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Curtain Wall Façades on the New Generation of Supertall Buildings Present and Future Directions

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Abstract

Beginning in the late 19th century, construction of skyscrapers spread throughout Chicago, New York City, and then the world as demand of space in buildings and increase of cost of land. With this change curtain wall systems have evolved to be more visually complex; these unique profiles of the skyscraper became powerful images and symbols of our cities. A curtain wall is defined as usually aluminum-framed wall containing in-fills of glass and metal panels. The framing is attached to the building structure and does not carry the floor or roof loads of the building.

Keywords: Esthetic, Integrated Design, High-performance, Cost-Effective, Innovative

1. Introduction

The design of supertall buildings has always challenged the imagination of architects and engineers. Exterior façades are the first aesthetic feature of buildings that distinguish one building from another. It is the most important characteristic that quantifies and qualifies the performance of the building.

The earliest modern curtain walls were based on the stick system using steel, which is basically assembled in situ piece by piece, with all glazing and other infills installed on the building site. This approach allows for flexibility and cost savings in smaller projects but requires a high level of on-site quality control.

In the mid-1970s, unitized and custom profiled extruded aluminum curtain walls became available. Unitized aluminum curtain walls are assembled in fabrication shops under controlled conditions. As a result of this prefabricated system, reliability in quality control was enhanced and reduced construction time for the installation of curtain walls. It not only reduced time of construction but also the cost by designing of identical unitized system for repeated use. Otherwise, it had been a major cost of total investment in tall-building construction.

This article will explore the historical development of the curtain wall system with an overview of optimizing curtain walls through an integrated design approach on building façades based on creativity and high performance while achieving elegant design of building façades. Designing and constructing the most durable and energy-efficient building enclosures requires careful integration of materials and assemblies, as well as the integration of various disciplines on the project team with consideration of appropriate use of innovation and innovative technologies.

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2. Historic Design Trends

The Crystal Palace London, UK-1851

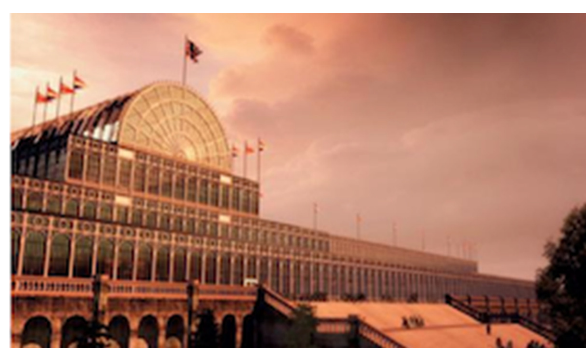


Figure 1. The Crystal Palace Sir Joseph Paxton. Source: Photo by Hulton Archive/Getty Images.

Figure 2. The Transept of the Crystal Palace Sir Joseph Paxton. Source: Photo by Hulton Archive/Getty Images.

The Crystal Palace, London, first curtain wall building built in a cast-iron and plate-glass structure, to house the Great Exhibition of 1851. The use of the plate glass method made possible the production of large and strong glass sheets.

Oriel Chambers Liverpool, UK-1864

Figure 3. Oriel Chambers-Peter Ellis. Source: Façades Confidential.

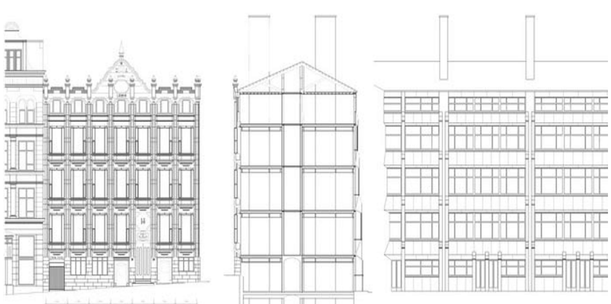


Figure 4. Elevation and Building Section, Oriel Chambers. Source: Façades Confidential.

The external façades are covered with oriels and bow windows with an overhang bottom support. Oriels facing Covent Garden Street are wider than those facing Water Street, which seemed logical since the former receives less natural light. The column line between oriels is externally clad with a thin section of stone pieces, reminiscent of slender Gothic columns.

Reliance Building Chicago, U.S.A-1895

The Reliance Building in Chicago was the first skyscraper to have large plate glass windows make up much of its surface area and they allow natural lighting on all floors. Its stacks of projecting bay windows and terra-cotta cladding create an effect of extraordinary lightness. The enameled terra-cotta would never need to be cleaned because its smooth surface would allow any dirt to be washed away in the rain.

Figure 5. Reliance Building-Burnham and Root CC BY-SA 3.0-commons.wikimedia.org/

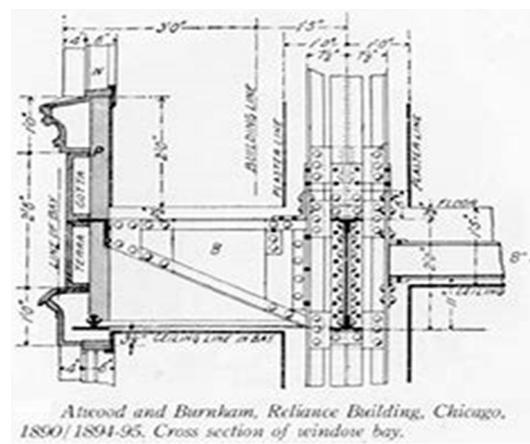


Figure 6. Curtain Wall Detail, Reliance Building. Source: tboake@sympatico.ca

Hallidie Building San Francisco, U.S.A-1918

The Hallidie Building is renowned for its complex architectural process and beauty. The building was the world's first glass curtain walled façade. A new technique was developed by hanging the steel window frames and glass

Figure 7. Hallidie Building - Willis Polk. Photo ©Sherman Takata

Figure 8. Exterior View. Photo is in the Public Domain.

outside edge of a structural frame, creating a glass façade.

The Bauhaus-Dessau, Germany-1926

Figure 9. The Bauhaus Building-Walter Gropius. Photo: toml 1959/Flickr/CC by -NC 2.0

Figure 10. Curtain Wall Corner View. Source: dezeen.com/ Photo Tadashi Okochi

The Bauhaus in Dessau is one of the earlier modernist examples of the curtain wall, which also used steel mullions and polished plate glass attached to the mullions with glazing compound. The most striking features of this building are its glass curtain walls, which wrap around corners and provide views of the building's interiors and its supporting structure.

2.1. Post World War II- Early Contemporary Curtain Wall System

The early 1950s marked the arrival of the new International Style of the curtain wall buildings, with signature aesthetic giving buildings a new character. Perhaps the most important element was the development of extruded-aluminum mullion and muntin shapes to support the glass. Aluminum became the principal material of curtain wall framing because of its corrosion resistance and ease of forming by means of the extrusion process in which the metal is forced through a series of dies to create complex cross-sectional shapes.

As the curtain wall system evolves the size of glass panel became large which gave a dynamic looking façade, but it is obvious that the occupants inside were uncomfortable from the direct sunlight and the heat gain and the building became dependent more on the mechanical air conditioning.

860-880 N. Lakeshore Dr., Chicago U.S.A-1951

Figure 11. 860-880 N. Lakeshore Dr Mies van der Rohe / Photo © Jeremy Atherton, 2006

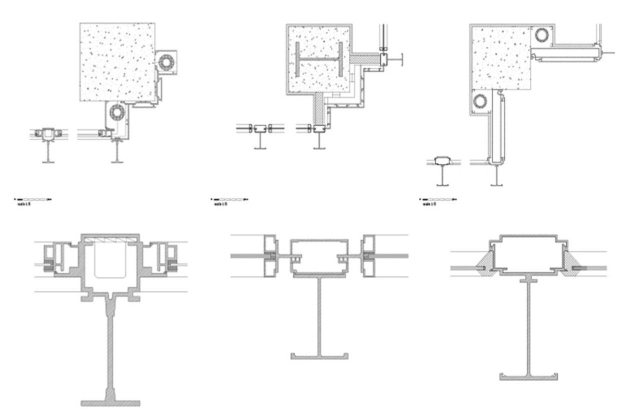


Figure 12. Curtain Wall Details. ©2016–THE FORMWORK-Cultural Association

The 254-ft tall towers in Chicago were designed by the architect Ludwig Mies van der Rohe and dubbed the "Glass House" apartments. The towers are considered to be emblemetic of the modern International Style and has the essential look of modern high-tech architecture: a modernistic tone with its verticality, grids of steel and glass curtain walls, and complete lack of ornamentation.

Lever House, New York City, U.S.A-1952

Figure 13. Lever House, New York City 1952/2001. Source: SOM / Photo ©Ezra Stoller/Esto

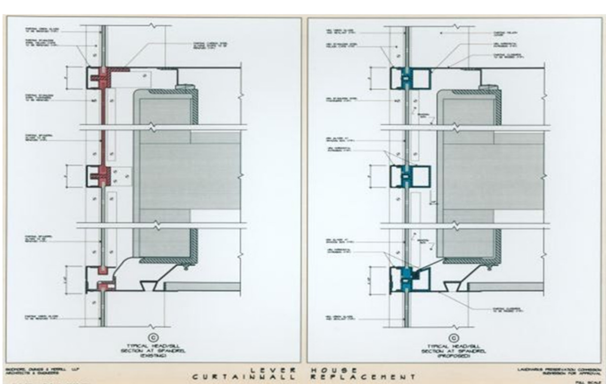


Figure 14. Curtain wall Details, Lever House. ©Skidmore, Owings and Merrill Source: SOM.com

Lever House comprises of two counterposed a rectangular tower and a podium located on the west side of Park Avenue in New York City. It was one of the first glass-walled International Style office buildings. The building façade is formed stainless steel and blue-green glass floating on the lower podium with a roof garden and a enclosed garden-atrium retreat.

Inland Steel Building Chicago, U.S.A-1958

Figure 15. Inland Steel Building. SOM / Photo ©Ezra Stoller/ Esto

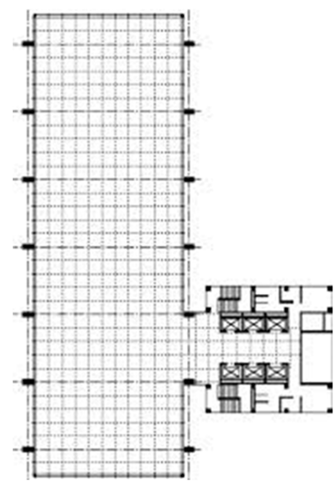


Figure 16. Floor Plan. ©Skidmore, Owings and Merrill

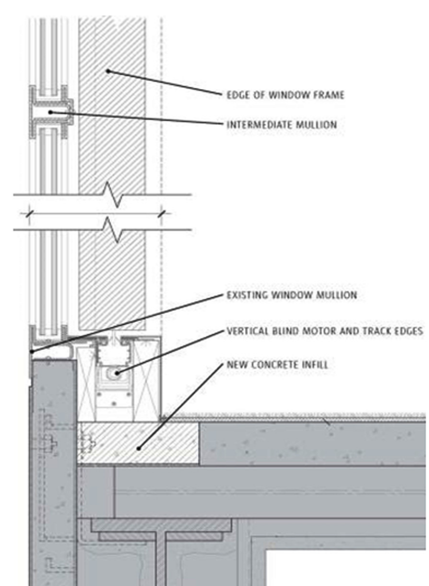


Figure 17. Restoration Curtain Wall. Source: SOM.com

The Inland Steel Building was built in the years 1956-1957 and was the first glass-walled International Style office building skyscraper built in the Chicago Loop following the Great Depression. The 19-story office tower's sleek façade combines aquamarine glass and brushed stainless-steel cladding, which reflects the image of the company, the Inland Steel.

Seagram Building New York City, U.S.A-1958

Figure 18. Seagram Building - Mies van der Rohe / Philip Johnson. Photo: Ken OHyama/Flickr/CC by-SA 2.0

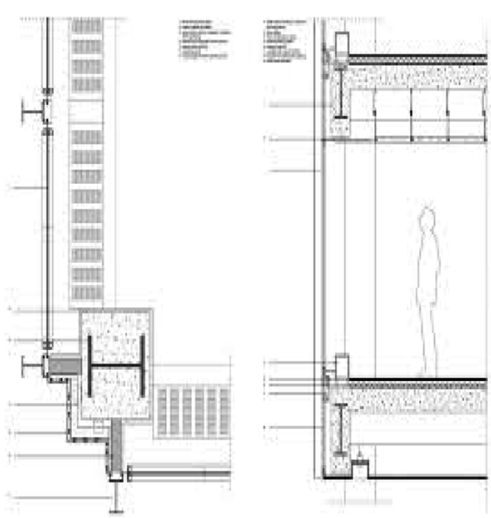


Figure 19. Curtain Wall Details. Source; e-flux.com

The Seagram Building was completed in 1958 and stands as one of the most notable examples of the functionalist aesthetic and a prominent instance of corporate modern architecture.

As required by the New York building codes, all off its structural steel is covered with concrete to hide the structure of the building. Non-structural bronze-toned I-beams were used to express structure instead for exterior wall. These are visible from the outside of the building and run vertically like mullions, surrounding the large glass windows.

2.2 The 1960-1990s

At beginning of the 1970, curtain wall industries began using customized aluminum extrusions for curtain wall frames. Aluminum alloys offer the unique advantage of being able to be easily extruded into nearly any profile required for design and aesthetic purposes.

Curtain wall assemblies are fully customizable unitized aluminum-framed enclosure solutions, based upon a series of engineered and pre-tested curtain wall systems. Each curtain wall application is tailored to meet the specific needs of engineering considerations, thermal performance, and nuances of the architectural design-intent. The unitized system is developed through shop drawings and physical mockup testing before fabrication begins at the fabrication shop. The factory-glazed assemblies are shipped to the site and installed in sequence to enclose each floor allowing team to minimize on-site efforts and maximize quality-control.

875 North Michigan Avenue (formerly the John Hancock Center) Chicago, U.S.A-1970

875 North Michigan Avenue, formerly the John Hancock Center, is the world's first 100-story, mixed-use skyscraper. The building is an architectural icon representing a historic collaboration between architects and structural engineers. The structure is steel framed with a distinctive exposed X-bracing system that resists lateral loads. The exterior façade consists of anodized aluminum and glass curtain walls, anodized aluminum clad steel columns, X-bracing, and spandrel beams.

Figure 20. John Hancock Center. ©Skidmore, Owings and Merrill/ Source: skyscraper.org

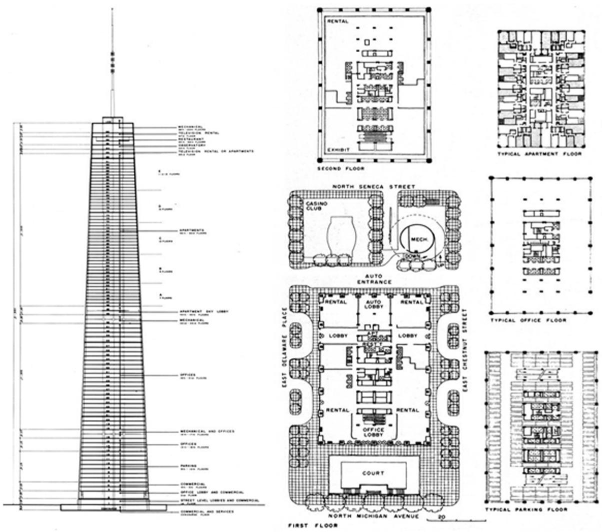


Figure 21. Floor Plans and Section. Source: 100 Years of Architecture in Chicago, published 1973.

Willis Tower (Formerly Sears Tower) Chicago, U.S.A-1974

For years, the tallest building in the world, the 110-story Willis Tower (formerly Sears Tower) marked a major step toward exemplifying and defining that a building's structure should naturally express its exterior profile. The tower's structure comprises nine squared tubes, each rigid within itself without internal supports.

Figure 22. Willis Tower(Formerly Sears Tower). ©Skidmore, Owings, and Merrill. Source: pinterest.com

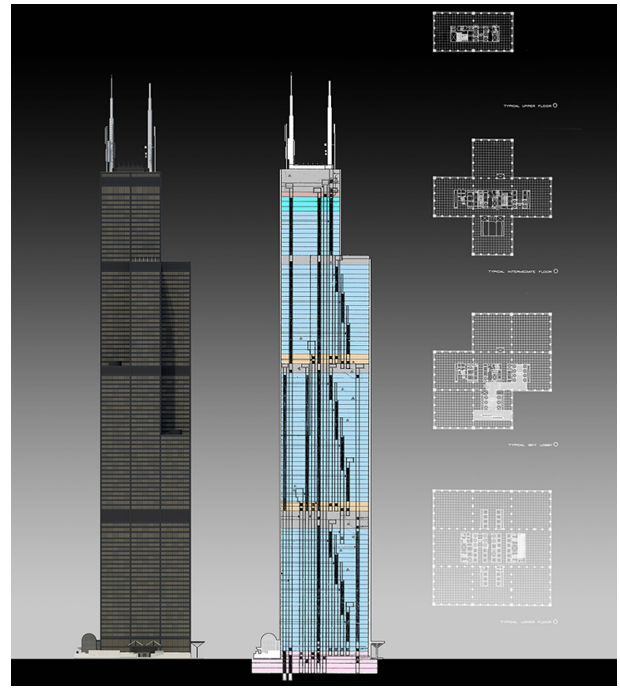


Figure 23. Design Drawings. ©Skidmore, Owings and Merrill. Source: SOM.com

The exterior skin is a black aluminum and single-pane, bronze-tinted, glare-reducing, glass curtain wall. It used a unique and progressive "pressure equalizing" design that allowed wind loads and pressures to be exerted directly upon the building structure rather than to the curtain wall.

2.3. THE 2000S-CURRENT DESIGN TREND

Beginning with the relatively simple but innovative concept of the curtain wall technology has been developed over the years and into a proliferation of highly engineered designs. The unitized curtain wall systems have evolved rapidly since their introduction, especially with respect to enclosure performance.

The early systems had a notorious history of problems: air and rain infiltrations, condensation on interior surfaces, thermal bridges, failure of glazing seals, glass breakages, and high energy consumption. Unfortunately, many curtain wall installations still do not live up to their excellent potential as high-performance enclosures. The key technical issues that should be considered in the design and specification of a curtain wall can be listed under the headings of structure, movement, thermal performance, rain penetration, and fire and acoustic control.

The Burj Khalifa, Dubai, UAE-2010

Burj Khalifa is the tallest building in the world with an architectural height of 828.0 meters and features a triple-lobed footprint, an abstraction of the Hymenocallis flower

Figure 24. The Burj Khalifa. ©Skidmore, Owings and Merrill. Photo: Nick Merrick © Hedrich Blessing

Figure 25. Typical Curtain wall system. ©Skidmore, Owings and Merrill. Photo: Nick Merrick © Hedrich Blessing

Figure 26. View to Hotel Entrance. ©Skidmore, Owings and Merrill. Photo: Nick Merrick©Hedrich Blessing

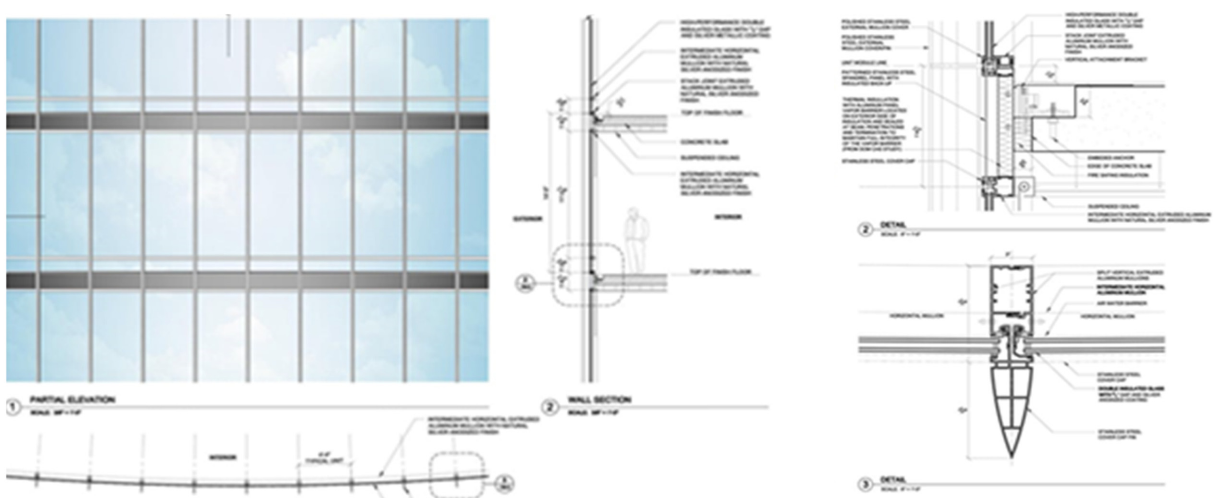


Figure 27. Curtain Wall System & Details. ©Skidmore, Owings and Merrill. Source: SOM.com

or Spider Lily. The tower is composed of three elements arranged around a central core. The modular, Y-shaped structure, with setbacks along each of its three wings provides an inherently stable configuration for the structure and provides good floor plates for residential.

The façade is curved in order to disperse sunlight. The reflective coating-SunGuard Solar Silver 20, which transmits only 20 percent of visible light and 15 percent of solar energy-would have turned a flat curtain wall into a blinding mirror. Since curved glass was beyond the budget, the rounded effect was achieved with flat panels whose angled joints are concealed behind the fins. To mitigate the inevitable buildup of dust, the panels have no horizontal ledges.

Jeddah Tower (formerly Kingdom Tower) Saudi Arabia-Under Construction

The project is in Kingdom City, a newly planned major urban development at the northern edge of the City of Jeddah, adjacent to the Red Sea. The Tower will be approximately 157 stories and a total overall height of 1,001 meters. The Tower consists of 3 main wings, which form the main architectural expression of the building as they culminate at various points in the Spire.

The design for Jeddah Tower is both highly technological and distinctly organic. With its slender, subtly asymmetrical massing, the tower evokes a bundle of leaves shooting up from the ground-a burst of new life that heralds more growth all around it. This symbolizes the tower as a catalyst for increased development around it.

Figure 28. Jeddah Tower. ©Adrian Smith + Gordon Gill Architecture-

Figure 29. Jeddah Tower.

Figure 30. Uunder construction. Source: smithgill.com

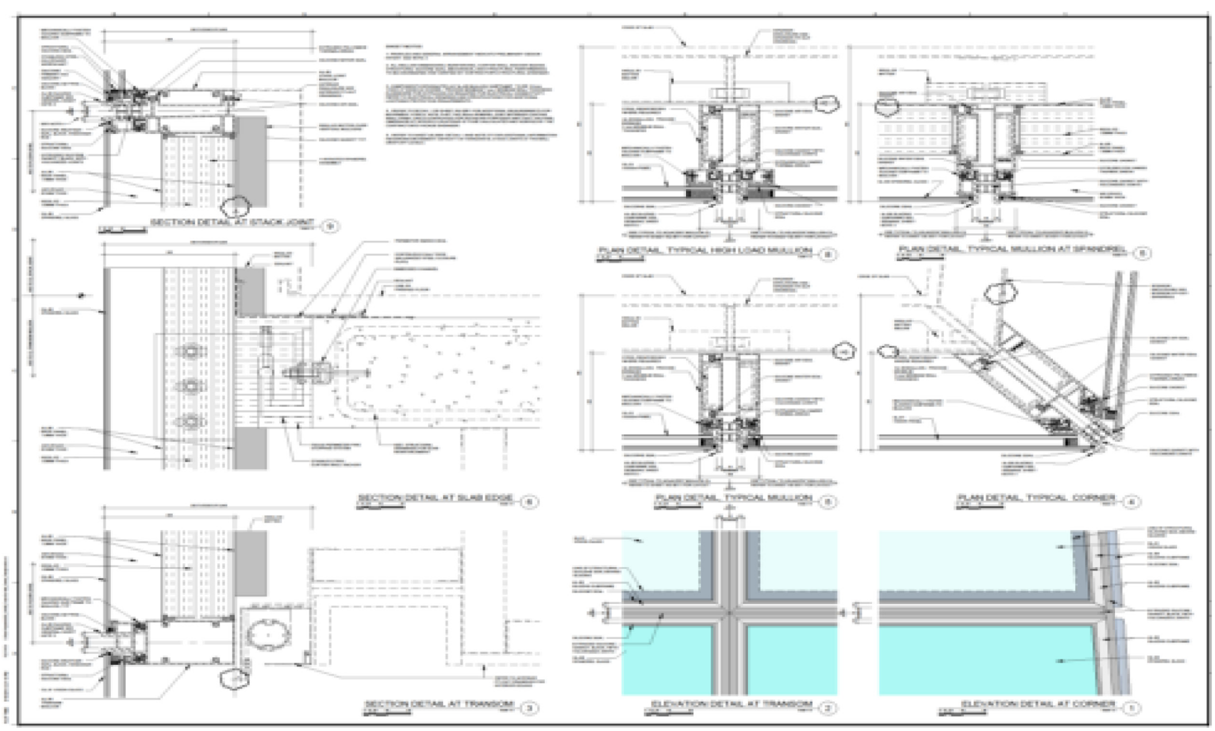


Figure 31. Curtain Wall system details. ©Adrian Smith + Gordon Gill Architecture - Source: smithgill.com

Central Park Tower, New York, U.S.A-Under Construction

Central Park Tower is located at the west 57th street near the southwest corner of New York's Central Park. The Tower is 1,550 feet tall and will be the tallest residential building in the World. The formal geometry of the sleek tower was designed as a direct response to the current residential market in New York City, which demands high-end, high-density residential condominiums that have unique views, double-height spaces, floor-to-ceiling windows, private balconies, and operable windows.

The tower also features a unique cantilever that was designed specifically for this location. Above street level, the tower protrudes eastward in the form of a cantilever. The cantilever extends the residential program allowing for improved unit layouts, enhanced views, and more advantageous structural depths.

Figure 32. Central Park Tower.
©Adrian Smith + Gordon Gill Architecture

Figure 33. Central Park Tower.

Figure 34. under construction.
©Adrian Smith + Gordon Gill Architecture / Source: smithgill.com

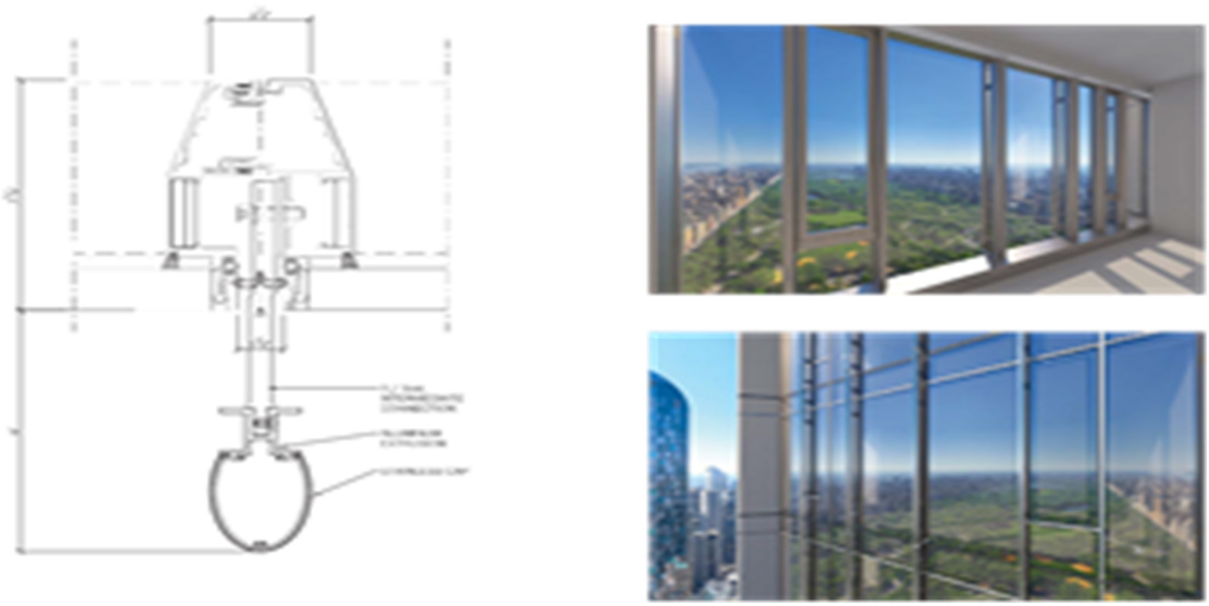


Figure 35. Curtain wall system, Central Park Tower. ©Adrian Smith + Gordon Gill Architecture / Source: smithgill.com

2.4. FUTURE TRENDS - Innovative and Sustainability Design

As skyscrapers are getting taller and larger, energy consumption and carbon emissions have increased significantly. In designing an innovative and sustainable building, exterior wall envelops are the most important building element to be considered in order to reduce energy consumption, environmental effects and enhance user comfort. Therefore, different design strategies for curtain wall systems need to be developed according to the different climatic zones for sustainability, energy efficiency, and conservation of natural resources.

An innovative, energy-efficient, high-performance façade work should be carried out. Economic glass and profile configurations should be investigated, and optimum models should be determined in terms of both energy efficiency and architectural feasibility. The cost of the high-performance curtain wall system is about 30 to 40% more expensive than insulated glazed traditional system, but the increase in the cost of the façade is generally not more than the increase in the M/E/P system cost.

Development of High-Performance insulated glass is for solar control glass that offer maximum design flexibility by pairing unique visual options with a range of solar heat gain and thermal insulation levels. Superior energy efficiency makes this High Performance the ideal choice for a wide variety of climate conditions, particularly in buildings where air conditioning is used and where energy regulations need to be met or exceeded. The variety of glass allows architects to decide every aspect of performance, from thermal and solar control to the style and design statement of skyscrapers.

DOUBLE SKIN GLAZING

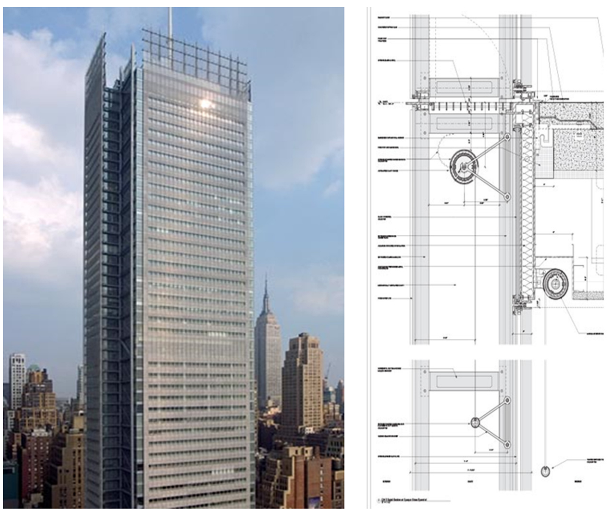


Figure 36. Overall View & Curtail Wall Details.

The New York Times Building is a skyscraper at 620 Eighth Avenue and promoted as a green structure. The design incorporates numerous environmentally sustainable features for increased energy efficiency. The double-skin curtain wall, automated louver shading system.

CLOSED CAVITY FAÇADE (CCF)

Figure 37. Overall New York Times, New York-2007.

As per the climatic factors of Seoul, the KT HQ buildings are cladded with closed cavity façade system. The required 40% quota of façade opacity is provided by white glass, insulated behind; the remaining 60% crystal facade is totally transparent. The whole exterior wall is clad in a second skin of white metal louvers, providing shade and protection against solar gain.

FRITTED GLASS

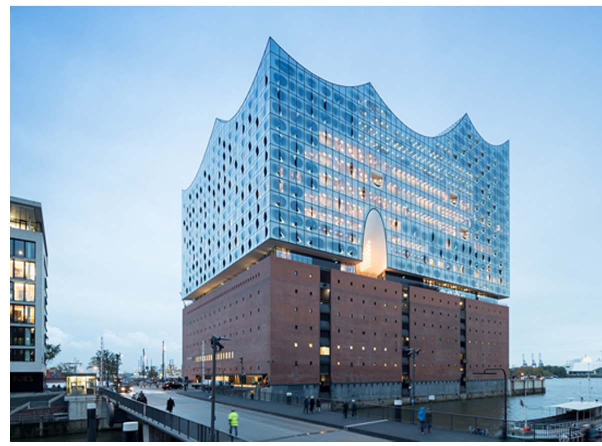


Figure 38. Elbphilharmonie Hamburg, Germany-2016. Herzog & de Meuron / Image via ArchDaily by Iwan Baan.

Figure 39. Interior View. Image via ArchDaily by Iwan Baan.

Elbphilharmonie is a 2,100-seat concert built on top of a historic warehouse. The upper area of this structure is wrapped in curved panels of glass that reflect the surrounding city and sky. While a portion of the glass panels are curved and punctured to create jarring openings, others are fitted, rendering eye-catching ellipses that allow selected streams of light to pass through.

Zhongzhou Holdings Finance Center is a mixed-use complex located in Shenzhen's Nanshan Culture District, consisting of a multi-purpose podium, a 300-meter office and hotel tower, and a related 160-meter residential tower.

INTEGRATED SUNSHADES AND SCRIMS

Figure 40. Zhongzhou Holdings Finance Center, Shenzhen, China-2015. ©Adrian Smith + Gordon Gill Architecture.

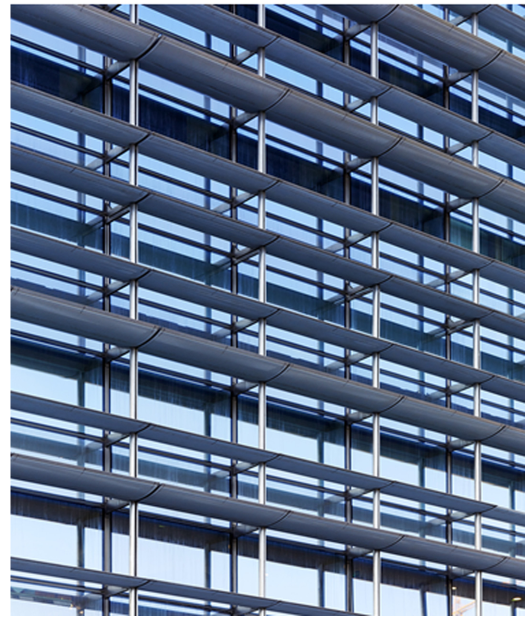


Figure 41. Curtain wall Sunshade. ©Adrian Smith + Gordon Gill Architecture.

The louvers also significantly shade the exterior walls. A frit is introduced to the non-vision glass panels to compensate where the louvers taper toward the corners. The tapered horizontal louvers also reduce view obstructions in the corners.

The louvers also significantly shade the exterior walls. A frit is introduced to the non-vision glass panels to compensate where the louvers taper toward the corners. The tapered horizontal louvers also reduce view obstructions in the corners. Throughout the development, the density of the louvers changes according to program type. For example, the residential and hotel units have the lowest density of louvers, while the podium has the highest density.

BUILDING-INTEGRATED PHOTOVOLTAICS GLAZING

FKI Tower (Federation of Korean Industries Tower) Seoul, Korea-2013

Figure 42. FKI Tower and Podium ©Adrian Smith + Gordon Gill Architecture Photo by Namgoong Sun

Figure 43. Front View. @thelux_photography-Park Hee Jin

Figure 44. Corner view of Curtain wall Photo by Author

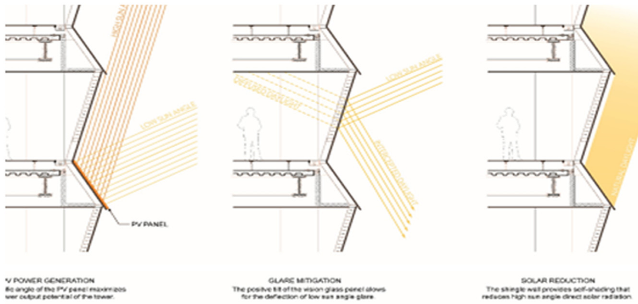


Figure 45. Study for Solar Optimization. ©Adrian Smith + Gordon Gill Architecture

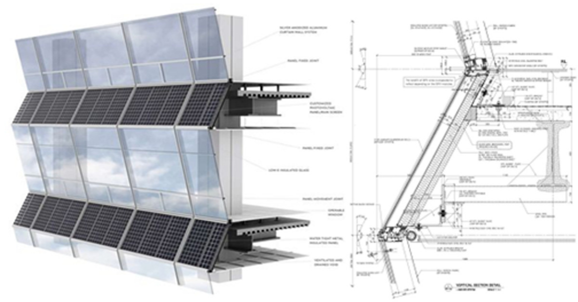


Figure 46. Curtain wall Details. ©Adrian Smith + Gordon Gill Architecture Source: smithgill.com

INNOVATIVE AND SUSTAINABILITY DESIGN OF THE FKI TOWER

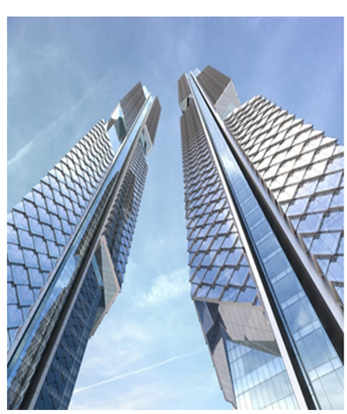
The FKI Tower is completed in December 2013, the new headquarters for the Federation of Korean Industries (FKI) which is a major new addition to the skyline of Seoul. The 240-meter tower features an innovative exterior wall, designed specifically for the project. The building's unique skin helps reduce internal heating and cooling loads, while collecting energy through photovoltaic panels that are integrated into the spandrel areas of the southwest and northwest facades. The result is a unique folded exterior texture that is both purposeful and visually distinctive.

The design team developed a strategy that would meet both requirements as well as reduce the amount of energy that the building used for its heating and cooling loads. The use of building integrated photovoltaic panels (BIPV) was an architecturally appealing way to meet the strict zoning requirement, while the optimization of the panels became a driving factor in developing the architectural expression.

The building integrated photovoltaics (BIPV) on the facades and the roof have a power output of 693 kW and annually convert a total of 600,216 kWh/yr of energy from sunlight to electricity.

The 600,216 kWh/yr account for a total savings of 2.4% (4.3 kWh/m²/yr out of 177.6 kWh/m²/yr) of the building energy use intensity and a cost savings of 1.6%, $54,200. In addition to the cost saved from the on-sight energy generation, the building uses the renewable energy policy.

YIBD Landmark Tower II – Dancing Dragon, Seoul, Korea-2013 Designed & Unbuilt



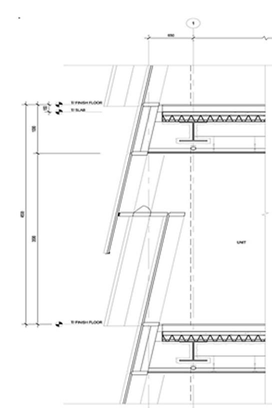


Figure 47. YIBD Landmark Tower II.

Figure 48. Twin Towers.

Figure 49. Curtain Wall.

Figure 50. Curtain Wall Section.

©Adrian Smith + Gordon Gill Architecture

Dancing Dragon is a pair of landmark supertall mixed-use towers for the Yongsan International Business District in Seoul. The buildings, which include residential, "high-end officetell and retail, consist of slender, sharply angled mini-towers cantilevered around a central core. The design aesthetic is highly contemporary yet informed by aspects of traditional Korean culture.

The twin towers feature a dramatic series of diagonal massing cuts that create living spaces at beyond the structure. This recalls the eaves of traditional Korean pagodas-a design theme echoed both in the geometry of the building skin. The theme is extended in the building skin, which suggests the scales of fish and Korean mythical creatures such as dragons, which seem to dance around the core. Triple glazing and BIPV along the edge of glass in unitized aluminum panel with gaps between its overlapping glazing panels feature operable 600 mm vents through which air can circulate, allow natural ventilation for each dwelling units.

3. Conclusions

Curtain walls can provide durable, high-performance, and energy-efficient enclosures and a wide range of aesthetic choices. However, regardless of the style, cost, or type of system, good performance can only be achieved if care is taken by the designer working with the manufacturer on detailing, specification, testing, and inspection. While curtain walls can be extremely beneficial, they sometimes come with extra expenses and complexity. Despite these challenges, the benefits of curtain wall design often outweigh the additional costs and complexity associated with them. Reduced energy use and added durability may decrease operational costs over time.

The primary conclusion which can be reached is that in order to achieve an integrated, comparable and innovative design response in the interfacing of the exterior façade system through understanding of the complex array of potential conditions of building size and curtain wall cost. The basic determinants of optimal enclosure solutions begin with considerations of climatic zone, site characteristics, orientation of the building massing, and window-to-wall ratio.

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