20th century curtain walls – loss of redundancy and increase in complexity

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ABSTRACT: Central to the development of the American skyscraper was the concept of the curtain wall. This development was rapid and was driven by the distinct cultural climate within American urban centers such as Chicago and New York. Skyscrapers would not have been technically feasible without the lightweight curtain wall, and it was through the skyscraper that the curtain wall achieved its greatest realization. The principal and confrontational factors of its development were economics and the need for fireproof buildings. The historical development of the curtain wall is presented and a comparison of deterioration mechanisms between masonry and metal and glass curtain walls is discussed. Finally the issues of loss or redundancy and increase in complexity of contemporary curtain walls are discussed and strategies for diagnosis and conservation are presented.

1 INTRODUCTION

One of Oscar Wilde’s aphorisms regards the United States: “America is the only country that went from barbarism to decadence without civilization in between.” The truth in these bon mots, at least with the topic of curtain walls, was that curtain wall typology would evolve as quickly as building codes would allow to accommodate ever-taller buildings in America’s wild skyscraper boom.

Central to the development of the American skyscraper was the concept of the curtain wall, which opened new avenues for architectural expression. As defined in the Kidder-Parker Architects’ and Builders’ Handbook in the first half of the 20th Century, a curtain wall is “an enclosing wall built and supported between columns or piers, and on girders or other support, and sustaining no weight other than its own.” Spanning between support points at floor levels, its primary functions are to provide weathertightness, provide a fire wall, and transfer laterally-induced loads to the structural frame. The curtain wall does not have the limitations of a bearing wall so that more wall area can be opened up for glazing.

Numerous factors of change were involved with the chief one being economic – buildings had to be built ever taller, faster, and cheaper. These factors were basic for a quickly growing and resource-rich country. A reactive factor was the need for fireproof buildings – this was not surprising in a country plagued by urban fires throughout the 19th Century. From wall construction that consisted of heavy masonry to contemporary metal and glass, curtain wall components changed dramatically during the course of the 20th Century. This curtain wall evolution resulted in shifting the functional burden onto thinner and different materials.
Economy in construction of buildings is an axiom of modern construction worldwide and the exceptions that one may cite would only prove the rule. In America this axiom was very specific and tied to the development of the American West.

Consider the development of the balloon frame, a distinctly American framing technique that fulfilled the requirements of a young and rapidly expanding country. In a balloon frame structure, studs run continuously from the sill to the second floor top plate which supports the roof structure. The second floor joists are nailed to the studs and rest on ledger boards that are fit flush into the studs. This system relies on the external sheathing rather than triangular bracing for lateral strength.

It was characterized by the use of plentiful wood from America’s once ubiquitous forests, rapid construction, and the limited skill required by the workers. The advent of cheap machine-made nails, along with water-powered sawmills in the early 19th century made balloon framing highly attractive. Standard wood elements such as studs were readily available. Although lumber was plentiful in 19th Century America, skilled labor was not. Relatively unskilled workmen were able to erect balloon frames quickly because the labor-intensive mortise and tenon connection of the braced frame technique was supplanted by the use of cut nails. Without balloon framing, the western boom-towns of America and Canada certainly could not have blossomed overnight.

These important economic factors of construction — namely rapid construction and limited skill required by the worker — set a trend for American and then World construction of large buildings in 20th century.

Another important but reactive factor was the need for fireproofed buildings as can be seen in Chicago. Chicago’s building history recommenced after 1871, when the Great Chicago fire devastated the City. Despite this catastrophe — and due to a strong local economy, the high cost of land, and rapidly evolving building technologies — Chicago quickly rose like the Phoenix and afforded an opportunity for the realization of innovations in architecture, engineering, and construction which established it as the birthplace of the skyscraper. The answer of who invented the skyscraper is debated to this day and depends entirely upon what are considered to be the defining characteristics. Comparative characteristics are the separation of the wall from the frame, the first use of the iron frame, appearance of the beam-column moment connection, height limits, use of the passenger elevator, and theories of frame stiffness. For this paper we use the wall and frame separation definition.

These structures needed to be fireproofed and the urban fires revealed that iron work, though inflammable would yield and fail beneath the flames. George H. Johnson, an English-educated architect working with the Architectural Iron Works of New York founded a business to manufacture the fireproof terra cotta tile that he patented in 1871. On trips Johnson made to Chicago to promote the sale of his fireproof tile may have become a precedent for the William leBaron Jenney’s 11-story Home Insurance Building (Chicago, 1885). The use of masonry, and lots of it, in skyscraper construction would prove to be difficult to move beyond in curtain wall development due to its fire resistant qualities.

Following these 19th Century building trends came the development of Modern Movement technologies characterized by experimentation and innovation in construction materials and techniques, many of which had neither the resilience nor the longevity of traditional construction. Materials such as cinder concrete, plywood, and particleboard; and systems including panelized construction, and thin curtain walls with little redundancy came into use. This experimentation with materials and systems remains unabated today.

The curtain wall dichotomy can be traced back to numerous 19th and early 20th Century antecedents. In the United States curtain wall development became intertwined with that of the skeleton frame. Skyscrapers would not have been technically feasible without the lightweight curtain wall. And it was through the skyscraper that the curtain wall achieved its greatest realization.

3 THE DEVELOPMENT OF THE SKYSCRAPER TYPOLOGY IN AMERICA

In the nineteenth century, engineers first utilized metal frame construction in bridges, factories, and warehouses, and cast and wrought iron were the major metals used in construction. The invention of the Bessemer process in England in 1856 made it possible to produce large quantities of steel affordably. In the United States, steel production on a large scale was realized in the 1870s. The transition from iron to steel was gradual, with iron still used in building construction as late as the 1890s.

Arguably, the first metal skeleton-framed skyscraper was the Home Insurance Building designed by Jenney in Chicago. In this structure, column loads were transferred to stone pier footings via the metal frame without load-bearing masonry walls. Each level of the exterior wall was supported on a shelf angle fixed to the spandrel girder. At that time skyscrapers were designed without lateral bracing under the assumption
that the heavy masonry cladding provided sufficient rigidity for the whole structure.

As skeleton framing came into common use, masonry bearing wall construction reached its practical limit. Burnham and Root’s 16-story Monadnock Block (Chicago, 1891) utilized traditional load-bearing masonry walls which at grade were almost 2 meters thick. This building also utilized the first rigid frame for lateral stiffness. At the same time, Burnham and Root developed a complete steel frame for the Rand McNally Building (Chicago, 1890). They also developed a steel frame laterally stiffened with a diagonal bracing system in the 20-story Masonic Temple (Figure 2). Within a three year period the same firm had erected a bearing wall; steel frame; and a diagonal-braced metal frame skyscraper revealing the experimental and quickly evolving nature of the typology.

Several years later, the structural innovations of the Chicago school were taken further by D.H. Burnham in the Reliance Building (Chicago, 1895). The exterior bays were designed as rigid steel frames, and two-story columns erected with staggered joints further increased frame rigidity. The construction of the Reliance Building also illustrated all of the familiar construction techniques which had come into widespread use at the end of the 19th century to facilitate rapid construction. The construction site was lit so work could continue into the night. Work spaces were enclosed and heated so the project could proceed during the winter months. The structural frame, which began erection in mid July of 1894, was topped off on August 1 and required only 15 days.

Steel and then concrete skeleton framing soon became universally accepted for skyscrapers. Thereafter, improvements of known design methods encouraged the construction of increasingly taller buildings.

4 THE MASONRY CURTAIN WALL AND ITS DETERIORATION MECHANISMS

A good place to begin discussion of the early curtain wall is with the Reliance Building in Chicago, the first skyscraper to fully utilize terra cotta as a cladding. The terra cotta units of the curtain wall are connected to a gridwork of cast-iron mullions, lintels, and sills which span between levels. Unlike the Home Insurance and other similar buildings, the Reliance frame did not rely upon the masonry curtain wall for lateral support.

In New York City the steel frame and masonry curtain wall became established with the American Surety
Another issue is the differential movement of the curtain wall relative to the structural frame. By 1894, lateral movement in curtain wall construction was actually being studied and analyzed. The masonry cladding is also exposed to temperature-related movements, while the embedded frame is protected. Structural frames shorten under dead load and material creep. Conversely, fired-clay masonry curtain walls expand due to the intake of moisture. Early curtain walls were not built to accommodate these differential movements resulting in the introduction of unanticipated stresses into the curtain wall and frame. This problem came to be understood as evidenced by displacement measurements that were performed during construction of the Empire State building in 1931. The horizontal deflection of the top of the Empire State Building was monitored by the American Institute of Steel Construction. Measurements were also made to determine exactly how much lower the various floors were from their theoretical position. These measurements showed that the 85th floor was 16 cm. below its theoretical elevation. (H.G. Balcom, “New York’s Tallest Skyscraper,” *Civil Engineering* 1 no 6, March 1931).

To address this differential movement, a pressure-relieving joint or “cowing” was developed by the 1930s. Cowing composed of corrugated lead was typically laid horizontally at mid-span in selected levels of the skyscraper facade. This form of pressure relief was utilized in masonry envelopes until the 1960s.

Besides serving the function of transmitting wind loads to the structural frame, the curtain wall also must resist moisture infiltration. To enter the interior, the moisture must pass through the mass of the wall; however it may take a relatively long period of time for this infiltration to become apparent. The mass of the wall may become saturated with slowly developing detrimental results.

5 THE METAL AND GLASS CURTAIN WALL AND ITS DETERIORATION MECHANISMS

New technologies resulting from World War II had a great influence on the acceptance of the machine-made metal and glass curtain wall. Given the abundant postwar supply, aluminum was reasonably priced. There was experimentation with mild steel, stainless steel, and bronze as well. Extruded components were suitable for standardization and could be prefabricated for delivery to the site. This was important because labor had become a significant part of construction costs. The new curtain wall technology further decreased building weight and construction cost, and increased usable floor area. Prefabricated construction was less limited by cold temperatures which prohibited erection of “wet” walls of brick and mortar. The invention
and development of float glass by Alistair Pilkington in the 1950s would make large panes of glass affordably available. American architectural philosophers of the day lauded the fact that craftsmanship had been transplanted from the site to the factory.

One of the first post-war buildings to be constructed with a glass curtain wall was the Equitable Building (Pietro Belluschi, 1948) in Portland, Oregon. Belluschi was able to take advantage of leftover aluminum stockpiled for World War II by smelters and to utilize assembly techniques derived from West Coast airplane plants. The 860–880 Lake Shore Drive buildings in Chicago (Figure 1) were among the first residential buildings in the United States to be sheathed entirely in glass, and were the realization of Mies’ 1920 proposal for a glass skyscraper. The steel, aluminum, and glass skin was assembled on the buildings’ roofs in two story high units, and then lowered into place on the facade.

At the Lever House (Figure 4), the curtain wall has an interior frame of mild steel clad with stainless steel. At the United Nations Secretariat Building (Harrison and Abramovitz, 1950), curtain walls were conceived as an assembly of aluminum windows held in place with a grid of reinforced mullions. At both buildings, the lower portion of the curtain wall at each level was backed up by a concrete masonry wall to provide the fire rating that code officials felt was not provided by the curtain wall. The masonry wall could not be immediately abandoned though it became hidden from view.

The approach to curtain wall design that quickly evolved was to make the joints as weathertight as possible, then provide positive means for conducting any water leakage out of the wall. Thus an interior drainage system was provided to collect water that leaks through the cladding and direct it back to the exterior.

The development of new curtain wall materials occurred in the post-war years: thin stone veneers, precast concrete, brick veneers, and structural silicone glazed facades. To bring things full circle, the aesthetic development of “Post-Modernism” led to a return to earlier architectonic forms, but not a return to earlier methods of construction.

Metal and glass curtain walls that we care for today consist of factory-fabricated and preassembled metal units that are connected to the structural frame. Glass has gone through radical technical developments and is typically no longer a monolithic material. In a curtain wall it can appear as an insulated glass unit or a sandwich of materials developed to strengthen it. It may have clear, colored, or reflective coatings installed on one or more of its surfaces or may have transparent or translucent colorants integral with the glass. The assemblies may also include panels of aluminum, ceramics, precast concrete, or stone.

Modern structural frames are more flexible because they are designed to tighter limits with less material and are more exposed to temperature extremes than the frames of a masonry-clad building. Prefabricated curtain wall units are detailed to accommodate these increased movements. However, lateral movements of the frame and differential movement between the frame and the cladding can lead to distress in the glass and metal curtain wall.

6 LOSS OF REDUNDANCY AND INCREASE IN COMPLEXITY

In a general sense, redundancy in design can prevent failures of a building system. Structural redundancy, allows for loads to follow an alternate path if the primary supports fail. Redundancy of design for curtain walls can apply not only to structural but to performance issues such as weathertightness.
The mass of the masonry curtain wall provided a redundant system with empirically developed strength capacities that extend far beyond that required. While lack of maintenance could lead to water infiltration problems or deterioration of the cladding system, these problems do not become immediately apparent but become manifest only over a period of time.

In the metal and glass curtain wall strength capacities are engineered to meet specific standards and redundancy is reduced. An engineered system of performance redundancy has been introduced that provides a weathertight barrier while providing internal drainage as well. However, a breakdown of these protective systems in the metal-and-glass curtain wall would lead to immediate water leakage on the interior.

High-tech materials have been adopted for use on these curtain walls that offer unique maintenance challenges. Tempered glass may fail due to nickel-sulfide inclusions. Thin-stone veneers may become distressed from material weakness, loss of strength hysteresis, or deterioration due to anchorage. Incompatible materials such as certain sealants and building stone or dissimilar metals can cause staining which can pose long-term maintenance problems. Little is known regarding the long term performance of sealants that are now being used to hold glass panels in place thus eliminating the metal grid.

7 CONCLUSIONS

Due to the sophisticated engineered systems that have been introduced, and the decreased redundancy, metal and glass curtain wall systems pose unique and complex problems. Diagnosis of this unique typology has been made much easier by following the guidelines provided in the ICOMOS Charter: Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage (ISCARSAH Principles) that was ratified by the ICOMOS 14th General Assembly in Zimbabwe in 2003. The ISCARSAH Principles provide a comprehensive and well considered philosophy for building diagnostics which proves just as valuable (if not more so) for engineered systems as they would for empirically designed medieval structures composed of masonry and wood.

However there is a wide chasm that presently exists between professionals in the preservation community and environmental professionals. The obvious debate is whether it is a sustainable strategy to maintain an aesthetic and keep original material or whether it is more important to achieve better water shedding and thermal performance by compromising the original material. Windows are sources of heat loss and gain and curtain walls even more so. This was not a great concern to designers of large structures enveloped in glass prior to the Energy Crisis of 1973. However energy use is of primary importance today and regulated by the US Government. Consequently there are numerous instances where curtain walls are discarded and replaced rather than conserved.

Another issue is obsolescence. Curtain walls are the embodiment of pure hard economics on the construction industry. Early metal and glass curtain walls, being avant-garde, were not designed with a discernible lifespan. The aluminum was cheap and easy to fabricate and not finished in a way that would preserve its luster. Some glass products were manufactured using technically sophisticated and obsolete processes, and it is no longer feasible to authentically recreate them. Original sealants or sealants used for repair are not always compatible with sealants that are presently available.

A third issue is defining significance of the metal and glass curtain wall. Is significance defined by the material itself or by the transparency that it provides? Perhaps a key to all of the issues cited can be found in the Nara Document on Authenticity, “authenticity judgments may be linked to the worth of a great variety of sources of information. Aspects of the sources may include form and design, materials and substance, use and function, traditions and techniques, location and setting, and spirit and feeling, and other external factors.” This statement infers that the historic fabric does not necessarily need to be conserved to maintain integrity.

Perhaps our approaches to energy inefficient building claddings will need to be reassessed as we enter into a new energy paradigm. Be that as it may, as our post-World War II buildings become historic landmarks, the challenges that we face will be complex as well and will require greater degrees of scientific inquiry and the active participation of the engineer.

REFERENCES