it to withstand temperatures of up to 1,200 C (2,192 F) without structural failure.

To achieve comprehensive fire resilience, single-family homes must be designed as systems. This includes fire-rated windows and doors, ember-resistant vents, roofing materials, and enclosed soffits, which prevent ember intrusion—a leading cause of home ignitions during wildfires. According to Brian Kite, managing principal, SRK Architects Inc., combining passive fire resistance with active measures, such as exterior sprinkler systems and localized water storage, can further enhance protection.[20]

By adopting these strategies, single-family homes can withstand future wildfires and serve

In California, Updated Fire Hazard Severity Zone (FHSZ) maps are now subject to an additional 566,560 ha (1.4 million acres) to stricter codes.

PHOTO COURTESY HUBBELL & HUBBELL ARCHITECTS

Fire-resilient construction techniques are pertinent to single-family homes, which account for 70 percent of the losses in last year's Palisades and Eaton fires.

PHOTO COURTESY PHNX DEVELOPMENT

as models for sustainable, disaster-resilient construction in California and beyond.

Practical guidance for construction specifiers

For specifiers working in wildfire-prone regions, achieving meaningful fire resilience requires deliberate decisions across three areas: the material specifications and code benchmarks that define a project's fire-performance floor, the structural systems that deliver noncombustible performance, and the design and construction process choices ensuring resilience does not come at the expense of affordability or sustainability.

Material specifications and codes

- Specify noncombustible/ignition-resistant exterior walls, Class A roofing, ember-resistant vents, and defensible space in Wildland Urban Interface (WUI) zones.[21]
- Move beyond minimum code, specify two-hour fire-rated assemblies in severe fire hazard zones.
- Address all components, including walls, windows, roofs, vents, eaves, and soffits, for comprehensive protection.[22]

System selection

- Consider wall systems such as ICFs, concrete masonry, ICCFs, and precast sandwich panels for superior fire resistance, speed, and cost-competitiveness with wood framing.
- Select concrete systems based on project needs, leveraging concrete's design flexibility and performance.

Design and construction process

- Engage builders and designers early to optimize cost, sustainability, and resilience.
- Evaluate the total cost of ownership, not just the initial cost, accounting for maintenance, insurance, and avoided reconstruction.[23]

additional information

AUTHOR

Tom Tietz is the executive director for the California Nevada Cement Association (CNCA), a not-for-profit organization committed to developing sustainable and economical construction solutions for California and Nevada with an emphasis on the use of cement and concrete. He is involved in and oversees CNCA's regulatory and legislative efforts focused on infrastructure and the environment. Tietz is also actively engaged in the association's mission to be an established technical resource in the region. For more information, visit www.cncement.org.

KEY TAKEAWAYS

Following devastating wildfires like the 2025 Palisades and Eaton fires, construction specifiers are shifting toward non-combustible concrete systems to protect entire communities. Concrete provides a cost-effective, durable solution for multifamily and commercial structures that balance fire resilience with sustainability, density, and significant insurance savings.

MASTERFORMAT NO.

03 30 00–Cast-in-Place Concrete
03 40 00–Precast Concrete

UNIFORMAT NO.

B20–Exterior Enclosure
B10–Superstructure
D30–Fire Protection

KEYWORDS

Division 03
Fire resilience
Non-combustible construction
Wildfire Urban Interface (WUI)
Insulating concrete forms (ICF)

- Integrate both passive (fire-resistant assemblies) and active (suppression and automation) systems.[24]

The specifier's moment to lead

From 2010 to 2020, the number of structures lost to wildfires in the western U.S. increased by 246 percent.[25] The trends that led to the destructive Palisades and Eaton fires will continue to increase, making resilient building even more urgent.

Today, California stands at a crossroads. Updated Fire Hazard Severity Zone (FHSZ) maps now subject an additional 566,560 ha (1.4 million acres) to stricter codes, and future code cycles are likely to expand WUI-level requirements even further.[26] Increasingly, insurance markets are factoring resilience into premiums and coverage.

Against this backdrop of climate realities and housing needs, this is a unique moment to shift from code compliance to genuine resilience. It is time for construction specifiers to embrace the responsibility and opportunity to help shape communities that are not only fire-resistant but also affordable, sustainable, and enduring.

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Seeing Clearly into the Future

Window Replacement Detailing in Historic Buildings

By Stephen Holland, P.E. and Josh Aisenberg, AIA, LEED AP, NCARB

PHOTOS COURTESY ANNUM ARCHITECTS

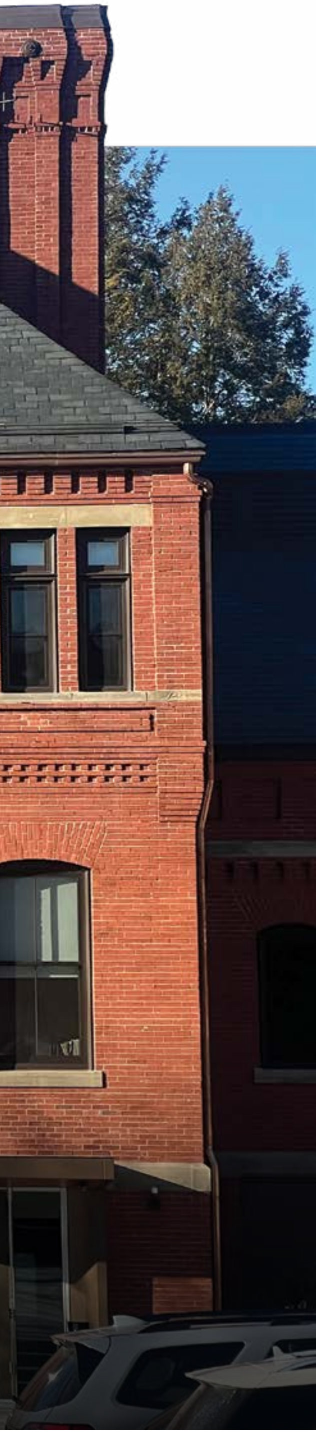
Windows are an essential component of historic building facades. They define both the building's exterior character and the relationship between occupants and the outside world.

Eventually, a replacement project becomes necessary when the windows no longer perform their core functions. They may be leaking water, thermally inefficient, or too drafty for comfort.

When windows are replaced, owners often seek to preserve the building's original appearance while achieving modern performance. Designers and builders face the challenge of installing contemporary window systems into wall assemblies that may be decades—if not centuries—old.

Despite the age and variability of surrounding construction, replacement windows are expected to integrate with these walls and provide a seamless facade.

This article examines best practices and lessons learned for specifying and installing replacement windows in historic buildings. It starts with early design and high-level decisions, then progresses to granular detailing during construction. Although the focus is on punched-window replacements in historic buildings, the



Building facade before window replacement and the original 1891 facade.

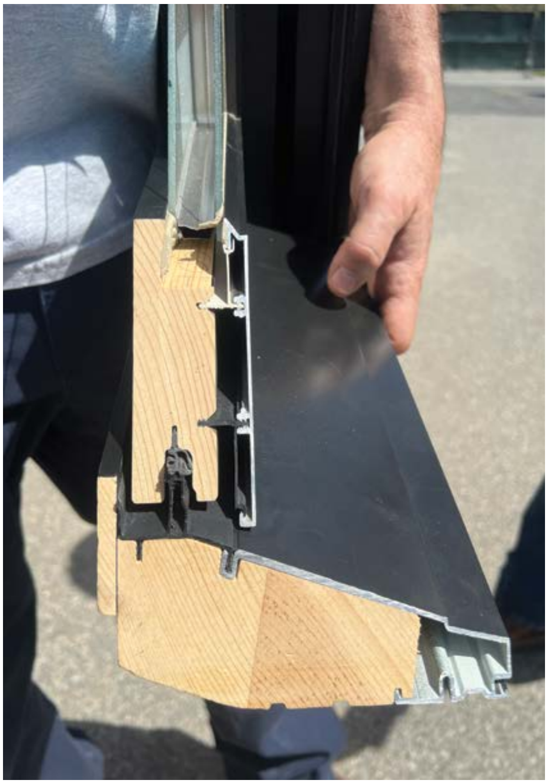
concepts and detailing strategies apply to many types of fenestrations and to existing construction in general.

Establishing aesthetic and performance goals and requirements

When planning a window replacement project, especially in a historic building, it is essential to begin with clear aesthetic and performance goals. Windows are primary visual elements that define a facade's character while also playing a major role in energy performance, occupant comfort, and long-term maintenance budgets. A successful project balances historic appearance with modern thermal, airtightness, and operational requirements. Start by defining the project's priorities: which visual features must be preserved, required thermal or acoustic performance, operational improvement expectations, and which constraints—budget, schedule, and maintenance capacity—will shape the final decisions.

Hazardous materials assessment

Before any window removal or refurbishment begins, it is critical to evaluate existing sealants



An aluminum-clad wood system combining the historic accuracy of wood windows on the interior with the improved finish durability and weathertightness afforded by the aluminum cladding on the exterior.

PHOTOS COURTESY ANNUM ARCHITECTS

and coatings for hazardous materials. Sealants used in historic windows, particularly those installed before the late 1970s, can contain asbestos, and older paint systems often contain lead. Disturbing these materials during demolition, surface preparation, or installation poses health risks to workers and occupants and can trigger regulatory requirements. Testing should be performed early in design to inform specifications, contractor means and methods, abatement scope, and project cost and schedule. Proactively addressing hazardous materials helps avoid delays, ensures compliance with safety regulations, and allows window replacement work to proceed without compromising worker safety or historic fabric.

Researching historic landmark and code requirements

Historic preservation guidelines and local building codes often set different, sometimes competing, requirements. Thorough research into applicable landmark commission standards and energy codes is the first technical task. Identify which elements of the existing windows contribute to the building's historic character—sightlines, muntin patterns, profile depths, and stile and rail proportions—and determine whether the reviewing authority protected or favorably recommends those elements. While most historic buildings will be subject to review by a state, county, or local historical preservation commission, some buildings are listed on the U.S. National Register of Historic Places and are therefore subject to prescriptive and often more stringent standards defined in The Secretary of the Interior's Standards for Rehabilitation as administered by the National Park Service (NPS).

Keep in mind that the building's current appearance may not reflect its original historical appearance. In one example, the owner provided historic photography from the original construction that revealed the window sashes were originally a darker color, not the lighter color they were painted before replacement. The local preservation commission agreed it would be appropriate to use a darker color so that the replacement windows would look more like the original windows.

At the same time, establish the minimum required U-values, air infiltration, and safety glazing standards under the current code. Many jurisdictions accept a range of compliance strategies, *e.g.* preserving original windows and improving thermal performance with interior storm sashes, while others may require replacements to meet prescriptive U-values. The design challenge is to reconcile preserved sightlines and muntin geometry with glazing performance. For example, historically narrow frames and sashes are often at odds with deeper, thermally broken modern systems. Document these conflicts early and prepare options to present to the reviewing body.

Owner concerns and objectives

Owners typically prioritize four interrelated concerns: cost, compatibility, operability, and durability/maintenance. Clarify how each will be weighted in the decision-making process:

- Cost—Distinguish upfront capital costs from life-cycle costs. High-fidelity historic replications or bespoke steel windows will command higher initial investments but may be necessary for landmark approvals. Present alternatives and expected maintenance costs over 10 to 30 years to support budgeting.
- Compatibility—Compatibility covers both visual integration and material behavior, *i.e.* thermal expansion and corrosion resistance. Ensure selected materials and finishes are

It is often necessary to find a replacement window system that can accommodate precise detailing to match the existing window features as closely as possible, such as integral radiused casing profiles and narrow, simulated divided lite muntins.

compatible with adjacent historic fabric to avoid long-term damage. Dissimilar metals such as copper, steel, and aluminum require a bond breaker to prevent galvanic corrosion.

- Operability—Users expect windows to open easily and lock reliably so they can control the natural ventilation of their spaces. Consider adding interior handles for easier operation. Locks should be within reach without the need for a stool or ladder. For hung windows, exterior insect screens are more common, though retractable interior screens connected to the operable sash are often available.
- Durability and maintenance—Low-maintenance exterior finishes, such as resin-based shop-applied coatings on metal, will be more expensive upfront than field-painted wood but will not require as much maintenance over the life of the window.

Refurbish or replace?

The next step is to evaluate whether to refurbish existing units or to replace them. This decision should be based on condition, historical value, performance needs, and lifecycle cost.

Selective refurbishment preserves high-profile units, such as prominent facade windows, while replacing others that are beyond economical repair. Comprehensive replacement may be appropriate when original windows are severely deteriorated, whole-building energy upgrades require uniform performance, or a uniform appearance is required.

A field mockup of a snap-in aluminum casing approximating the size and shape of the existing wood casing.

Interior storms are an effective, historic-sensitive approach to improve U-values and air tightness without altering the exterior appearance. They are reversible, preserve the original windows, and often meet code and reviewer requirements when exterior changes are restricted.

A lifecycle cost analysis compares initial repair or replacement expenses with projected maintenance, energy savings, and residual values. Careful repair, combined with added weatherstripping and interior storms, yields a favorable cost-to-benefit ratio when the original windows are intact. Conversely, when wood rot, corrosion, or failed glass seals are extensive, replacement may be an economical long-term choice.

Samples of standard aluminum window cladding color options under consideration (far right) are reviewed alongside the palette of material samples being considered for other architectural elements.

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Figure 1

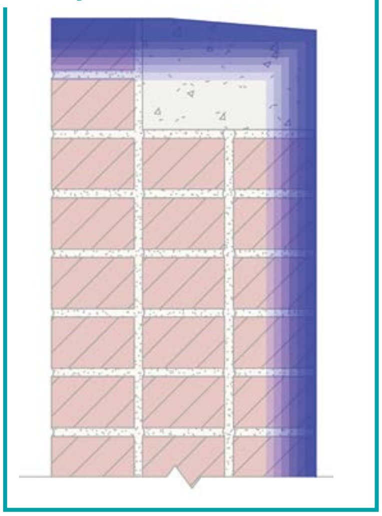

Figure 2

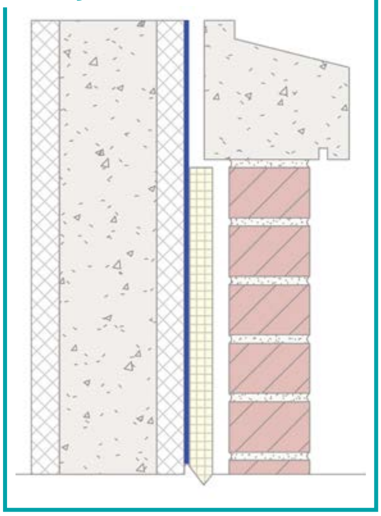

Figure 1: The outer face is generally the best surface to seal to, but the wall's weather barrier (shown in blue) is supplemented by its depth of material and reservoir capabilities.

Figure 2: An existing wall membrane (shown in blue) or the backup wall is the best place to seal to.

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Materials, finishes, and glazing types

Material choice impacts aesthetics, performance, durability, and cost. Steel windows replicate the thin profiles and slender sightlines of many industrial or early 20th-century buildings. However, they also require attention to corrosion protection and thermal breaks. Wood windows are often found in many residential and civic buildings. Wood works well with high-quality paint finishes and is easier to repair than steel. Still, it requires regular maintenance because it is susceptible to rot if the outer finish is neglected. Clad systems, primarily constructed of wood but featuring aluminum or composite exterior cladding, combine wood's general appearance with lower exterior maintenance and increased weather resistance, a good compromise for reduced upkeep.

True divided lites use multiple glazed units separated by full muntins and are historically accurate, though modern replacements often use sealed units with thermal spacers, increasing the depth. The individual panes of glass create slightly different reflections, adding to the overall look and appeal. Conversely, simulated divided lites (SDL) use a full panel of insulated glass and place muntin grids on the exterior and interior glass surfaces. SDLs can also be specified with a spacer bar between panes to closely mimic the look of a true divided lite at a lower cost. Some review commissions permit SDLs if they convincingly replicate proportions and shadow lines, while more stringent commissions may require true divided lites. The surface muntins are available in a variety of widths and profiles, including the traditional ogee profile and the more contemporary square profile. It is essential to confirm available window details and compare them to the existing trim profiles, sill dimensions, drip edges, and head details to maintain historical proportions.

Accessories, including screens, shades, and hardware, should be considered early as they affect the window's overall aesthetic, functionality, and cost. Screens can be retractable or removable to minimize visibility, while shades and blinds affect occupant comfort and solar gain. Hardware should match the period's appearance while meeting modern function and security standards.

Implementation: Required approvals from historic commissions

Once goals, materials, and a preservation strategy are agreed upon, the implementation phase converts design intent into approvals, shop drawings, and field execution. Prepare a submittal anticipating questions from the historic commission, including elevations showing

proposed changes, material samples, muntin profiles, glazing sections, and photographs of existing conditions. Where replacements deviate from originals for performance reasons, show mockups or precedents and provide a rationale grounded in energy or safety codes. Early engagement with commission staff can streamline approvals and reduce redesign delays.

Engaging manufacturers and installers for detailed support

Select manufacturers and installers with proven experience with similar historic replacement projects. Manufacturer engagement can provide critical technical data, including thermal performance, computer-aided design (CAD) and building information management (BIM) profiles and details, and glazing options. Installers should demonstrate sensitivity to preserving surrounding masonry or trim during removal and to installing flashings, sills, and interfaces that prevent moisture infiltration. Contractually require coordination drawings and outline responsibility for interface elements, *e.g.* whether the new windows include exterior trim such as head/jamb and sill extensions, or if those will be provided by others and integrated on site.

Finish samples and assembly mockups

Finish samples and full-scale assembly mockups are critical. Review actual paint or finish samples on a representative substrate. Field mockups allow stakeholders to evaluate sightlines, reflectivity, muntin shadows, gasketing colors, and the fit of the hardware. Mockups also serve as quality benchmarks for final acceptance and reduce disputes over finish sheen, color matching, and profile dimensions.

Window detailing and existing wall assembly

Once the basis-of-design window, including its essential features, is approved by all parties, the more granular detailing of the windows can begin.

It starts with the rough opening and the adjacent wall assembly. What is the construction of the existing wall? It could be a mass assembly, such as multi-wythe masonry or precast concrete, or a veneer assembly, such as cavity brick or a vinyl rainscreen. This is an important distinction because it determines what part of the wall the window should seal to and anchor to.

In a mass assembly, the air and water barrier is provided by its thickness and layering, as well as the continuity of its joints. This is mostly on the surface, but interior components in a mass wall will contribute to the weatherproofing. In a veneer assembly, there is typically an existing wall membrane that acts as the primary air and water barrier.

Detailing in wood blocking

In most installations, the rough opening needs to be modified to accommodate the new windows.

This is usually achieved with wood blocking, such as pressure-treated lumber or plywood. The wood blocking serves multiple purposes. It helps distribute the wind load through the rough opening and provides a hard, flat, continuous substrate to anchor the window. Most existing openings are a grab bag of oddities and obstructions. In one mockup, existing stone anchors at the window head obstructed sealant-joint installation, but removing them was infeasible. This would be an ideal opportunity to add blocking around and over the anchors to smooth out the head.

Left: Stone anchor interrupting the window head seal.

Right: Membrane flashing installed over wood blocking forming a window sill pan.

PHOTOS COURTESY LEMESSURIER CONSULTANTS

Top: Membrane flashing lapped onto brick masonry at a mass wall opening.

Bottom: Membrane flashing lapped onto adjacent wall membrane at a veneer opening.

PHOTOS COURTESY LEMESSURIER CONSULTANTS

Window installation is precise work that requires plumb, level, and watertight installations. Glazers should not have to wrestle with the varying construction tolerances of the existing substrate. Use wood blocking to sculpt the desired condition so the glazer can install windows in ideal conditions.

In addition to creating this uniform substrate, blocking can be strategically installed behind the window to provide support for a sill pan.

It is prudent to mock up the window with wood blocking before installing blocking everywhere. Frequently, contractors will hold back the glazers until the mockup is approved, but will greenlight the carpenters before mockup approval.

Detailing in membrane flashings

Once the blocking is in position, the membrane flashings can be installed around the rough opening. These membranes can include a variety of sheet-applied and fluid-applied products designed to resist air and water infiltration. Like wood blocking, these also serve multiple purposes. They can form a pan flashing at the sill to collect any infiltrating water and prevent it from reaching the interior. It will protect the wood blocking from moisture and can serve as the bridge between the window and the rough opening's weather barriers.

For mass assemblies, the membrane flashing should lap onto a significant portion of the mass wall to establish continuity. At veneer assemblies, the membrane flashing should lap onto the existing wall membranes. If there are no existing membranes in the cavity, the membrane flashing can lap onto the backup wall.

For the flashing to be effective, the different pieces must be properly lapped and sealed, especially at the sill-to-jamb and jamb-to-head interface locations. Sequencing drawings can help explain how the pieces should lap.

Most window details call for two sealant joints, installed on the outboard and inboard faces of the windows. Since the exterior sealant joint is expected to break down from UV exposure, the interior sealant joint is usually the integral component to air and water barrier continuity, and the exterior sealant joint is considered a sacrificial rainscreen. Designers often go a step further and install weeps in the exterior sealant joint sill. This allows any incidental water leaking through the window, jambs, or head to drain harmlessly.

In collaboration with the air and water barrier continuity, interior and exterior trims need to be considered. One negative to adding blocking is that the potential size of the glass opening is reduced. However, this can be positive if the original window had ornate trims that the project is trying to replicate. The blocking will support the trim piece, and the trim piece will hide the waterproofing seals.

Detailing in window anchorage

The window's weather seals cannot be designed without coordinating with its anchorage. When attaching the window to the rough opening, fasteners must pierce the membrane flashing or sealant joints. Manufacturers offer multiple attachment methods, and some are easier to waterproof. This is mostly a concern at the sill, which will have to resist potential pooling water.

Some manufacturers will even allow installers to omit fasteners at the sill, depending on the unit's size and wind-load testing. This is the best solution if allowed. These options will vary depending on the window's style and material, and a typical aluminum sill is shown in the details below:

- Direct attachment—The default anchorage is to drill a fastener straight through the frame into the rough opening. This is not problematic with the head and jambs, but it may be at the sill, where ponding water can occur. The fastener will penetrate the membrane flashing, but the frame will prevent the discontinuity from being sealed.
- Strap anchor attachment—Many window manufacturers offer strap anchors as an alternative. Strap anchors are useful as they can be fastened farther inboard, avoiding the need to pierce the membrane flashing. A drawback is that they require interrupting the interior sealant joint. Installers need to pay special attention when detailing around each anchor. At the sill, a strap anchor extends directly back from the bottom of the window. Some strap anchors are rigid, limiting the height of the back dam.
- Angle attachment—If there is an integral back leg at the windowsill, the window can be secured horizontally to a preinstalled angle. This has multiple benefits. The flashing membrane can run up the preinstalled angle to form a back dam. The fasteners from the window to the angle are installed horizontally above any potential standing water. It is far less likely for water to leak through a horizontal fastener than through a vertical one.

Nail-fin windows are also an option for window anchorage when the window is flush with the rough opening, such as in historical wood-framed buildings.

Acceptance of installation

These details can be discussed and thoroughly vetted through a shop drawing review and performance mockup. Shop drawings should include material specifications, glazing details, thermal break placement, sealants, anchorage, and flashing interfaces.

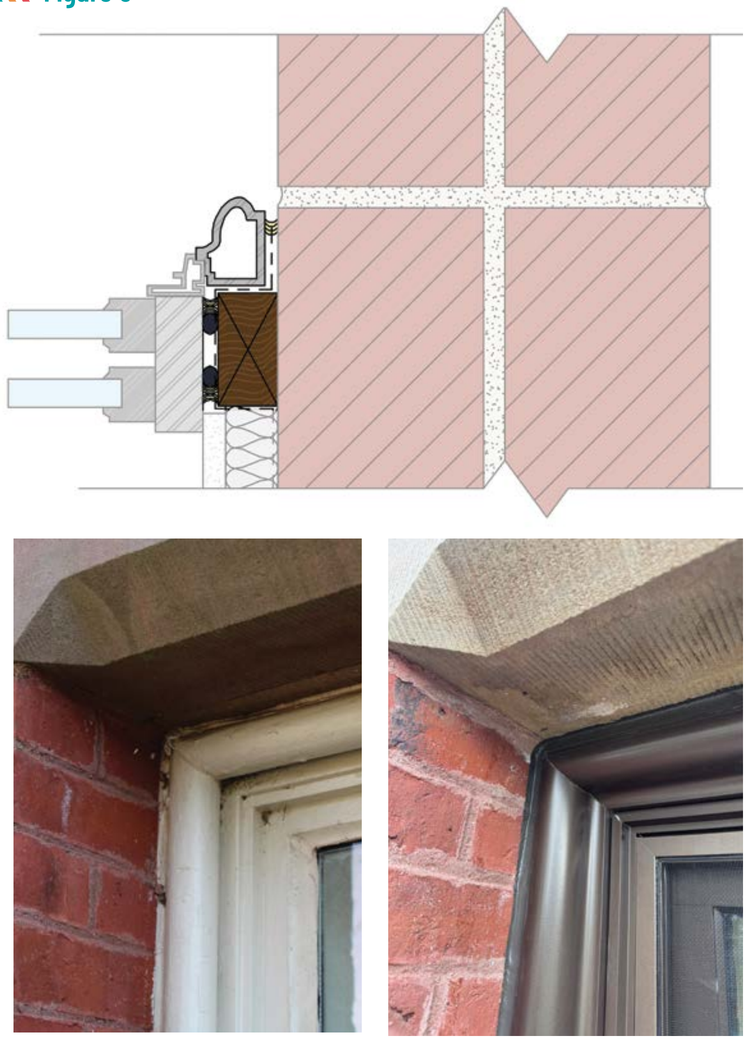
During installation, conduct periodic progress reviews. Ensure the installers protect adjacent historic fabric; verify rough opening dimensions and square-out conditions; confirm anchorage and shimming tolerances; and perform final performance testing, including air infiltration, water penetration, and operability, as required. Acceptance criteria should be tied to the project's goals—visual conformance with the approved mockup, performance test pass/fail thresholds, and a documented maintenance and operation manual for the owner.

Conclusion

Balancing historic aesthetics and modern performance requires considerable research, clear owner priorities, careful selection of systems and materials, and disciplined implementation.

Whether the project preserves original sashes and augments them with interior storms, or replaces units with historically compatible new windows, the most successful outcomes respect the building's character, satisfy regulatory and code requirements, and provide owners with a predictable maintenance and performance

Figure 3



Left: Original window jamb-to-head corner.

Right: Replaced window jamb-to-head corner.

IMAGE AND PHOTOS COURTESY LEMESSURIER CONSULTANTS

Left: An example of a strap anchor attachment.

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Figures 4 to 6: These diagram depict different variations of flashing membranes, show in the dotted blue lines.

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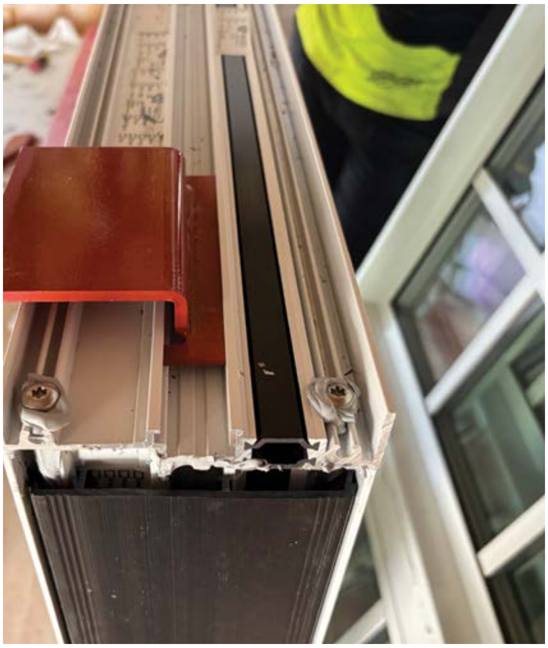


profile. With early coordination among designers, manufacturers, installers, and reviewers, a solution that meets visual, functional, and financial goals can be found.

The importance of successful window replacement projects is growing as the industry focuses on reusing existing buildings rather than new construction. New windows not only improve the building's performance but also enhance occupant comfort, encouraging owners to keep their buildings. This allows institutions to preserve their history and culture while

Figure 4

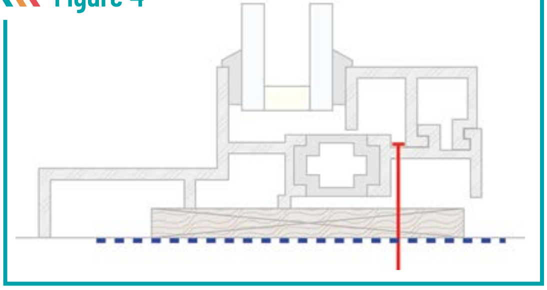


Figure 5

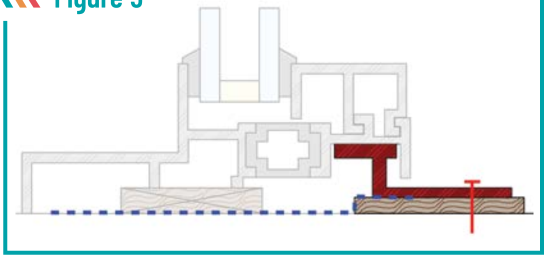
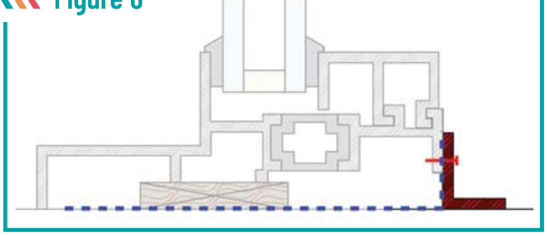


Figure 6



addressing the modern performance challenges they face. When done well, a successful window project can shepherd an existing building into the next generation of its use.

additional **information**

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KEY TAKEAWAYS

Window replacement in historic buildings requires balancing preservation of original aesthetics with modern thermal and airtightness performance. The process involves evaluating hazardous materials (asbestos/lead), researching landmark requirements, and deciding between refurbishment or replacement. Successful implementation relies on detailed rough opening preparation, including wood blocking and membrane flashings, to ensure continuity of the air and water barriers.

MASTERFORMAT NO.

08 01 51–Operation and Maintenance of Metal Windows
08 01 52–Operation and Maintenance of Wood Windows
08 50 00–Windows

UNIFORMAT NO.

B2010–Exterior Walls
B2020–Exterior Windows
C1020–Interior Windows and Glazing

KEYWORDS

Division 08
Air and water barrier
Historic window replacement
Membrane flashing
Preservation guidelines
Window anchorage

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Brushing Up on Sustainability

Rethinking Titanium Dioxide in Coatings

By Tonino F. Margani

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The coatings industry and its suppliers readily acknowledge the severe carbon footprint associated with titanium dioxide (TiO_2) production. However, as their primary customer, the new construction and maintenance market shares an equal measure of this environmental responsibility. This interconnectedness has inadvertently driven both sectors into a precarious situation. But is there a viable escape route?

Architects, developers, and builders prioritize efficiency in their daily operations, generating business, managing resources, and serving clients. Consequently, they often overlook the profound impact of a single raw material, TiO_2, on their ecological footprint, as highlighted by the Sustainable Paint Index.[1] This impact extends beyond the coatings to encompass the labor and time involved in their extraction, production, supply, and application, regardless of economic conditions.

Since 1921, TiO_2 remains the immutable material in paints and coatings. This naturally occurring, finite resource, provides unparalleled opacity—the essential whiteness and refractive index that defines paint's hiding power. Yet, this very utility creates a paradox, contributing to both economic and environmental burdens through high production costs and an out-of-control carbon footprint.

Akzo Nobel's 2017 exploration of a world without it revealed the challenge: significantly more coats (beyond the typical 2.5–3 using TiO_2) were required using zinc (the average using zinc goes up to five coats), the next best alternative. Bound by traditional formulation design that struggles with diminishing returns, chemists can only increase its content so much before the cost-benefit ratio becomes unfeasible.

As the largest consumer of global paints and coatings, the construction and maintenance market accounts for more than 66 percent of the industry's total life-cycle waste, emissions, and carbon profile of society at large. While minimizing costs for better margins is a constant driver, it should ideally align with environmental considerations. However, aligning cost-saving measures with environmental considerations often means sacrificing either performance or maintaining affordable pricing.

The sustainability conversation once centered on volatile organic compound (VOC) limits—a concept that took a generation to permeate the construction industry, yet yielded limited environmental benefit despite its relevance to human health. Today, the focus has shifted to CO2 footprint and waste reduction, resonating with an increasingly informed consumer base that demands tangible and quantifiable environmental action from the products they purchase. This directly influences how the construction sector procures and uses coatings for its clients.

In today's landscape, costs are inextricably linked to carbon emissions and waste footprint as much as to supply-side economics. Both are fundamentally determined by the number of coats or gallons required and the opacity or hiding power provided by TiO_2. Controlling the number of coats or gallons means controlling both economic and environmental costs. Achieving this, however, requires gaining control over this pivotal material.

TiO_2: The linchpin of sustainability in construction coatings

A groundbreaking sustainable construction technology, leveraging advanced light scattering and optimized TiO_2 usage, offers a novel universal coatings system for diverse substrates and market segments—potentially resolving a critical industry dilemma. This method, termed "Self-Build Technology," maximizes the efficiency of paint's core function: opacity, upon which all other performance benefits depend.

Insufficient opacity detrimentally affects peripheral benefits such as UV resistance, adhesion, washability, moisture resistance, color retention, and gloss level. The need to "paint another coat" is more than just a minor inconvenience; it reflects fundamental limitations in how coatings perform in real-world conditions. Application variables such as user skill, tools, and the number of coats applied directly influence how well a coating adheres, how durable it is, and how consistently it delivers color or gloss. No other function is more universally tied to performance, cost, and reliability across all markets and coating sectors than opacity.

This naturally occurring, finite resource, provides unparalleled opacity—the essential whiteness and refractive index that defines paint's powerful hiding power.

PHOTO ©NORMAN POGSON/COURTESY DREAMSTIME.COM

Interestingly, while the industry acknowledges the challenge of optimizing TiO_2, it often overlooks its core value because traditional formulations cannot address opacity directly. This innovation changes that. Through a unique "mechanism of action," which allows paint molecules to self-assemble in real time like Lego bricks during standard application, yielding equivalent performance from thinner film build thickness (and all other desired properties) of multiple coats from traditional coatings, but without the need of a primer or a second coat and with significantly greater durability. The technology uses "thin film building" as it does not rely on heavy, thick coats to function, but the film build result is equivalent to multiple coats and not thinner.

The underlying concept poses a simple yet profound question: "If conclusive opacity, the visual queue to stop painting, is currently achieved through multiple coats applied sequentially over time, how can these layers, and therefore the complete result, be achieved instantaneously during a single application?"

This idea draws inspiration from the optical behavior of sodium chloride (NaCl). In its static form, NaCl is transparent. However, when many grains are clustered together (mechanism of action), they become opaque, effectively scattering light. Remarkably, although TiO_2 boasts a significantly higher refractive index (2.61 versus 1.54 for NaCl), traditional coatings still require multiple layers to achieve complete opacity.

Self-Build Technology maximizes the efficiency of paint's core function: opacity, upon which all other performance benefits depend.

PHOTO ©INGVALD KALDHUSSATER/COURTESY DREAMSTIME.COM

Category	Current system: Uncontrollable chain reaction in economy and environment	Proposed system: Total control through reduced consumption
System characteristics	Maximum waste recycling infrastructure and CO2e/GHG emission generation. No control of the system using the second and third "R" (reuse/recycle).	Total control with 66 percent reduced TiO_2 means 66 percent reduced consumption through the supply chain and maximum reduced Scope 1, 2, 3 emissions. Achieved through the principle of the first "R" (reduce).
Coats and coverage	Two-and-a-half to three coats average. The general measure is one coat to a gallon, which averages 33 m² (350 sf) of paintable space. The average DIY paint job is a purchase of 12 L (3 gal) or 100 m² (1,076 sf).	Eliminating the primer and second coat through Self-Build Technology.
Raw material stage	Raw material suppliers extract and supply inherently limiting natural resources in opacity, such as TiO_2 with no synthetic counterpart, initiating excessive life-cycle waste and CO2e/GHG emissions.	Reduce TiO_2 extraction, which reduces all other material inputs through production and supply through to the end user.
Manufacturing stage	Manufacturers overproduce due to opacity limitations, compounding waste, and CO2e/GHG per gallon.	Optimize opacity, the core utility of coatings.
Regulatory and association impact	Coatings associations charge "eco-taxes" to fund fledgling recycling infrastructure to manage their image, further compounding life-cycle impacts as, ironically, recycling requires waste generation to be successful.	Not directly applicable in proposed list, but implicitly addressed through reduction strategy.
Users/construction/ maintenance stage	Users/construction/maintenance generate significant annual "post-production and use waste" (16 percent of production/860M litres in North America), CO2e/GHG per gallon at this stage hits 18 kg (40 lb).	To control the number of coats is to control costs, minimizing labour, time, and materials.
Recycling and end-of-life	Paint and product care recapture an insignificant 0.3 percent of annual waste for reuse. No demand for recycled products leads to repeated costly processes and eventual landfill disposal, continuously compounding waste and CO2e/GHG emissions.	Control of eco-effects—maximum possible prevented CO2e/wastes means detaching growth from footprint.
Overall outcome	Excessive life-cycle waste, carbon footprint, and inefficiency throughout the value chain.	This minimizes all waste across the supply/value chain: raw material extraction, finished goods production, containers, transport, energy, water, CO2e/GHG emissions, Scope 1,2,3, and recycling infrastructure limitations.

Current standards inadvertently position titanium dioxide (TiO_2) as an adversary when it could become a valuable ally, enabling genuine control over the environmental footprint while encouraging economic growth.

PHOTO ©LUCHSCHEN/ COURTESY DREAMSTIME.COM

This innovative approach reaches opacity through thin film building, where paint molecules adhere to the substrate and each other, capitalizing on refined surface tension principles. This is achieved during production through a controlled shearing effect, "magnetizing" paint molecules through specific treatment and sequencing of raw materials within each chemical component. Despite this distinctive outcome, the system uses 90 percent of the same raw materials and standard equipment manufacturers use globally. This method yields three times the opacity of traditional architectural construction coatings, using two-thirds less TiO_2.

While traditional coatings excel at surface adhesion, they often shift and move before drying, leading to an incomplete finish that necessitates multiple layers/gallons to achieve opacity and, subsequently, all other desired properties, such as sheen, texture, color, and durability. This reliance on layering is the established hallmark. Critically, opacity remains the only uncontrollable aspect of

As the largest consumer of global paints and coatings, the construction and maintenance market accounts for more than 66 percent of the industry's total life-cycle waste, emissions, and carbon profile of society at large.

PHOTO ©NOPPON KOBPIMAI/COURTESY DREAMSTIME.COM

a coating's performance, as current techniques and methods in formulation cannot tame it.

With TiO_2 emerging as an environmental concern, its reduction seems inevitable. The EU is considering bans, while some producers, such as Chemours, acknowledge its systemic impact, subtly encouraging reduced consumption. Resin suppliers, such as Arkema, are also exploring long-term alternatives through stakeholder conferences. Meanwhile, global trade dynamics, such as China's anti-dumping tariffs, add further instability that spirals a global industry and customer base.

Publicly, this signals that simply banning TiO_2 without a viable alternative would likely exacerbate the problem. This would lead to increased material consumption to compensate for reduced opacity, further burdening the production infrastructure and supply chain. Without a new formulation paradigm, manufacturers will continue to purchase more TiO_2 and pass their limitations onto construction and its customers, perpetuating a less sustainable system that affects national and global markets.

To remain competitive, construction requires a more responsible approach to both business and the environment. Current standards inadvertently position TiO_2 as an adversary when it could become a valuable ally, enabling genuine control over the environmental footprint while encouraging economic growth.

The implications of construction gaining control over this systemic issue extend far beyond a single raw material. By effectively optimizing TiO_2 use and consumption, the industry can inherently control the demand for all material inputs to serve its function. Just as planets orbit the sun, peripheral materials such as additives, resins, water, fillers, energy, transport, and packaging will naturally reduce to their minimum required levels. This is the profound power of this control: the ability to shrink supply chain consumption across the board and prevent maximum life-cycle waste from the outset. This represents the only path to sustainability when using all coatings.

Achieving this goal allows the coatings industry to offer the construction sector a significantly minimized eco-footprint as a tangible benefit, nurturing a new era of environmental stewardship. Customers should not be expected to pay a premium for eco-friendliness; rather, the responsibility lies in innovating apex solutions that deliver environmental benefits while increasing economic viability. This genuine integration is the only way forward and acts as a double incentive model to perpetuate its success.

Echoing the sustainability messaging of leading manufacturers, who aim to "detach growth from environmental footprint," the reality remains that the most environmentally friendly coating is used least. However, the current global market lacks a readily available paint product portfolio that supports this aspiration.

This concept aligns with the principles of extended producer responsibility systems (EPRS), initially conceived by governments to curb post-consumer waste. While EPRS evolved into a manufacturer-led initiative funded by consumer eco-fees for recycling Self-Build Technology and its control over TiO_2 and, therefore, the entire footprint of the construction industry can revive a somewhat forgotten inclination to control waste at the source—from the point of raw material extraction.

By effectively optimizing titanium dioxide (TiO_2) use and consumption, the industry can inherently control the demand for all material inputs to serve its function.

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A paradigm shift: From uncontrolled waste to total control

The following illustrates the fundamental difference between the current life-cycle system and this proposed novel system, where the construction sector leverages its influence to drive real change in coatings consumption back up the chain:

Current system: Uncontrollable chain reaction in the economy and the environment

- Maximum waste recycling infrastructure and CO2/GHG emission generation.
- No control of the system using the second and third "R" (reuse/recycle).
- Two-and-a-half to three coats average. The general measure is one coat to a gallon, which averages 33 m^2 (350 sf) of paintable space. The average paint job is a purchase of 12 L (3 gal) or 100 m^2 (1,076 sf).
- Raw material suppliers extract and supply inherently limiting natural resources in opacity, such as TiO_2 with no synthetic counterpart, initiating excessive life-cycle waste and CO2/GHG emissions.[2]
- Manufacturers overproduce due to opacity limitations, compounding waste, and CO2/GHG per gallon.
- Coatings associations charge "eco-taxes" to fund fledgling recycling infrastructure to manage their image, further compounding life cycle impacts as, ironically, recycling requires waste generation to be successful.
- Users/construction/maintenance generate significant annual "post-production and use waste" (16 percent of production/860M litres in North America), CO2/GHG per gallon at this stage hits 18 kg (40 lb). This refers to paint waste, which is from any paint or coating, regardless of market segment use.
- Paint and product care recapture an insignificant 0.3 percent of annual waste for reuse. No demand for recycled products leads to repeated costly processes and eventual landfill disposal, continuously compounding waste and CO2/GHG emissions.

Proposed system: Total control with reduced consumption

- Total control with 66 percent reduced TiO_2 means 66 percent reduced consumption through the supply chain.
- Achieved through the principle of the first "R" (reduce).
- Eliminating the primer and second coat (a gallon) through Self-Build Technology.
- Raw materials—Reduce TiO_2 extraction, which reduces all other material inputs through production and supply.
- Manufacturing—Optimize opacity, the core utility of coatings.
- Users/construction/maintenance—To control the number of coats is to control costs, minimizing labor, time, and materials.
- Control of eco-effects—Maximum possible prevented CO2/wastes means detaching growth from footprint.

This minimizes all waste across the supply/value chain: raw material extraction, finished goods production, containers, transport, energy, water, CO2/GHG emissions, and recycling infrastructure limitations.

Moving beyond symbolic gestures

How does the industry achieve genuine, quantifiable environmental change? While initiatives such as planting trees, carbon capture post-generation, and encouraging cycling, in principle, feel good and are aesthetically correct, these are reactionary notions benign of any significant consequence. If the construction industry's commitment to sustainability is as strong as it claims, consider the transformative power of every architect, developer, and builder adopting this novel system. What would be the national and global impact? For generations, marketing has convinced people that fewer coats are desirable and common sense, yet current market products have not made this a reality.

This construction technology would immediately reduce global TiO_2 consumption from 50 percent of feedstocks to just 17 percent. This, in turn, would maximize the preservation of peripheral resources and permanently minimize the CO2 footprint and all excess input costs throughout the entire supply chain.

This paves the way for genuine climate-tech coatings, the foundation for true environmental, social, and governance (ESG) principles, addressing global sustainability megatrends. This approach is rooted not in superficial marketing but in the fundamental purpose of paints and coatings production. Ultimately, this empowers consumers and defines construction's true participation and responsibility within a renewed system.

Currently, the construction industry is constrained by its reliance on TiO_2 while facing increasing pressure from consumers, environmental agencies, and innovators. Progress will remain inhibited unless a real-world alternative offering a dual economic and environmental incentive, as proposed here, is embraced.

The irony for construction is that, in this instance, bigger is not synonymous with better. The more development is undertaken, the greater the environmental responsibility. If the coatings and construction sectors fail to optimize TiO_2 usage and bring innovative solutions to fruition, significantly altering the current unsustainable trajectory will be challenging, making it difficult to justify the continued operation of two of the world's most wasteful and expensive supply chains to the mainstream consumer.

In conclusion, refer to George Pilcher's "Transformational thinking" paper from the October 2012 *European Coatings Journal* article, "Innovating for the future." Pilcher highlights that paints and coatings, aside from the shift from oil to latex in the 1950s, have seen little fundamental change in a century—a timeline that coincides with the widespread adoption of refined TiO_2. The paper argues that true innovation requires transformational thinking, a spark that fundamentally alters the perception of coatings and the processes through which they are applied. It is crucial to steer clear of gradualism and embrace a conversion to recalibrate the relationship between the coatings industry and its most prominent user, thereby empowering the construction and maintenance markets to lead the way for all stakeholders.

Notes

[1] Learn more about the Sustainable Paint Index at constructioncanada.net/sustainable-paint-index-a-shift-in-architectural-coatings/

[2] While it is possible to mainstream the use, the process is synthetic, and the author is referring to offsets. No lab-created material (synthetics), such as pre-composite polymers, can replace the effectiveness of TiO_2, which is naturally occurring. In 2011, Dow Chemical launched "Evoque," a polymer that won the EPA Green Chemistry Award that year. In 15 years, it has successfully offset only 7 percent TiO_2 in a standard paint and coating formulation.

additional information

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Tonino F. Margani is a fourth-generation painter in Toronto, Ont., and the EVP of science and environment for Nobilis Inc., a family office in the research and commercialization of global paints and coatings.

KEY TAKEAWAYS

Titanium dioxide (TiO_2) has been the fundamental raw material for ensuring opacity and hiding power in paints and coatings since 1921. However, its extraction and manufacturing carry a massive carbon footprint and high production costs. Since the construction and maintenance sector represents the largest global consumer of coatings, specifiers and manufacturers must look to advanced alternative formulations—such as Self-Build Technology—to optimize TiO_2 consumption, reduce life-cycle waste, and meet evolving sustainability targets.

MASTERFORMAT NO.

09 90 00—Painting and Coating

UNIFORMAT NO.

B2010-Exterior Wall Veneer
C1040-Interior Finishes

KEYWORDS

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Carbon footprint reduction
Opacity and hiding power
Self-Build Technology
Sustainable paint index
Titanium dioxide (TiO_2)

The Dark Side of the Moon: Dangers of Concealed Spalls

As discussed in the article "Failures: Bad Moon Rising" in the August 2024 issue of *The Construction Specifier*, a common failure of stone masonry veneer is the formation of "half-moon" spalls at kerf cuts that receive the lateral anchorage of the stone panel. When this failure occurs on the panel's exposed face, it is readily identified and repaired, mitigating the loss of lateral support and the associated hazard of falling material. However, depending on panel geometry and anchor placement, similar spalls may occur on the concealed rear face with little or no visible evidence. This hidden damage can result in a loss of lateral support for the stone panel, which can become dislodged from the wall. Two recent projects illustrate this.

The first project is an institutional building in a high-seismic-risk area. Limestone masonry units on the facade are anchored to the structure with stainless-steel strap anchors set into kerf cuts. A recent repair project addressed several units that had developed incipient half-moon spalls on the exposed face (Figure 1). Removal of the damaged units provided access to the veneer cavity and adjacent panels, revealing significant cracks and spalls on the concealed back faces of multiple units (Figure 2). The repair scope was subsequently expanded to include the replacement of numerous cracked panels.

The second project involves a historic structure clad with large marble panels, only 40 mm (1.5 in.) thick but exceeding 1 m^2 (12 sf) in area. Aside from intermittent surface corrosion staining, the cladding appeared intact. During mortar removal in preparation for repointing, two panels were destabilized and fell to the ground. Investigation revealed that the original lateral anchorage consisted of 20 mm (0.75 in.) diameter steel pins engaging the panels' top back edges. Corrosion of these anchors had created half-moon spalls on the back face of many panels, compromising their lateral support (Figure 3). Until the panels fell, corrosion staining was the only visible indication of failure. The repair scope was expanded to include shoring followed by remedial pinning of the entire wall.

When assessing a facade incorporating metal lateral anchorage, a visual survey alone will not identify reverse-face spalls. Depending on the assembly, additional investigation may include metal detectors to locate anchors, hammer sounding to identify delaminated or loose panels, ground-penetrating radar to detect voids, removal of joint materials to inspect panel edges, borescopes to view concealed cavities, or selective panel removal to observe concealed conditions. If the investigation is conducted during the preparation of construction documents and before starting repairs, the scope of required work can be better understood.

Figure 1

Incipient spalls on the exposed face were identified visually, and the units were marked out for replacement.

Figure 2

After removal of the units with damage on the exposed face, adjacent units were visible within the wall cavity, and numerous cracks and spalls were discovered on the back face (arrow).

Figure 3

Removal of a few representative marble cladding panels revealed that many panels had spalled on the reverse face at the locations of pin anchors (circle).

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