Title: **Reconstruction as Research: Digital Modeling of Key Postwar Skyscrapers**

Authors: Saranya Panchaseelan, MArch Candidate, Iowa State University
Shawn Barron, MArch Candidate, Iowa State University
Thomas Leslie, Morrill Pickard Chilton Professor, Iowa State University
Paolo Orlando, Intern Architect, substance architecture

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Saranya Panchaseelan


Shawn Barron


Thomas Leslie


Paolo Orlando

Authors

Saranya Panchaseelan, MArch Candidate
Shawn Barron, MArch Candidate
Thomas Leslie, Morrill Pickard Chilton Professor
College of Design
Iowa State University
146 College of Design
Ames, IA 50011
United States
t: +1 515 294 8460
e: tleslie@iastate.edu
www.design.iastate.edu/architecture

Paolo Orlando, Intern Architect
substance architecture
1300 Walnut Street, Suite 201
Des Moines, IA 50309
United States
t: +1 515 699 1675
f: +1 515 243 4692
e: porlando@substancearchitecture.com
www.substancearchitecture.com

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Abstract

The 2016 CTBUH Student Research Funding Program, kindly sponsored by Underwriters Laboratories, allowed researchers to use digital reconstructions from extant drawings and publications to research and illustrate the evolution of key cladding and environmental technologies used on tall buildings constructed in the Post-WWII era. They uncovered that the "glass box" model only emerged once MEP systems and glazing technology had both advanced.

Keywords: Curtain Wall, Façade, Construction, Digital Modeling

Introduction

The postwar "glass box" is perhaps the most ubiquitous skyscraper type – even today, this fundamental formulation of the 1960s defines much high-rise construction. Yet cladding a structural frame with a thin, mostly transparent curtain wall was a counterintuitive strategy for much of the 1950s. Architects instead relied on the pre-war formula of punched windows within a predominantly solid, often vertically-striated curtain wall. The authors argue that glass skins only emerged as enabling technologies evolved, and that systems such as fluorescent lighting and air-conditioning had to be supplemented by developments in glazing before the International Style dream of high-rise glass architecture made any sense (Leslie 2018).

Approach

Much of this research involved archival work on the materials and systems themselves, examining patent documents, corporate archives, and accounts of new innovations in the architectural press. To show how this influence worked, the authors wanted to examine key buildings in detail, in particular, to look at how systems and materials were integrated into floor plate layout and in curtain wall design. The 2016 Student Research Grant from the CTBUH, sponsored by Underwriters Laboratories, funded Research Assistantships for Iowa State's Construction History Research Group (CHiRG). These assistantships were dedicated to building fully detailed digital reconstructions of building floor plates and skins, which allowed visualization of the three-dimensional ramifications of these technologies.

The Evolution of the Glass Box: Six Key Buildings

The selection of examples for this project was determined by a review of press coverage in the early- to mid-1950s, regarding the application of then-new technologies in commercial construction, such as ducted air-conditioning, insulated glazing, heat-absorbing glass, and fluorescent lighting. Six buildings demonstrate the then-contemporary state of the art in construction, and the application of a new product or system: Equitable Building, now called the Commonwealth Building (Portland, 1949), United Nations Secretariat (New York, 1952); Alcoa Building, now called the Regional Enterprise Tower (Pittsburgh, 1953), Lever House (New York, 1953); Prudential Building, One Prudential Plaza (Chicago, 1954); and Inland Steel Building (Chicago, 1957) (see Figure 1).

These buildings present a convoluted but discernible timeline in the evolution of the so-called "glass box." Lever House and Inland Steel are paradigmatic instances of the type – though, as the research confirmed, Lever House was not as extensive an application of glass cladding as is often claimed. Similarly,

Figure 1. From left to right: Equitable Building, Portland (1949); UN Secretariat, New York (1952); Alcoa Building, Pittsburgh (1953); Lever House, New York (1953); Prudential Building, Chicago (1954); and Inland Steel Building, Chicago (1957).

the United Nations Secretariat is often claimed as the "first glass curtain wall," though its installation shows the complicated influences of burgeoning technology and conservative expectations for elements such as operable windows. Alcoa and Prudential are rarely mentioned in standard architectural histories, as their predominantly solid-paneled skins appear to be both stylistically and technically retrograde, given their dates. This is particularly the case with the extent of glazing and the sophisticated detailing of Equitable, which was precocious in almost every aspect of its cladding and environmental control. From a chronological standpoint, these buildings trace an unclear evolutionary path; the advances made in the Equitable Building and the glazed nature of the United Nations were ignored by designers of solid-skinned buildings of the early 1950s. In the case of Alcoa, the same firm that had designed the United Nations' façade just a few years earlier, Harrison & Abramovitz, reverted to a more solid façade appearance.

Simple chronology, however, does not account for the technical and environmental influences that shaped these structures, which have not been adequately accounted for in standard architectural histories. In particular, as environmental technologies came online through the 1930s and 1940s, cladding materials and systems lagged behind lighting and air-conditioning in their effectiveness. Glass proved troubling in terms of both its insulating value and its transmission of sunlight, until key innovations that addressed these issues became technically feasible two decades after air-conditioning established itself as a reliable, affordable amenity. As late as 1958, authoritative writing on curtain walls described an ongoing "reconsideration of the window," noting that with atmospheric and lighting control now being handled mechanically, "the functions of the window have often been narrowed to providing outlook or view alone" (Hunt 1958).

Windowless office and factory buildings present a persistent counter-narrative to the mythical march toward glass architecture promoted by Modernists such as Mies van der Rohe. Smaller windows – and thus solid skins – were promoted throughout the key decade of the 1950s for their ability to "considerably reduce air-conditioning equipment requirements and operation costs" (Hunt 1958). Predominantly solid skins, such as those of Prudential and Alcoa, were logical responses to the availability and efficacy of the mechanical and cladding technologies of the moment. Equitable's prescient glass and aluminum skin was the result not only of a forward-thinking architect and client collaboration; it was also a response to Portland's mild, cloudy climate and to the ready availability of affordable aluminum in the Pacific Northwest.

Deeper floor plates also resonated with developing planning standards, to allow larger expanses of open, flexibly-planned offices. This was evidenced not only by the size of the floor plates themselves – in some cases twice as wide as recommended depths for pre-war, naturally-ventilated floor plates – but also by the provision of mechanical services (see Figure 2). Supply registers and fluorescent light fixtures were typically arrayed on three-meter modules, a recommended dimension for offices and open-plan workspaces that appeared in standard references of the era, in particular Kenneth Ripnen's encyclopedic ***Office Building and Office Layout Planning*** (Ripnen 1960).

Despite their apparently retrograde skins, Alcoa and Prudential do deserve greater recognition for their technical achievements alongside their deeper plans. Harrison and Abramovitz's charge at Alcoa was not only to provide office space for the newly-renamed Aluminum Corporation of America; it was also designed to be a demonstration of aluminum's versatility for a company keen to find new markets for its product. Aluminum

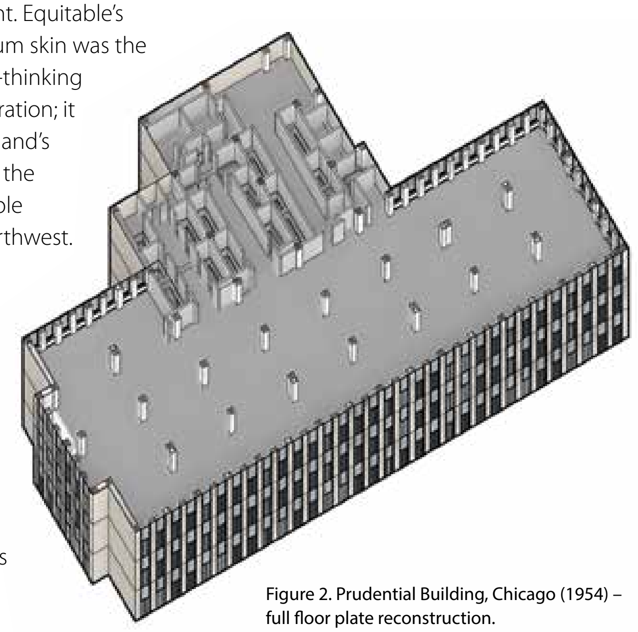

Figure 2. Prudential Building, Chicago (1954) – full floor plate reconstruction.

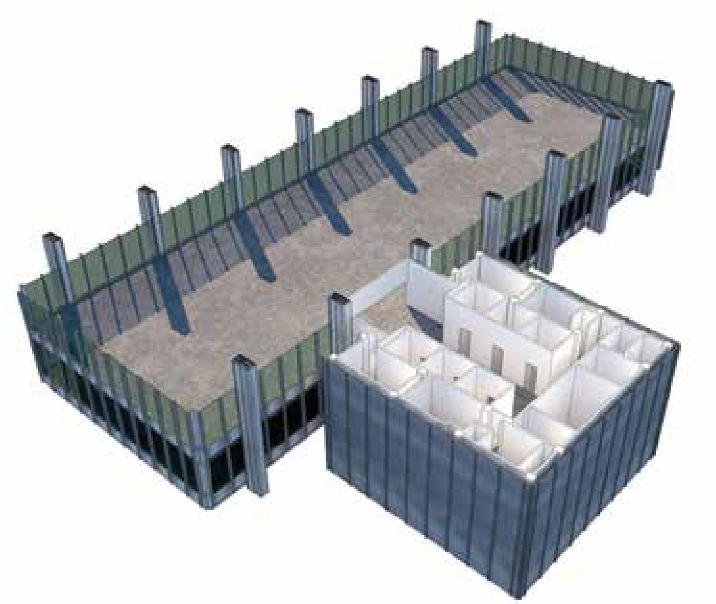

Figure 3. Inland Steel Building, Chicago (1957) – full floor plate reconstruction.

Figure 4. United Nations Secretariat, New York (1952) – cladding detail reconstruction.

had, since its discovery by Sir Humphrey Davy in 1809, been expensive enough to be considered a precious metal. Advances in the 1880s, such as using electricity to refine pure metal from aluminum oxide, made it commercially available, but its price remained high – over US$441 per kilogram. By the 1930s, however, aluminum prices had imploded, to around US$4.96 per kilogram.

The military demand for the metal – vital to aircraft manufacture in particular – ramped up production four-fold, a prodigious acceleration that left the industry with an enormous surplus in capacity after the war. (Roberts 1942). Alcoa (and its rivals, in particular Reynolds Aluminum) recognized the potential to transfer aluminum's light weight and precise fabrication into the building industry. Its headquarters building thus used the metal to demonstrate new applications, in particular electrical cabling, interior finishes, fixtures, and cladding.

Alcoa's curtain wall was composed of pressed aluminum panels: solid sheets stamped with x-shaped stiffening creases, and punched sheets fitted with extruded aluminum frames for aircraft-like windows measuring 1.2 square meters. To assist cleaning, these windows were mounted on pivots, with inflatable rubber tubes forming an airtight seal when closed (Holmes 1952).

Aluminum was an obvious cladding choice for Alcoa's corporate mission. It also made more economic sense in the electricity-rich Pacific Northwest, where power from the Grand Coulee-Bonneville hydroelectric power grid was used to produce more than a quarter of the country's aluminum during the war (Engle 1944). In Chicago or New York, however, other materials remained more economically viable. The Prudential Building used a similar pivoting window detail to Alcoa's, relying on the precise machining of aluminum frames to make these weather- and air-tight (Chase 1954). Between its vertical striations of aluminum and glass, the Prudential is clad in similarly-sized stripes of Indiana limestone, which remained a local, affordable material that recalled for some the façade treatment of the 1934 Field Building in the Loop, or even the earlier Rockefeller Center in New York. The selection of a cladding system similar to examples that were a generation old – in the midst of such extraordinary technical innovation – shows the lingering effects of both regional economics and the slow development of reliable glass technology (Architectural Forum 1952).

> “Smaller windows – and thus solid skins – were promoted throughout the key decade of the 1950s for their ability to considerably reduce air-conditioning equipment requirements and operation costs.”

Research and Digital Reconstruction

These buildings were widely covered in the professional press, and details published in contemporary articles allowed the initial assembly of digital models. The study of Inland Steel was aided by the Chicago office of SOM, which provided copies of key construction drawings and arranged a tour of one of the building's floors in the midst of renovation. This allowed first-hand confirmation of the study's initial findings about the building and its status as a truly innovative synthesis of these various advances.

The team constructed two models for each building – one showing a complete, typical floor plate, and one focusing on the junction

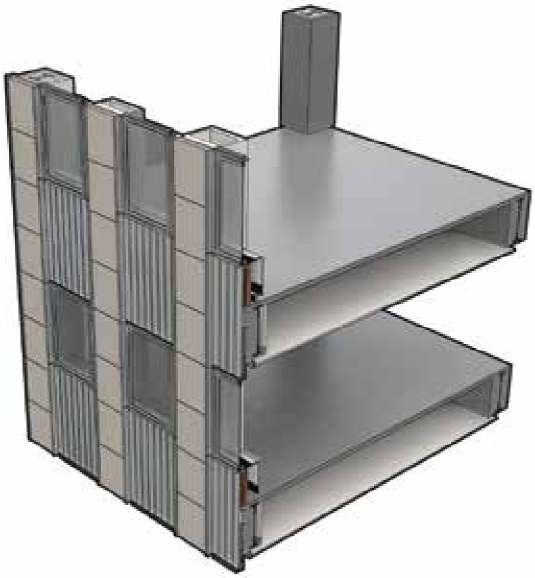

Figure 5. Prudential Building, Chicago (1954) – cladding detail reconstruction.

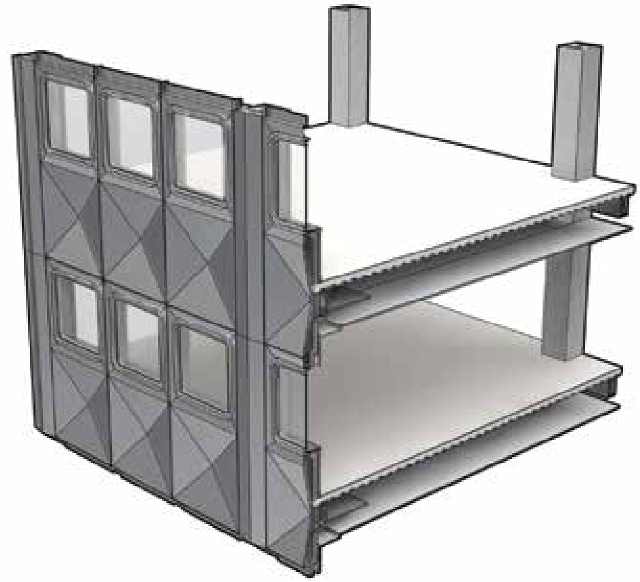

Figure 6. Alcoa Building, Pittsburgh (1953) – cladding detail reconstruction.

between floor slab, cladding, and mechanical systems (see Figures 3 and 4). Because nearly everything in these buildings was custom-designed – there were virtually no standard, packaged curtain walls, mechanical systems, or interior partitions on the market throughout this era – each model needed to be built from scratch. The floor plate models allowed study and illustration of the large-scale effects of air-conditioning and fluorescent lighting, which together eliminated the need for each desk to be located in proximity to a window. Examining the pathways for mechanically-conditioned air revealed assumptions about comfort and performance in various zones of these larger floor plates. Contemporary literature discussed intractable problems with condensation and with radiant heat loss endemic to large windows. These buildings all provided two systems of ducted air: one to provide comfortable conditions at each desk, and another that directed much warmer or cooler air over perimeter glass surfaces, depending on the season, to control condensation and to provide a conditioned "blanket" that would minimize radiant effects.

These perimeter details were universal whether the cladding in question was single- or double-glazed, showing that insulated glass – while an important advance – still had to be supplemented with conditioned, humidity-controlled air. These integrations of services and cladding were the subject of the second "family" of models (see Figure 5). For each structure, models extrapolated from published or drawn details of a full corner bay allowed a closer study of the physical relationships between perimeter air-conditioning, building structure, and cladding. Here there is evidence of definitive evolution. Both Prudential and Alcoa rely on a fundamentally solid approach to their exterior skins – the former is a combination of limestone and stainless steel, while the latter was seen by its client as a test bed for aluminum as a cladding material. Both skins are punched with windows, provided more, for views than for light (Architectural Forum 1952). Under each of these windows, Prudential and Alcoa have a sill-height air-conditioning box containing a fin-tube radiator that circulates air over the surface of the window (see Figure 6).

Interestingly, this detail – a roughly waist-high air-conditioning box – remained consistent in the first generation of postwar skyscrapers with predominantly glass skins. The Equitable Building, the United Nations, and Lever House, all of which appear to be early "glass boxes," actually have significant areas of solid, spandrel glazing and fireproof concrete or masonry walls on their perimeters, each backed up by tall air-

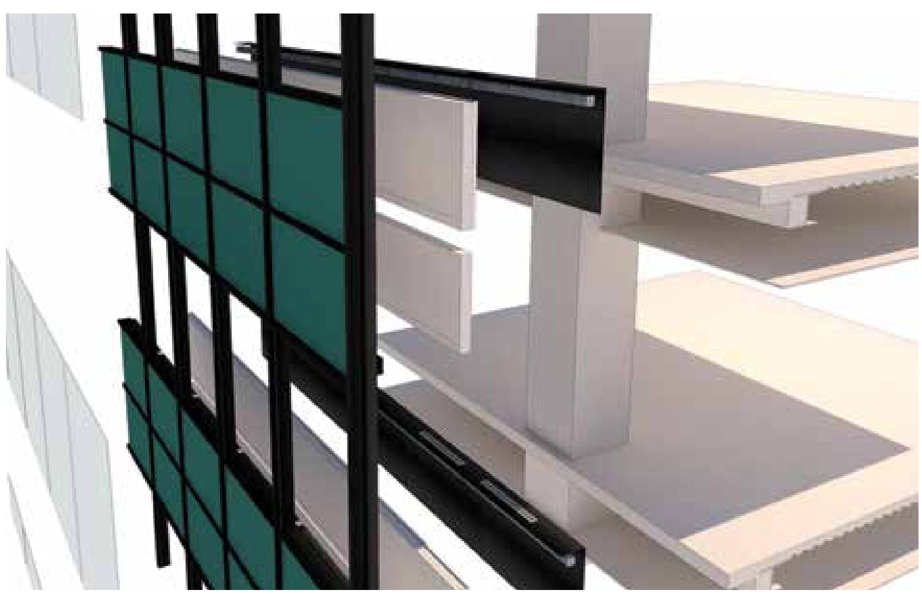

Figure 7. Lever House, New York (1953) – exploded cladding detail.

Figure 8. Inland Steel Building, Chicago (1957) – exploded cladding detail.

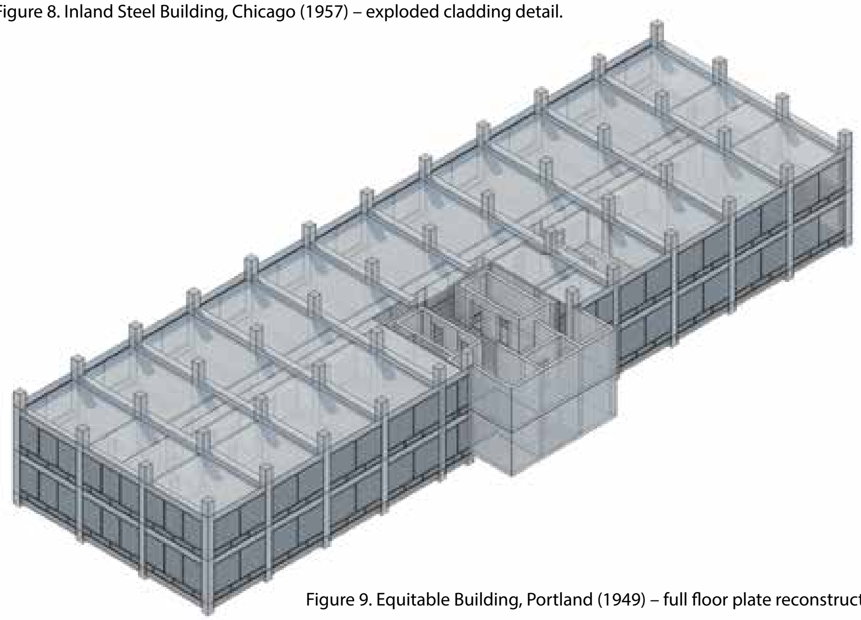

Figure 9. Equitable Building, Portland (1949) – full floor plate reconstruction.

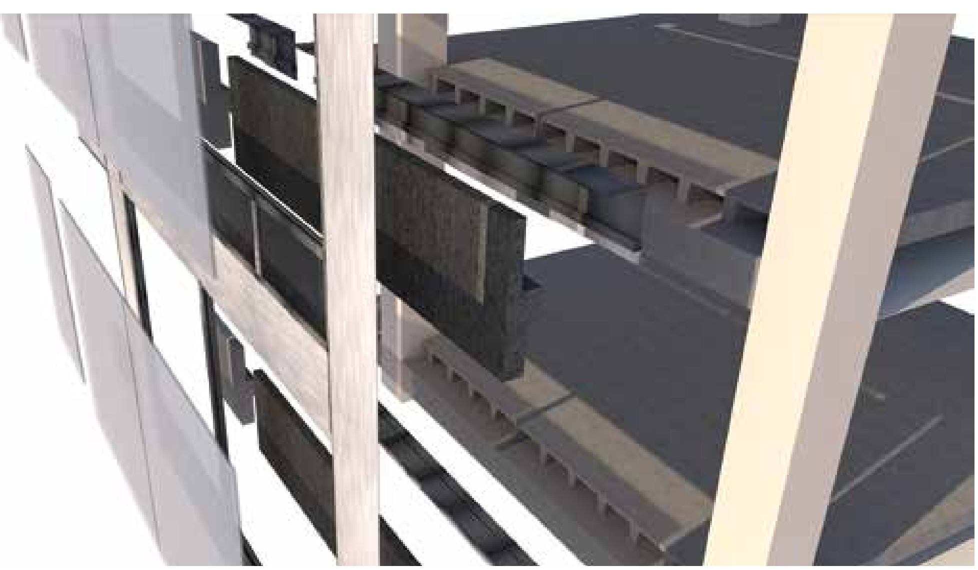

Figure 10. Equitable Building, Portland (1949) – cladding detail reconstruction, showing the location of perimeter air-conditioning cabinets.

conditioning boxes similar to those in solid-skin buildings (see Figure 7). This configuration was due to building codes predicated on the assumption that building façades would be some form of masonry. These codes required a physical separation between windows to prevent fire from spreading from floor-to-floor by re-entering apertures placed too closely together. These codes did not account for the potential effectiveness of fire sprinklers, instead relying on a passive philosophy of structural integrity to contain blazes until firefighters arrived (Hunt 1958).

As a result, early glass skins were still required to have significant fire-resistant backup; Lever House, for instance, is nearly 50% solid behind its masking glass skin, an otherwise invisible reality that is neatly illustrated by the team's digital modeling. Chicago's postwar code, developed by a committee that included SOM partner John Merrill, was intentionally progressive in relaxing this requirement, allowing an early version of performance standards that eliminated the proscriptive requirement for such solid panels. The firm took advantage of this in its design for Inland Steel, which thus became the first commercial high-rise in America to feature floor-to-ceiling glass windows (see Figure 8) (Chicago Daily Tribune 1957).

Analysis

Modeling these skyscrapers required thinking through their systems holistically, re-creating – as nearly as possible – discussions that must have taken place around the drawing table during their design processes. This often led to further findings about these structures. The Equitable Building's floor plans, for instance (see Figure 9), contained far smaller vertical shafts than its contemporaries. Further reading of contemporary press confirmed that this structure was not only a pioneer in its glass and aluminum cladding; it was also one of the first large buildings to use a heat pump for air-conditioning and warming (Architectural Forum 1948). Portland, because of its proximity to cheap hydroelectric power and its benign climate, is an ideal location for this technology. But while the heat pump as a concept was discussed as early as the 1850s, it was not practically demonstrated until 1945. The Royal Festival Hall in London, completed in 1951, has often been claimed as the first large-scale installation of this technology (The Architects' Journal 2001), but detailed technical information published about Equitable upon its opening shows clearly that a heat pump in its basement provided heated and chilled water to small air handlers on each floor. These, in turn, provided conditioned air through ducts to offices (Architectural Forum 1948, Clausen 1991). Water was also piped to Equitable's perimeter air-conditioning cabinets (see Figure 10). By using a heat pump and piped water, Belluschi's and Equitable's engineers eliminated the need for vertical air ducts, as well as the inefficiency of moving tempered air over long distances.

Findings: "Deep Plan: Thin Skin"

The researchers' primary interest was in the integration of glass, environmental, and lighting technology, and efforts concentrated on studying the relationships between lighting, air-conditioning, planning, and cladding in these postwar towers. By tracking articles in the professional and technical press, the study established a definitive sequence to these innovations. Air-conditioning, a long-developing technology that was first employed throughout a commercial high-rise in the 1922 Milam Building in San Antonio, saw a huge increase in popularity during the Dust Bowl summers of 1934 and 1935 (see Figure 11). Fluorescent lighting became commercially viable after 1938 and was boosted by factory construction during WWII. Fluorescent lamps produced more usable light for less electricity than incandescent lamps. They also ran cooler, which put less strain on air-conditioning systems, and allowed for plastic housings and diffusers that could distribute light far more effectively (Bright and Maclaurin 1943). Together, air-conditioning and inexpensive, efficient fluorescent lighting enabled deep plans that separated office space from windows. Examples of "windowless" buildings, such as the Simonds Saw Factory in Fitchburg , Massachusetts, show a tendency toward climate- and light-controlled buildings that eliminated daylight entirely from the interior – along with windows' troublesome shortcomings such as water and air infiltration, heat gain, and glare (see Figure 12) (Architectural Record 1939).

Innovations in glass that permitted "thin skins" to go along with these deep plans, however, did not reach commercial markets until after the war. Insulated glazing was first marketed by Libbey-Owens-Ford in 1938,

Figure 11. Milam Building, San Antonio (1922), the first air-conditioned commercial office building.
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but the first generation of "Thermopane" was beset by leaky seals (Lowenthal 1939). Only with newly developed metal seals, perfected during the war, did this technology become reliable enough to gain market share. The John Hancock Building in Boston (1949) was the first major commercial building to employ Thermopane (see Figure 13), yet it did so in a curtain wall that owed more to the vertically-striated, mostly solid skins of pre-war buildings such as Rockefeller Center.

Pietro Belluschi used insulated glass on the Equitable Building, but its application and

Figure 12. The pre-eminence of the "glass box" office building was by no means assured. Many of the contemporary advances in technology also led to a windowless ideal.
Source: Simonds International

> "It was not until the combination of heat absorption and insulated glazing was successfully demonstrated in Inland Steel that this combination, and the full glass curtain wall it enabled, flourished in tall building construction."

Figure 13. John Hancock Tower, Boston (1949).© SM2545 (cc by-sa)

performance revealed continuing shortcomings. Libbey-Owens-Ford was unable to supply Thermopane in the sizes required, leaving Pittsburgh Plate Glass (PPG), which manufactured a competing product targeted at the residential market, as the only other supplier available (Clausen 1991). PPG also employed a new heat-absorbing product, Solex, at Equitable, but problems with shedding heat gain led to cracking. Similar problems with thermal expansion in heat-absorbing glass at the United Nations meant that architects remained wary of all-glass skins throughout the early 1950s (Gonchar 2012). Concerns about glare in previous projects commissioned by Prudential mandated a more solid skin on that building, and it was not until the combination of heat absorption and insulated glazing was successfully demonstrated in Inland Steel that this combination, and the full glass curtain wall it enabled, flourished in tall building construction throughout the country.

"Deep plan, thin skin" thus has as its main argument the importance of technical development to stylistic changes. Much as combinations of material prices and electrical technology influenced the composition of building masses and skins in early Chicago skyscrapers, innovations in cladding and servicing clearly impacted these aspects of postwar structures as well.

Historians saw the spread of glass across residential and commercial architecture and the distillation of load-bearing walls to lightweight, transparent "screens," as the fulfillment of Modernist dreams of "volume over mass." But detailed analysis of the physical fabric of these buildings shows that such stylistic concerns were secondary to the economics and performance of these volumes and screens in the minds of architects, engineers, and clients.

Conclusions

Architectural history can be productively re-cast by thinking about what must have occupied designers, engineers, and clients at the drawing board and around the conference table. This is a goal of construction history, a relatively new academic discipline which seeks to explain buildings from various technical and economic points of view. Such a stance ties architecture more directly to industrial, labor, technological, and even political history, and emphasizes the importance of practice to the production of buildings throughout history. In looking at the evolution of the "glass box" through these lenses, the authors hope to add to historians' understanding of the complex forces that shaped these iconic structures, in one of the most innovative and productive eras of high-rise construction. ■

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