



Jacob K. Javits Convention Center | New York

Facade Retrofits: The Dilemma of the Highly Glazed High-Rise Facade

Mic Patterson, LEED AP [BD+C]
Jeffrey C. Vaglio, PE, LEED AP [BD+C]

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The post-war building boom in the mid-twentieth century produced the first crop of glass curtainwall office towers. This trend has continued through the decades, growing to include highly glazed residential towers in the urban environment. This building type represents a problematic component of the existing building stock. Many of these high-rise towers are now thirty to forty years old – or even more. Moreover, the curtainwall technology of this time would be regarded as significantly substandard today. Improving energy consumption in the existing building stock will require the retrofitting of many, if not most, of these facades. While many buildings are currently undergoing energy retrofits, the scope of the renovation often stops short of the facade because of the relatively high cost and the potential disruption to ongoing building operations. Even when the facade is included in an energy retrofit program, the options for approaching the facade element are often unclear. This paper will examine the dilemma presented by the facade retrofit, and explore the complex issues related to this component of a building renovation.

1 INTRODUCTION

The statistics are well known: buildings consume more energy than any other commercial sector, including transportation, accounting for nearly 49% of all energy use and 77% of all electricity, while responsible for 47% of greenhouse gas emissions. Meeting the aggressive goals for energy reduction established by such initiatives as the White House Agenda and the 2030 Challenge will require energy retrofits to the existing building stock on a widespread scale. The building stock is comprised of a wide variety of building types, many of which present very particular problems with respect to retrofit. None are more challenging, however, than those presented by the tall building facade.

The statistics are often repeated:

- Buildings consume more energy than any other sector.
- 76% of building energy comes from fossil fuels.
- Building energy use is growing faster than any other sector.
- The building sector produces 47% of all green house gases.

Tall buildings are virtually synonymous with highly glazed curtainwall facade systems, especially those constructed from the mid-twentieth century onward. Many of these buildings were constructed during post-war boom times in the 1960s and 1970s, and are approaching 40 years of age and older. Insulated glass warranties are typically 5 to 10 years, with the products having a life expectancy of 20 to 30 years. Similar durability can be expected from many of the sealants and gasket materials used to provide the weather seal. Nor was this emergent curtain-wall technology particularly robust to begin with: problems with water penetration and air infiltration were common; thermal performance was often miserable resulting variously in condensation, unwanted heat transfer, and general discomfort to building occupants.

Architectural glass is not recycled, a fact surprising to many outside of the glass industry.

Curtainwall technology is simple enough in concept, with complexity found in the design, performance and delivery.

Meanwhile, there have been many developments in curtainwall technology over the past three decades involving progressive design technique, high performance materials, and advanced fabrication processes.

These factors combine to create a real opportunity in the retrofit of tall buildings. Retrofit is, quite simply, the application of new technology to existing systems. Yet there remain many uncertainties, and more questions than answers. Facade retrofit, or re-clad, is expensive: Does it make economic sense? What are the programmatic options with a facade retrofit? Is glass a blessing or a curse in the building facade? What are best (and sustainable) practices in undertaking a facade retrofit? What means-and-methods and project delivery options are available? This paper attempts to provide a framework for these issues suitable to furthering a comprehensive dialog that may yield answers to these and other questions regarding the facade retrofit of tall curtain-wall buildings.

2 STRUCTURE + SKIN: EMERGENCE OF THE GLASS SKYSCRAPER

Several technologies and a dominant architectural movement combined to make possible the high-rise building tower that now dominates our urban centers. The separation of skin and structure as individual building components evolved through the 19th century in the design and construction of the great iron and glass conservatory structures built throughout Northern Europe and England. By the turn of the 19th century, William Jenny had developed structural steel framing systems, Willis Carrier was poised to contribute the air conditioner, and elevator technology as pioneered by Elisha Otis was well established. The masonry practices of the day, however, remained in use in the construction of walls, even as those walls were no longer load bearing and building heights were climbing ever higher. Windows slowly grew larger in turn-of-the-wcentury Chicago architecture, but they were still framed by heavy masonry walls.



The vision, in this case, had preceded the technology. Paul Scheerbart's 1914 novel, *The Gray Cloth*, predicts contemporary glass architecture with stunning detail and accuracy, right down to the double-skin facade. Mies van der Rohe beautifully conceived of and expressed the lightweight, highly transparent glass facade in work such as the Friedrichstraße Skyscraper in 1921, a competition entry, followed by a study for the Glass Skyscraper in 1922. Both projects went unbuilt but were widely published, and the influence they had on the modernist vision and what was to come in architecture some few decades later is hard to overemphasize.

The first of the glass skyscrapers to foreshadow the dramatic upcoming changes to urban skylines included 860-880 Lakeshore

Drive (Mies van der Rohe, Chicago, 1949), Lever House (Skidmore Owings and Merrill, New York City, 1951), and the Seagram Building (Mies van der Rohe, New York City, 1957). These facade designs were sophisticated and exceptionally innovative. Skyscraper construction finally boomed in the 1960s, driven by a real estate industry that recognized a way to maximize leasable area in a fixed building footprint by using the new facade technology, and fueled by material advances that included a plentiful supply of inexpensive and high quality flat glass, and an abundance of aluminum to feed the extrusion process for framing components. The modern curtainwall industry was thus born, and has remained the dominant technology for cladding tall buildings today.

Figure 1: The Lever House by SOM (left), 1951, and the Seagram Building by Mies van der Rohe, 1954, across the street from each other in New York City, are iconic examples of the building type discussed here. The Lever House has already required a remedial retrofit completed nearly a decade ago. (Lever House photo by Shankbone)

2.1 UNDERPERFORMING FACADES

The quality and performance of this new exterior wall technology was problematic, resulting in a proliferation of what Michael Wigginton refers to as high-rise “heat sinks” [2]. The technology was new and largely untested. Thermally broken framing components had not yet been developed, so the aluminum frames acted as thermal conductors between inside and out. The gasket and seal materials were inferior by today’s standards. Design practices were often dictated by the speculative developer intent upon minimizing initial construction costs and a quick turnaround of the building. Many of the buildings were only single-glazed, and the highly efficient low-e coatings of today had yet to be created. Insulated glass units (IGUs) did not come into widespread use in North America until after the oil crisis of 1972. Mirror coatings emerged early on as a means to mitigate the poor thermal performance of glass, but so reduced the visible

light transmission that electrical lighting was required all day despite sunny exterior conditions.

The abysmal energy efficiency was enabled by cheap energy and the new air conditioning technology. The result is a building type with poorly designed and constructed facades at the onset, facades that are now deteriorating with age.

There are other issues, as well. In addition to being a poor thermal insulator, glass is an equally poor acoustical insulator. A significant threshold has been recently crossed, whereby the majority of the global population now lives in densely populated urban environments. In the early decades of tall buildings, the applications were predominantly office towers with the urban centers cleared out in the early evening as people returned to homes in the suburbs. Recent decades, however, have seen the rise of many highly glazed residential tow-

ers within the urban context, where noise pollution is a significant and growing concern, albeit one not particularly well understood or easily dealt with. Today’s insulated – and particularly laminated – glass panel constructs possess significantly improved acoustical properties as compared to those often used in early curtainwall systems.

2.2 CURTAINWALL TECHNOLOGY

It is necessary to have an understanding of basic curtainwall technology in order to assess the potential for facade retrofit. The technology is simple enough in concept, with complexity found in the design, performance and delivery. While today’s curtainwalls are little different in concept than the early applications of the 1960s, important differences have evolved over the past decades.

Stick and unitized systems are the predominant forms of curtainwall. Stick systems were the earliest, with its name deriving from the

long aluminum extrusions (“sticks”) that were used to construct the wall system in place on the building facade. Typically, the long vertical mullions were first installed on the glazing grid by attaching them at the floor slabs. Horizontal mullions were then installed between the vertical mullions. Gaskets and seals were installed as dictated by the system design, and finally, the infill panels were lifted into position, fitted into the framed openings, then fixed and sealed in place.

Unitized systems developed as a prefabrication strategy, driven by the intent to minimize expensive site labor, and to improve quality as provided by manufacture under factory-controlled conditions as opposed to the adverse conditions often presented by the building site. The design necessitated the division of vertical and horizontal mullions into two pieces, a so-called split mullion, accommodating the provision of a frame around each unit. The origin of the term *unitized* is unclear. It essentially refers to prefabricated modular systems. The extruded aluminum framing members are first fabricated (drilled, notched, cut to length), and then assembled into complete frames. The units are most often designed to span a single floor in height, with the width determined by the width of a single infill panel. Economics sometimes favor larger panels, however, and some systems have utilized units spanning two floors in height, or multiple infill units in width. Regardless, once the frames are assembled, gaskets and seals are fitted and the infill panels are installed and glazed as required. Unit construction may include such add-on items as sunshades and photovoltaic

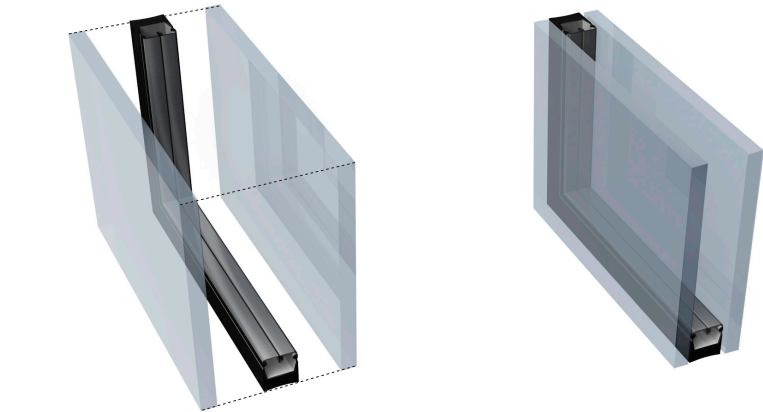


Figure 4: The construction of a typical double-glazed insulated glass unit (IGU), exploded (left) and assembled.

panels. The assembled units are shipped to the site, lifted into position and attached to pre-installed anchors at the floor slabs. The adjoining split mullions are typically designed to interlock in such a way that installation must proceed with the sequential setting of neighboring units wrapping a floor level, typically starting at a lower level and progressing upward floor by floor. The weather seal between units is typically a dry gasket, and only minimal onsite caulking is required.

The ability of curtainwall systems to incorporate virtually any panel material, metal panel constructs, natural stone, or tile, allowed for extensive use of glass in the building skin. In fact, curtainwall became synonymous with the glass skin of the 1960s high-rise, establishing glass as the dominant cladding material for this new building form.

3 THE RETROFIT OPPORTUNITY

Today, the problem of poor performing, aging glass curtainwall is now an opportunity to combine need with solutions in a facade retrofit. Sustainable building practice will certainly recognize reuse of these aging buildings as superior to a strategy of deconstruction, recycling and rebuilding. Retrofit supports a sustainable strategy of reuse. There is no question that many buildings of the type addressed here could benefit significantly from a facade retrofit, and there is equally no doubt that recent material developments and technology can significantly improve their performance and likely their appearance.

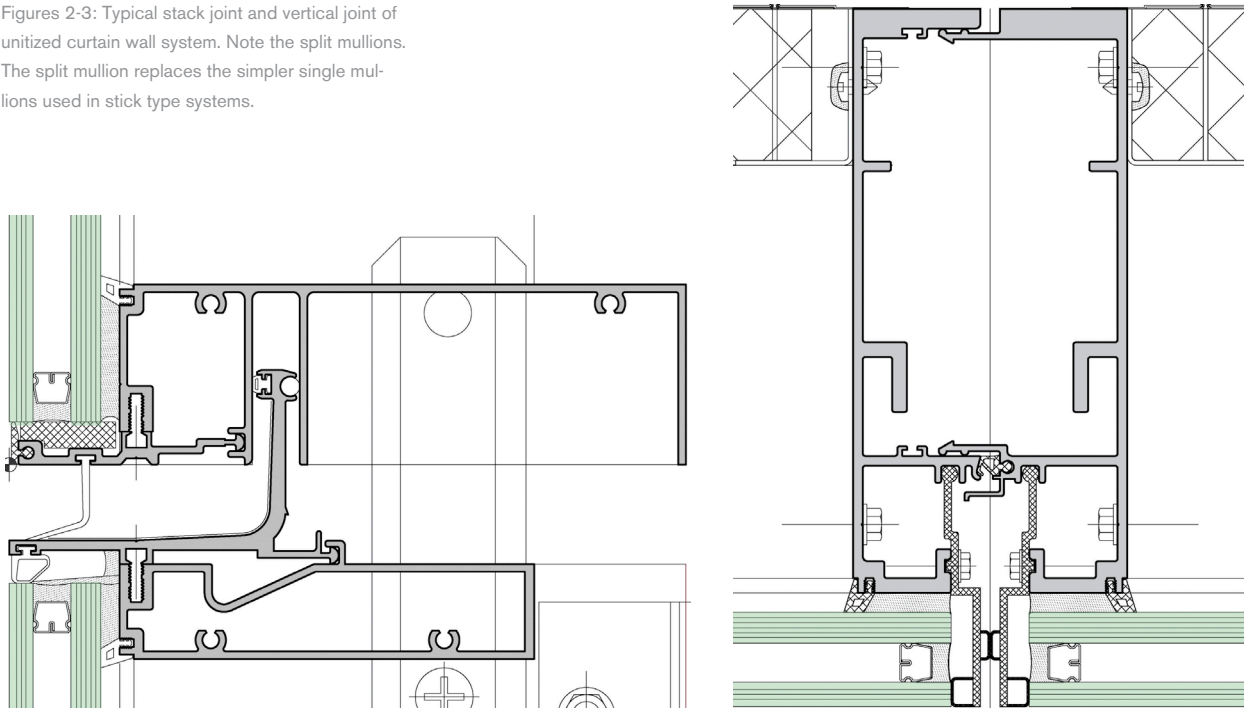
Curtainwall framing systems have improved somewhat; the mullions are often thermally broken, at least in colder climates, to prevent heat transfer through the mullion. However, much of the opportunity for performance improvements resulting from facade retrofit yields from two sources: material advances in architectural glass, and increasing sophistication in facade design.

3.1 THIN SKINS

Material advances in architectural glass can be characterized as “thin skin” developments. Most glass building skins are comprised of a single glass panel, whether it is single glazing, laminated and/or insulated. This puts the vast majority of building skin thickness at one inch or less. Even triple-glazed panels – IGUs with three glass plies and double cavity – are less than two inches in thickness.

Developments in architectural glass have been quite dynamic. Glazing materials keep improving. Architectural glass is a highly engineered material bearing little resemblance to the raw material produced by the float process. The value-added post processing of raw float glass has come to dominate growth in the glass industry. Glass is variously heat-treated, laminated, coated, and built up into insulated panels. Thin-film coatings, for example, have significantly improved the thermal performance of glass in the building skin over the past 30 years. Ongoing improvements include interlayer materials for laminating glass, and cavity enhancements of IGUs as provided by aerogels and mechanical

Figures 2-3: Typical stack joint and vertical joint of unitized curtain wall system. Note the split mullions. The split mullion replaces the simpler single mullions used in stick type systems.



Facade Retrofits

shading devices built into the cavity. Vacuum glass products are beginning to appear on the market with super insulation properties provided by very shallow, evacuated cavities, promising future multi-ply super-insulating vacuum glass units (VGUs) fitting within the same thin-skin envelope.

3.2 DEEP SKINS

In contrast to thin skins, deep skins are much more about the design of the building facade than simply about the material properties of the glass. Facade designers are becoming increasingly inventive with advanced facade designs in recognition of the combined effect of the building skin on both performance and appearance. The skin is no longer merely a membrane enclosing the building, measured in inches of depth, but a multi-layered construct comprised of both indoor and outdoor elements measured in feet. Some double-skin designs have even been developed that use the cavity space for public circulation. The Loyola Information Commons incorporates a vestibule entry space that is part of a double-skin cavity buffer. Consider a facade on a Morphosis building such as the San Francisco Federal Building, or the new Cooper Union in New York City; where exactly does the facade begin and end? Layers of material and function comprise the facade in response to internal, external and programmatic factors (solar exposure, natural ventilation, circulation, etc.), with the weather barrier but one among them. On either or both sides of the weather barrier may be found sensors and controllers, operable blinds and shades, fixed louvers and screens, and daylight redirecting devices such as light shelves.

The double-skin facade is a particular configuration of deep skin in which a cavity is developed between two skins, separated by a depth that can range from inches to feet. The cavity affords opportunities for enhancing the thermal and acoustical performance of the wall, controlling glare, and providing natural ventilation. In fact, a double-skin strategy may provide an optimum solution for certain retrofit applications, for reasons discussed later.



Figure 5 (above): Working within the deep cavity of a multi-story double skin system, workers install the outboard skin. A grating system divides the cavity at each floor level to provide maintenance access without restricting airflow.

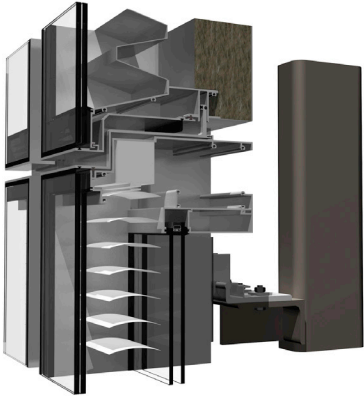


Figure 6 (right): Section rendering of a unitized double-skin system showing glass makeup and operable blinds located in the cavity between the two skins.

Figure 7: With over 10,000 landfills in the United States, it is imperative that future building facade retrofits maximize material reuse and recycling strategies.



3.3 SMART SKINS

Smart skins also represent emergent technology with potential application in facade retrofit projects. Smart or intelligent skins are facades or facade materials that undergo an adaptive response to changing internal or external conditions. They may be comprised of smart materials, as with electrochromic glazing, or smart systems, such as dimmable lighting and operable shading systems that employ sensors and controllers to optimize daylighting effect, moderating glare and minimizing electricity consumption from artificial lighting. The differentiating characteristic of smart systems is the dynamic response to environmental change. There is often an active integration among the facade components in a smart system, and with other building systems, through a building management system (BMS), which may involve such things as energy management, lighting control, natural ventilation, solar-tracking sunshades or rooftop photovoltaic arrays, or other building integrated photovoltaic (BIPV) devices.

4 THE RETROFIT CHALLENGE

Facade retrofits can be considered a subcategory of building energy retrofits, a relatively new market phenomenon. There have been past instances of facade retrofit, but these were largely isolated instances of remedial work on facades that had suffered some kind of failure. In contrast, energy performance considerations are driving the

current retrofit dialogue, and the whole-building energy retrofit is the manifestation of that conversation. Many of these retrofits focus on items with the quickest payback cycle: more efficient mechanical systems, for example, or lighting and lighting controls. Most of these programs stop short of including the facade, other than with perhaps an adhesive film application to the interior glass surfaces, a “band-aid” approach to the problem. The usual reasons for this are cost and the potential disruption to ongoing building operations. The relative cost of a facade retrofit compared with other energy retrofit program elements can be significantly higher and challenging to justify in a simple payback equation.

In many cases this will prove a false economy, however. Payback and lifecycle costs incorporate basic assumptions about the cost of energy. These figures seldom include the true cost of non-renewable energy use, not accounting for the escalating cost of extraction and environment cleanup associated with post peak-oil production, or the cost of developing renewable energy sources to replace the dwindling supply of non-renewables. And what value should be placed on issues of national security as related to continued dependency on oil from increasingly politically volatile foreign sources?

The building energy retrofit presents an opportunity to address the energy efficiency of a building holistically to truly optimize energy

consumption and greenhouse gas emissions. There is also an economic efficiency to addressing these issues in an integrated manner. If the facade is not retrofitted as part of an energy retrofit program, the opportunity to integrate the facade with the BMS will be missed, resulting in a larger mechanical system than might otherwise be required. Such a building may yet require a facade retrofit in coming years as energy costs increase and regulations for energy consumption become stricter. The BMS and mechanical systems will then need additional evaluation and potential modification to accommodate the new facade.

4.1 SUSTAINABILITY ISSUES

If improperly implemented, upcoming facade retrofits may create more problems than they solve. Sustainability issues, which are always complex, can be even more so with retrofit work.

The predominant materials in curtainwalls are aluminum in the framing systems and glass as the infill material. The metals used in curtainwall systems, particularly the aluminum, are typically recycled into new products. Architectural glass on the other hand is not recycled, a fact surprising to many outside of the glass industry. It turns out that the product development of glass to compensate for its performance deficiencies in the building envelope has rendered the material unrecyclable. The value-added

secondary processing of float glass, including insulating, laminating, coating and fritting, all alter the raw float material, making it unfit for reintroduction into the float process. The float process is sensitive to contaminants, and while raw float glass is theoretically recyclable simply by reintroducing it into the melt, this is not practiced by any of the major float glass producers beyond recycling the cullet, the breakage that occurs within the plant during the manufacturing process.

The reality is that very little raw float glass is used in buildings today, thus architectural glass is not recycled. It is occasionally down-cycled, ground up and used as asphalt fill or landscaping material, but there is no current recycling technology capable of efficiently processing float glass products into a form that renders the material recyclable. In reality, most ends up in landfills. There are currently over 10,000 landfills in the U.S. How many more will be required to accommodate all the architectural glass that must be replaced in the existing building stock if energy efficiency goals are to be achieved? The complexity of the problem is evident in the example of the low-e coatings that have so dramatically and effectively improved the thermal performance of glass. The coatings are comprised of many layers of different heavy-metal oxides in combination to produce specific performance and appearance (color, reflectivity, etc.) attributes. Even if a process can be developed to effectively clean the glass of the coatings, another challenge remains in what to do with the metal-oxide soup resulting from the process. There are solutions to these problems, no doubt, but there are also costs associated with these solutions. Current costing models used in payback and lifecycle analysis do not account for the cost of recycling, a fundamental requirement for sustainable building practice.

Considerations of sustainability necessarily embrace a long-term timeframe. Another effect on the sustainability of glass in the building skin resulting from the value-added processing of glass is the durability of the resulting materials. Float glass can last for hundreds of years in the building envelope. Glass coatings can fail through oxidation and

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weathering, compromising performance and appearance, and considerably shortening the effective lifetime of the material. The same is true of laminating and insulating processes. Laminations can fail and discolor, and the seals of IGUs can fail allowing condensation to occur within the unit cavity. Manufacturer's warranty for these products is typically in the range of 5 years, with superior product warranties running from 10 to 12 years. In fact, in the absence of fabrication defects or damage during installation or use, the materials will likely last well beyond the warranty period, but their lifespan is significantly less than raw float material.

5 FACADE RETROFIT PROCESS

Unfortunately, curtainwall systems, like many other products, are not designed with retrofit in mind. Partly for this reason and partly because few of this building type have actually been retrofit, re-clad strategies are poorly articulated in the industry. Unitized systems can be particularly challenging for infill retrofits. The glazing joints that essentially glue the glass to the framing units can be difficult to access, and separating the glass from the unit frame as part of an infill retrofit can be a challenge. With facade replacement retrofit strategies, unitized systems present challenges because of the way they typically interlock, different from the older stick systems, preventing their ad hoc removal. They are most easily removed as they are

installed, in a progressive, sequential fashion, peeling floor after floor of building skin, thereby limiting important flexibility in the retrofit installation strategy.

A facade retrofit program must anticipate the deconstruction requirements of the existing facade and the implementation of a new facade solution, most often in the context of a building that will remain operational throughout the process. It is this context of maintaining ongoing building operations throughout construction that most differentiates the retrofit process from new building construction. The dominant consideration with such projects becomes the mitigation of disruptions resulting from the construction work that might negatively impact ongoing operations and the comfort and efficiency of the building occupants. It is therefore critical that all aspects of the re-clad process, from design through fabrication, delivery, installation, and commissioning, be developed in the context of this overriding consideration. There are other differences as well. The makeup of the design and construction teams may vary considerably between retrofit jobs, as well as differing considerably from conventional new construction practice. Many retrofit jobs may not even include an architect or a facade consultant. If the scope of work is limited to the building facade, the building owner may contract directly with a specialty facade contractor, foregoing a construction manager or general contractor.

6 CONCLUSIONS

Facade retrofit thus represents a unique process, significantly different from that of new construction, for which there is a tremendous looming need of some importance. It is critical that this retrofit work be carried out efficiently and effectively. Yet this remains largely undefined territory. Everything from contracting strategies to system designs and means-and-methods considerations involve considerable ambiguity, and sustainability issues are problematic in the extreme. Following are the primary conclusions derived from this exercise.

1. The looming requirement for facade retrofit should be regarded as a fundamental infrastructure problem; energy efficiency and carbon reduction goals cannot be achieved without addressing this problem.
2. Meeting the demand will be costly and complex, with a high potential for the process being wasteful.
3. There is urgent need for defining appropriate retrofit strategies, evaluation criteria for their application, and the definition of means and methods for the implementation of the various strategies, possibly taking the form of best-practice guidelines for the various stakeholders.
4. Design practices for new facades that anticipate and accommodate the eventual need for retrofit could facilitate future retrofit requirements. Facade systems should be designed to facilitate the retrofitting of new materials and technology as developments occur.
5. Sustainable facade retrofit practices must be developed; a focus on material reuse is imperative to avoid filling landfills with discarded facade materials, particularly glass.
6. New architectural glass recycling (not down-cycling) technologies are needed.
7. Advanced facade solutions using raw float glass should be pursued because of the uncompromised material life and the



Figure 8: The Javits Convention Center in New York City is currently undergoing a facade retrofit involving the removal and replacement of the entire facade system.

potential for easy recycling. Double-skin strategies may accommodate this in certain applications.

8. Costing models that factor in the environmental cost of damaging construction practices and the true cost of energy are urgently needed to correct inaccurate perceptions of long payback periods for energy efficient technology.

9. Legislative measures regarding building energy and carbon performance will be required in the private commercial sector to achieve appropriate goals for energy use in existing buildings within this sector.

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