Insight

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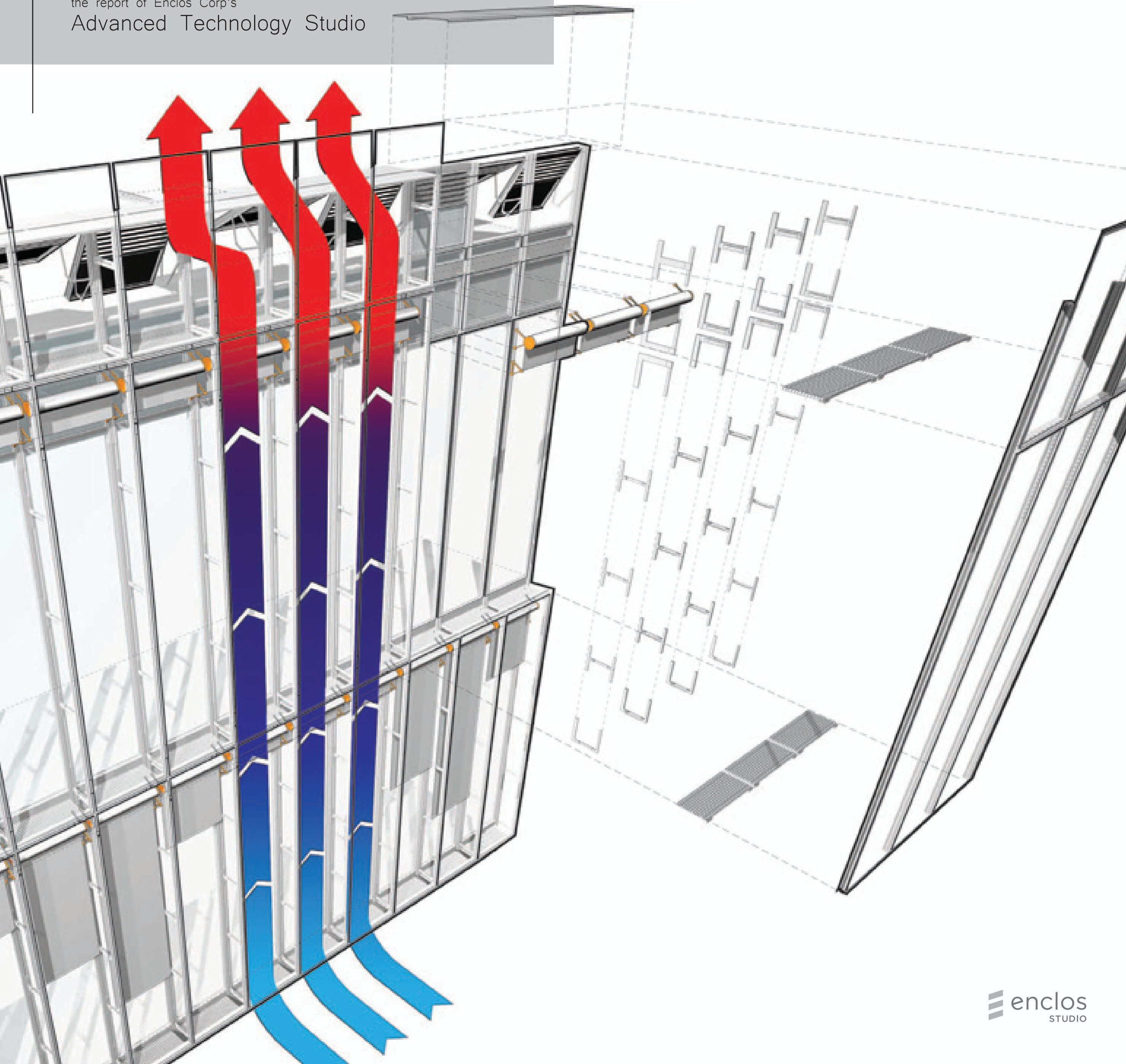
the report of Enclos Corp's
Advanced Technology Studio



enclos STUDIO

Insight

ADVANCED
TECHNOLOGY
STUDIO

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ATS Executive Summary

Welcome to the second issue of Insight, the publication documenting the activities of the Advanced Technology Studio of Enclos. With this second issue we evidence our ongoing commitment not only to a sustained research and development effort intent on defining the future of the building skin, but to documenting and sharing this effort with the AEC profession, industry and the academy. The issue highlights many of the activities from 2011.

It was a busy year. Our primary focus has been the support of the preconstruction effort on projects incorporating advanced facade technology, and the development of automation and computation tools to improve the efficiency of the engineering production group. Along the way, nearly a dozen research papers prepared by various Studio personnel were accepted for presentation at key industry conferences, including a major showing at Glass Performance Days in June 2011 in Finland, with six people making the trip to Tampere. The Studio team also participated in pre-sale concept design and development on over 20 unique building projects with an approximate value of over $400 million.

Recent highlights include:

- The E-Generator software used for the electronic creation of the fabrication drawings of our unitized curtainwall systems was launched last year. The software is currently being utilized in production on most of our newly contracted projects. The initial feedback from the production team is very positive, in some cases resulting in a staggering 200% improvement in throughput. The refinement of the software continues to be a Studio priority, with the goal of full production utilization in 2012.
- The Studio continues its advances in the development of state-of-the-art double-skin facade technology. This past year we initiated the use of pressurized double-skin technology in collaboration with Rinaldi Structal, a French facade design and engineering firm, including the first U.S. application of an actively pressurized double-skin wall system for a new hospital project on the Stanford University campus in Stanford, California. The product is currently undergoing mockup testing and is scheduled to be commissioned in early 2013.
- The Studio has initiated new research endeavors in areas of product optimization, cladding retrofit and kinetic facade systems, while continuing the development of mobile assembly concepts and cassette cladding systems. We also filed for patent protection on a new blast

mitigation product that is expected to provide a new standard in structural blast performance. Full scale product testing is proceeding concurrently.

Building upon the success of our first Advanced Technology Studio launch in 2009, we are excited to announce the opening of a second in New York City. This new venture was fully staffed in the last quarter of 2011, and is now operating from a leased loft space in Chelsea — immediately adjacent to the High Line. Both Studios are intended to function as a resource to our clients, and we are confident that the introduction of the New York team will result in enhanced service for our many East Coast clients.

We welcome your feedback regarding this publication and our Studio efforts, particularly with respect to additions or modifications of our research agenda that would be of interest to you. Moreover, we invite you to visit us at either Studio at your convenience; we are certain you will find our activities of considerable interest.

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Vice President of Engineering, Enclos

INSIGHT is the publication of the Studio and serves as a conduit to share our research and development with others throughout the AEC community. The report is a glimpse into our recent efforts and we encourage you to share your ideas to help shape the future of the building envelope.

Publications

Activity within the Studio is dynamic and the result of an environment which embraces collaboration. This is most true with our ongoing research and development projects. Outside experts may be used to validate internal investigations or perform advanced testing. One method of obtaining valuable feedback in response to our work is through publication in journals and presentations at relevant conferences. The outside perspective of leading experts in the facade industry helps shape the direction of future research. This participation in publications and conferences keeps us in touch with industry trends and advancements while gaining visibility for Enclos and our commitment to advanced technology leadership.


Jacob K. Javits Convention Center | New York

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

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Original paper and presentation for the 2011 Building Enclosure Sustainability Symposium: Integrating Design & Building Practices at Cal Poly Pomona.

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.

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

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.

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

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 curtainwall 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.

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 curtainwall 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.

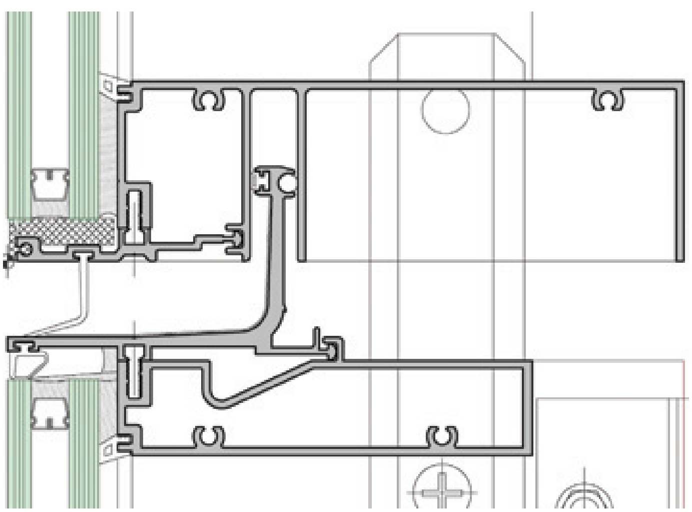
There are other issues, as well. In addition to being a poor thermal insulator, glass is an equally poor acoustical insulator. A significant threshold has been recently crossed, whereby the majority of the global population now lives in densely populated urban environments. In the early decades of tall 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 towers 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.

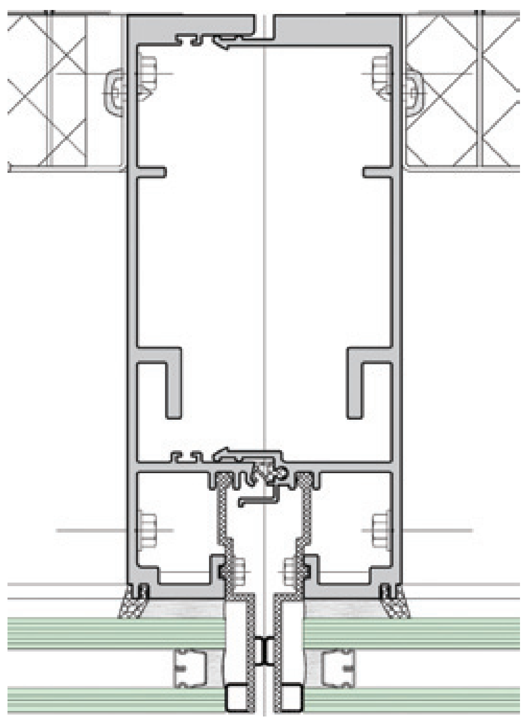
2.2 CURTAINWALL TECHNOLOGY

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

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.





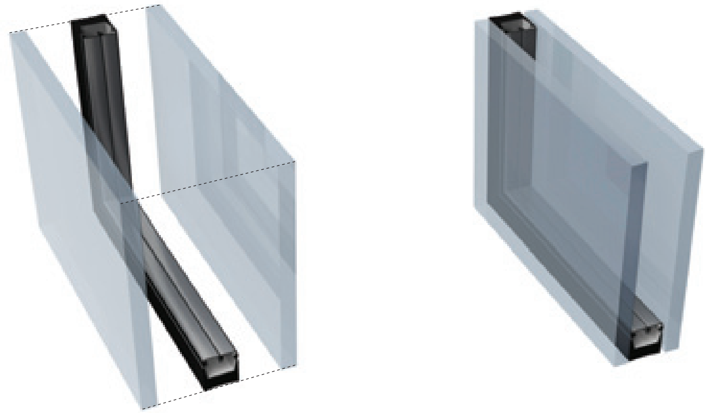


Figure 4: The construction of a typical double-glazed insulated glass unit (IGU), exploded (left) and assembled.

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 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 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 responsive 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.

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.

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

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.

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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Riverhouse | New York, NY

Seeing Double

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Mic Patterson, LEED AP [BD+C]

Original article published in the March 2011 issue of US Glass Magazine.

We've heard about them, some of us have seen them, and a lot fewer of us have actually worked with them, but that may be about to change. In spite of the adverse economic conditions, double-skin facade (DSF) applications have actually increased as part of the green trend that continues to thrive in the down economy. So what are they, what's the point, and can I expect to see one in my backyard any time soon? Well, it depends a little on where you live, but with recent applications in major metropolitan areas including New York City, Boston, Chicago and Los Angeles, the chances are that there may be one not too far from your doorstep.

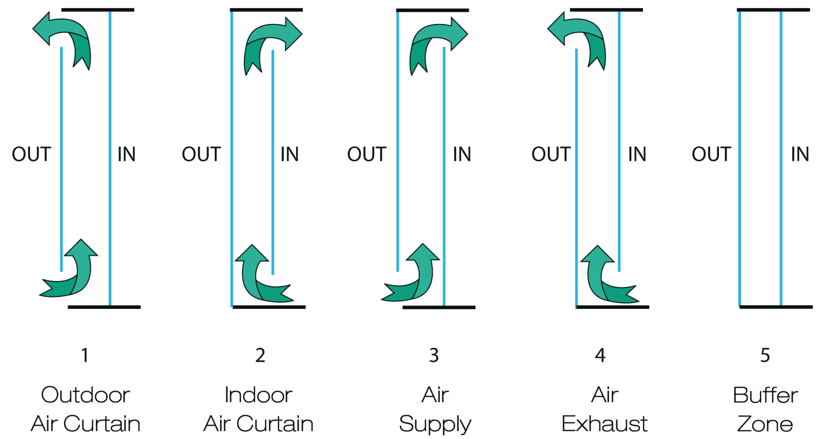
DSFs are simply a strategy for improving building envelope performance through the introduction of a second glazed layer, thereby creating an airflow cavity between the two.

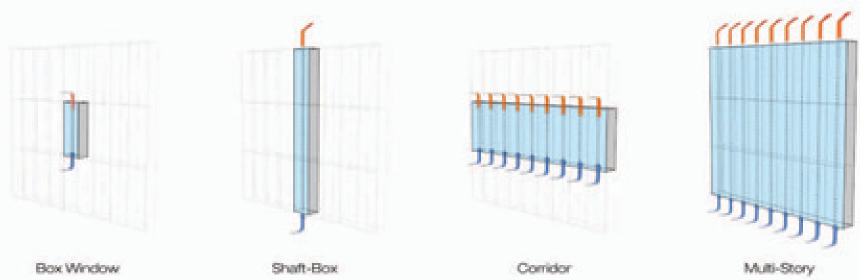
The application of the technology in the U.S. has been a long time coming. Although early examples of DSFs exist stateside – the Occidental Chemical Center in Niagara Falls, New York (1980), as but one example – the major development and implementation of the technology took place in Northern Europe through the 1990s and 2000s, with numerous completed works of great variety, driven by legislative mandates for improved energy efficiency in buildings. The impetus for the initial development of DSFs was not only thermal comfort and energy efficiency, but also acoustical performance; mitigating sound transmission through the glazed building envelope. This is still a very good reason for their use, especially as our dense urban environments become increasingly populated with residential dwellings. Nonetheless, thermal performance and natural ventilation have been the more recent drivers of this advanced facade technology.

IT'S ALL ABOUT THE CAVITY

The cavity is useful for a few things. First, it acts as a thermal and acoustical buffer between the inside and outside environments. Second, the cavity can be employed in various ways to provide airflow, and even building ventilation. Third, the cavity provides an optimal space for the location of shading devices: outside the inboard skin so that solar radiation is stopped before penetrating into the building, yet shielded from the elements by the outboard skin. If the cavity is deep enough, it can also house mechanical equipment and maintenance platforms. It turns out that cavity depth ranges widely from about 4 in. to 6 ft. (10 cm to 2 m) among the various built DSFs. It should be no surprise, then, that the applications of DSFs are most often categorized by variations in cavity design and behavior. Ventilation type, ventilation mode and cavity partitioning are the most commonly used criteria.

The ventilation type refers to the driver of airflow within the cavity, which can include natural, mechanical and hybrid systems. The ventilation mode refers to the airflow pathway from intake to exhaust. The five common ventilation modes are 1) outdoor air curtain, 2) indoor air curtain, 3) air supply, 4) air exhaust, and 5) buffer zone. The diagrams in Figure 2 trace the pathways characteristic of each mode. Finally, DSFs are most usefully classified by the cavity partitioning strategy employed in any give design. The four primary cavity configurations are box window, shaft-box, story-height (corridor) and multi-story (Figure 3). Each configuration possesses unique attributes of design, performance and application. The multi-story types tend to be the deep cavity systems, while the other configurations typically utilize much shallower cavities.





(top to bottom)

Figure 1: Internal view of DSF cavity at USC's Eli and Edythe Broad CIRM Center for Regenerative Medicine and Stem Cell Research (Broad Center) by ZGF Architects LLP, and Walters & Wolf (facade contractor/installer) with W&W Glass Inc. (cable system engineer and supplier).

Figure 2: DSF ventilation mode diagrams characterizing the airflow path from entry to exhaust orifices.

Figure 3: DSF cavity configurations with various subdivision of the cavity geometry.

Figure 4: West elevation of DSF with cable net supported outboard skin at the Richard J. Klarchek Information Commons, Loyola University, Chicago, by Solomon Cordwell Buenz (architect) and Enclos (facade design-builder).

TRENDS IN DSF APPLICATIONS

In a recent evaluation of twenty-three existing applications, the most common DSF cavity partition configuration in the United States is the multi-story (70%) and the most common ventilation mode is the outdoor air curtain (74%). The multi-story DSF cavity has no horizontal or vertical divisions, and may encompass an entire elevation of a building facade. Intake air openings are placed at the bottom of the cavity with exhaust openings at the top. Ventilation of the cavity can be naturally induced through the stack effect (as the cavity air warms it rises and is exhausted through the top vent, in turn drawing air into the cavity through the bottom vent) or mechanically assisted as required to prevent overheating of the cavity air. The more advanced designs utilize this cavity behavior to provide ventilation to the building. The Richard J. Klarcheck Information Commons at Loyola University in Chicago (Figure 4) utilizes this effect in a west elevation DSF. In this application the stack effect is augmented by offshore winds that act to draw air from the cavity at the top vent.

Multi-story DSFs can provide a unique, highly transparent aesthetic with abundant daylight, a thermal buffer, enhanced acoustical performance, and contribute to building ventilation. Potential disadvantages include flanking sound and odor transmission through the cavity, overheating of the cavity air if ventilation is inadequate, and building code issues with respect to fire-safety because of the lack of fire safing between floors. Design flexibility is greater with the multi-story DSF types than with any other category. Many variations are conceivable, and this DSF type has been applied on educational, museum and healthcare facilities, among other building types. Recent examples of multi-story DSFs include the Eli and Edythe Broad CIRM Center for Regenerative Medicine and Stem Cell Research (2010, Los Angeles) by ZGF (Figure 5), New York Presbyterian Hospital (2010) by Pei Cobb Freed, Cambridge Public Library (2009) by William Wrawn Associates, and the Modern Wing at the Art Institute of Chicago (2009) by Renzo Piano Building Workshop.

Figure 5: Point-supported exterior glazing installation at the Broad CIRM Center utilizing permanent maintenance platforms during installation to attach glass to tensioned vertical cables.

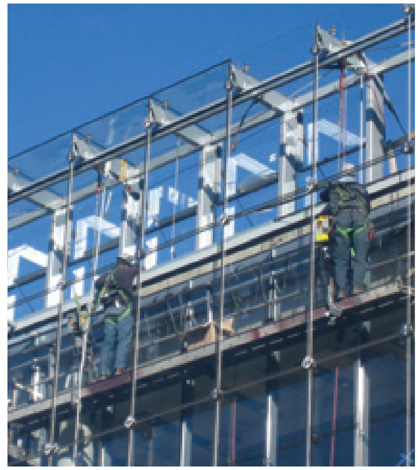


Figure 6: Workers on swing stages outside and within the cavity, access both sides of the outboard skin of the Loyola Information Commons DSF.

The evolution of DSFs in the U.S. exhibits other emerging trends. An alternative to the multi-story system is the increasingly popular box-window type, with a cavity depth at the shallow end of the spectrum, typically in the range of 4 to 8 inches. This DSF type is easily configured as a modular, prefabricated unitized curtainwall system appropriate for application on high-rise buildings. An early example of this DSF type is the Manulife US Headquarters (2003, Boston) by SOM. The location of mechanized systems, such as shading products within the cavity of the DSF, means that the cavity must be accessible for maintenance purposes, significantly complicating the design of a unitized facade system. The lack of a hermetic seal in the unit means that airborne particulates and moist air can potentially infiltrate the cavity, resulting in dirt and condensation on the inner glass surfaces and further escalating maintenance requirements. Current development efforts are aimed at addressing these issues.

In addition to high-performance unitized curtainwall systems capable of cladding an entire building, box-window configurations can be developed as discrete window or window-wall units, and have been used as a facade component in office, residential, and hospital projects where the floorplan is subdivided into many repeating units (offices, condos or patient rooms). Riverhouse (2008, New York) by Ennead Architects is an example of a residential development that adopted such an approach.

DOUBLE-SKIN DOUBLE INSTALLATION

Assembly and installation issues with DSFs range as widely as the system variations. Unitized double-skin curtainwall systems can be complicated by the need for panel operability to accommodate maintenance needs. Prefabrication may include the installation of shading devices and controllers as part of the unit assembly process. Once the units are assembled, however, installation proceeds much the same as with conventional units, except the units are typically heavier, which may preclude lifting several units simultaneously.

Multi-story DSFs present quite another scenario. Because of the long spans typically involved, these applications will often have exposed structural systems, sometimes requiring architecturally exposed structural steel (AESS) standards. This type of work is often unfamiliar to glazing contractors and steel fabricators alike, and is rightly regarded as a specialty item. In fact, many of the multi-story DSFs referenced above make use of structural glass facade technology, including the use of frameless glass systems as a support strategy for the exterior skin. The interior skin is often a conventional curtainwall or storefront type system. The issue is with the exterior skin, its means of support, and the required cavity work. The cavity often incorporates maintenance platforms, shading devices, and potentially other mechanical components such as operable vents. These may or may not be included in the facade contractor's scope of work. An issue of particular concern is the cavity depth: the deeper the cavity the easier it is for workmen to operate with all the required equipment. Cavity depths less than 30" begin to seriously constrain ease of movement for the workmen.

A particularly elegant way to support the outboard skin is with the use of a cable net. This presents a new set of challenges to the facade installer relating to the pre-tension requirements that must be applied to the cable system. The magnitude of force is typically high enough that hydraulic jacking equipment is required to achieve the required cable prestress. However, tensioning a cable net is not generally as simple as moving from one cable to the next with a tensioning device. Progressive tensioning tends to alter the previously tensioned cables, resulting from the residual effects to the supporting boundary steel. Cable tensions must be confirmed with the use of an appropriate tension metering device. The installer should request a detailed installation method statement from the facade designer, and carefully consider the cost impacts in the estimate of work.

Access is a consideration on any facade, with little difference here. If there are maintenance

Figure 7: A mast climber (continuous work platform at top of wall) was used to install the outboard skin working from the bottom up at USC's Eli and Edythe Broad CIRM Center, Los Angeles.

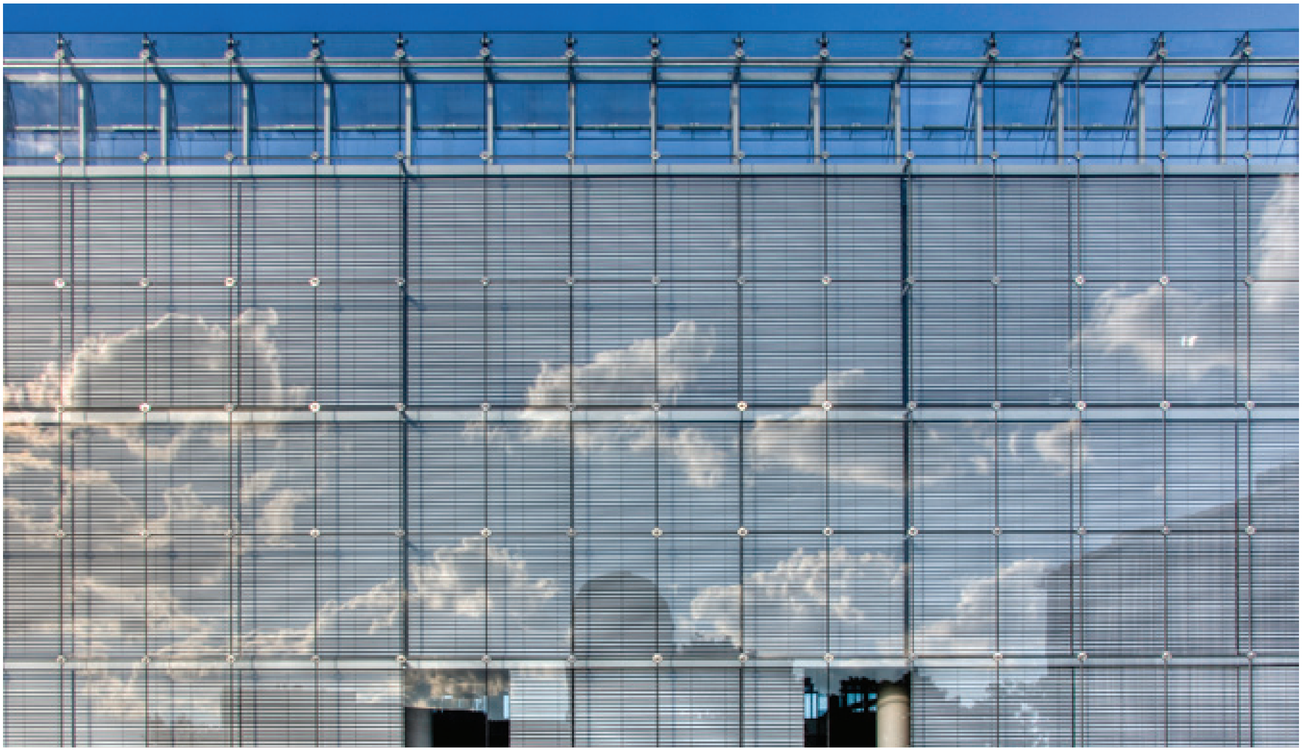
platforms in the cavity and they are installed before the outboard skin, they can be used during installation. If not, temporary platforms may be required within the cavity (see Figure 6). Depending upon the glazing system design, workers may be required on both sides of the skin. In Figure 7, a mast-climber is being used to position men and materials outside the outboard skin of a DSF.

A final consideration for the facade contractor is commissioning. The requirement for system commissioning of advanced facade designs, DSFs among them, is becoming increasingly common, and is something that progressive facade contractors should prepare for. While commissioning requirements will vary between jobs, it is essentially a process of validating that the facade is installed and functioning as intended. With operable and dynamic components integrated into the facade design and critical to the intended function, commissioning processes are vital in assuring the building owner of future performance.

INFORMAL SURVEY DATA

The Advanced Technology Studio of Enclos, a national provider of curtainwall systems, has been conducting an on-going survey of architects, engineers and facade designers. Among their findings with respect to DSF technology: 50% of respondents are either using, or considering using, a DSF system on a current project, and a whopping 73% regard DSF systems as an important component of future facade technology. Not surprisingly, cost is perceived as the biggest barrier to the diffusion of the technology into the broader building marketplace. Despite a general agreement on the energy saving potential of DSFs, designers and owners remain skeptical of the value provided by the technology in terms of system payback and return-on-investment. Life-cycle costing analysis (LCA) has proven challenging for the industry, partly because of the inherent complexity and partly because of the lack of hard data on the performance of the systems built to date – unfortunately post-occupancy monitoring of buildings is seldom performed. LCA methods are also often compromised by the energy costs used in the models, which fail to reflect the true cost of energy, such as the cost of continued dependency on oil from increasingly volatile foreign sources, and the cost of developing renewable energy sources so that they are ready as the nonrenewable sources are depleted. Higher energy costs and improved LCA methods will have more impact on future applications of DSF technology than any other factors.

Other emerging trends include the application of DSF technology in a broader range of climate zones. The technology was conceived and developed in colder northern climates of the U.S. and Europe, climates dominated by heating degree-days where solar heat gain can be harnessed from the DSF cavity during winter months, and ventilated to the outside during summer months. Presently, DSF technology is receiving heightened consideration in project developments across the U.S., primarily for its perceived attributes of sustain-



ability, including increased energy efficiency, acoustical insulation and access to natural ventilation. Driven by the combined effect of the need for improved energy performance and comfort in buildings, with a continued desire for facade transparency in work and home environments, the DSF continues to evolve in new architectural programs. The result is that DSF designs are now being incorporated into buildings in more moderate climate zones, such as recent applications along the Pacific Coast – from Seattle to Los Angeles. Some designers question the value of DSF designs in these more moderate and warmer climates, uncertain that they represent an effective use of resources. Again, the lack of solid post-occupancy data to measure the performance of DSF applications against initial design targets yields only uncertainty.

Finally, a related trend worth noting is that DSF designs are also diffusing into a broader range of building types. Originating (with notable exceptions) largely in commercial office buildings, recent applications include institutional, cultural, residential, and health-care projects.

FUTURE DEVELOPMENTS

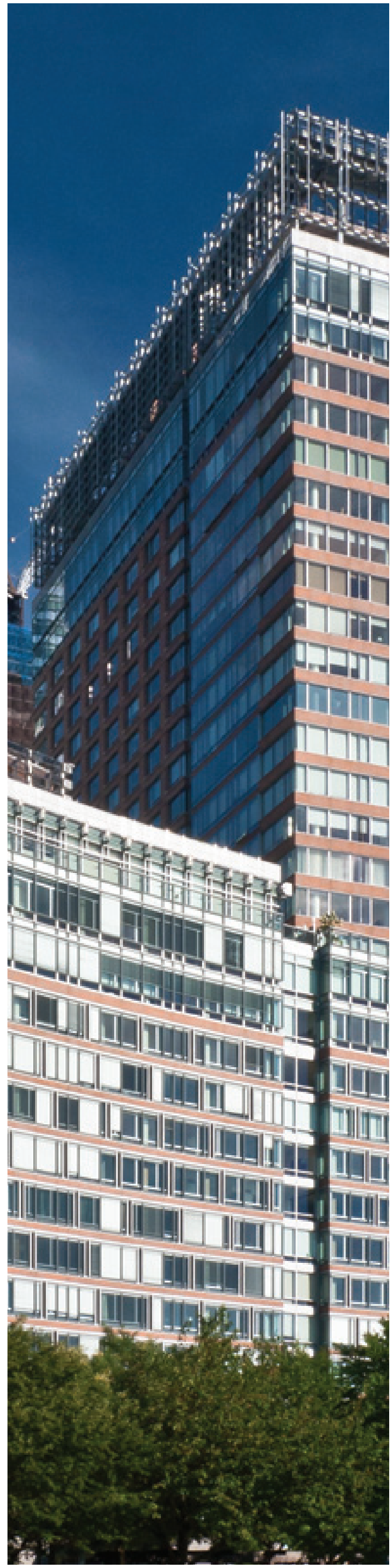
Arguably the most compelling future application of DSF technology is in building retrofits. Realizing energy consumption and carbon emission reduction goals established by various green platforms such as the White House Agenda and the 2030 Challenge initiative will require energy retrofits to a large percentage of the current building stock, many of these programs should include facade retrofits. Many of the early glass curtainwall towers built during the 1960s and 1970s, for example, were originally constructed as single-glazed facades with low visible light transmitting glass (mirror coatings), were poor energy performers from the beginning, and are now approaching something very close to old age. Reuse is a primary tenet of sustainable building practice. Not only should we avoid demolishing our old buildings and replacing them with new ones, we should also make every attempt to renovate the existing facade, reusing as much of the material as possible. The addition of a second skin may prove to be a viable approach in some, if not many of these buildings, providing greater economy, modernizing the appearance, and improving energy performance - all while projecting a positive message of environmental stewardship.

Several buildings which have used a second skin as a strategy for facade retrofit include the 100 Park Avenue and 330 Madison Avenue projects in New York by Moed De Armas & Shannon Architects, and the planned modernization of the Rodino Federal Building in Newark, New Jersey, by Dattner Architects.

CONCLUSIONS

DSFs are a reflection of the escalating demands on the building skin, the most engaging of building systems, which singularly combines attributes of both performance and appearance. DSFs are one strategy of emerging advanced facade technologies that include new glazing materials, improved framing systems, progressive techniques, and novel designs. That unique combination of glass, transparency, and the manner in which it enriches our built environment with daylight and view, assures that glass will remain a predominant material in the building skin. Unfortunately glass, as we well know, is a poor thermal and acoustical insulator, and these negative attributes threaten to limit its use in this same context. It is imperative that we as an industry do not adopt a defensive position in an attempt to protect a vested interest. We must embrace the mandate for improved energy efficiency and reduced carbon emissions in buildings, and deliver solutions that optimize facade performance and nullify the negative qualities of glass, thus assuring the benefits provided by the unrestricted but appropriate use of glass in the building envelope. The ultimate viability of DSF technology, and the role it will play in future building facades, is unclear. We need to make a more aggressive and sustained effort to better understand how these very interesting experiments in advanced facade design are actually performing.

DSF technology, however, is but one strategy made in response to the challenge presented by facade performance. There are others and there will be many more. The needed solutions will involve an intensifying collaboration between the profession, academia, and industry – one long overdue – and will require ongoing investment in research and development by all stakeholders.




North
Building
Atrium
Entrance
Café
South
Building


Seattle Family Foundation Campus

Sean Airhart | NBBJ

Sustainable Facade in Tension

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

Original paper and presentation for the 2011 Building Enclosure Sustainability Symposium: Integrating Design & Building Practices at Cal Poly Pomona.

The new Seattle, Washington headquarters campus for the world's largest philanthropic organization targets aggressive sustainable performance with maximum transparency by utilizing curtainwall and specialty-glazed structures. A transparent glass atrium serves as the primary entry, centrally located and programmatically versatile with grandeur to host receptions, banquets or other events. The atrium features two custom point-clamped glass walls supported by a series of slender vertical cables, elegant by design and innovative in their responsiveness to programmatic demands, climatic context and an aggressive project schedule. The lantern-like portal acts as a fulcrum between indoor and outdoor space, while establishing a strong connection to the immediate public realm and emphasizing the benevolent character of the Foundation. The atrium's point-supported approach minimizes thermal bridges within the envelope and exemplifies the degree of high-performance that can be attained outside the traditional curtainwall facade paradigm to achieve a transparent environment with sustainable priorities.

Figure 1. Aerial view of the Foundation headquarters under construction. Photo taken from the southwest, atop the Space Needle observation deck.

1 INTRODUCTION

The Foundation currently has more than 900 employees working in various locations. Looking to unite locations and increase capacity to 1,500 employees, the Foundation conceptualized a new sustainable campus located in the heart of Seattle which reflects their values and mission. The first phase broke ground in July 2008 and includes the construction of two sweeping boomerang-shaped six-story structures, resulting in 900,000 square feet of office, event and visitor space. Phase One was completed in spring 2011. A third building will be constructed in a second phase, adding 400,000 square feet. Utilizing a whole-building approach for Phase One, the project team was able to achieve a balance of transparent aesthetics and sustainable performance by evaluating the enclosure and mechanical systems hand-in-hand. The facade program includes in excess of 300,000 square feet of surface area and uses multiple custom systems to enclose the office spaces. The atrium's tensioned support structure sits at the core of the campus and is designed to meet high performance, security and blast requirements. The atrium facade structure and glazing attachments are completely exposed to the interior space, requiring the highest level of craftsmanship throughout every aspect of construction. The atrium's tension structure, in combination with high-performance argon-filled insulated glass units, is an example of how facade and mechanical engineers can collaborate to leverage the thermal advantages of point-supported systems – in comparison to conventional curtainwall systems – to attain aesthetic and aggressive sustainable performance goals.

2 SITE CONTEXT

The Foundation sits on a 12-acre pentagonal site in the backyard of Seattle's iconic structure, the Space Needle. The site, formerly a city-owned and operated parking lot, is located adjacent to Seattle Center, a cultural center with a storied history of regional and international gatherings.

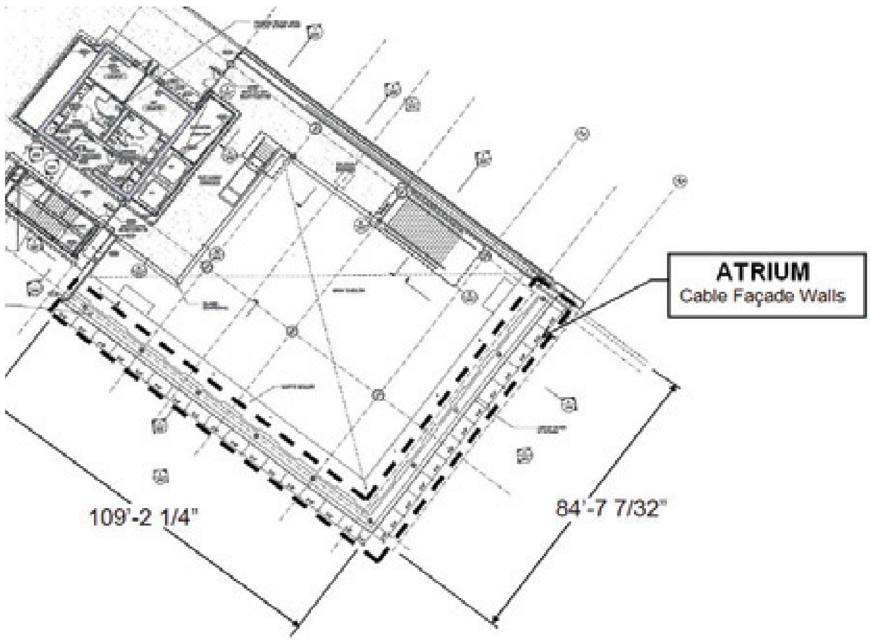


Figure 2. Atrium layout building plan at Level 3.

The site is well connected with the metro transit system, including bus stops along the west and northeast boundaries of the campus and a 0.3 mile walk to the Seattle Center Monorail terminus to the southwest – adjacent to the Frank Gehry-designed Experience Music Project. In order to provide adequate parking for the campus (700 spaces total), a new public-private partnership between the city and the Foundation was established to build the multi-level LEED Gold certified Seattle Center 5th Avenue N Garage. Garage construction began in January 2007 and opened for operation in July 2008. The parking structure includes a visitor center and 1.4-acre living green roof that replaces 12-acres of surface parking [2]. The green roof is covered in sedums and natural plants to reduce the energy consumption approximately 40% compared to similar structures, as well as reduce the rainwater runoff by 90% [5]. The two buildings continue the sustainable initiative adopted by the Foundation to develop an environmentally conscious headquarters campus.

3 BUILDING ENERGY DESIGN

The new headquarters design prioritizes resource conservation in creating a healthy work environment. The building was designed with an array of sustainable features, ultimately reducing energy consumption 25% lower than code requirements. A notable sustainable feature on the campus is over a half an acre of green roofs, which reduce the urban heat island effect and create on-site water conservation through rainwater harvesting. Local and recycled materials are used throughout the building structure, in addition to extensive daylighting of the interior spaces. These features are designed to interact with and complement one another while simultaneously defining the building and landscape aesthetically.

The atrium's glass includes a low-e coating applied to the inner surface of the outermost pane (number 2 surface) to provide solar control and moderate the visible light transmittance characteristics with a relatively color-neutral coating. These insulated glass units with low-e coating and argon gas fill are designed to reduce heat loss but permit solar gain – a solution most appropriate for a heating dominated climate such as Seattle. The extensive use of low-e glass with argon fill throughout the project was critical in meeting the reduced energy targets and permitting expansive areas of transparency throughout. The extensive use of glass also reduces the need for electrical lighting during the day.

An under floor air distribution system is used throughout the project for ventilation. In the atrium, where air exchange rates are high due to its entry function, a series of operable transoms are provided above each door to extract heat or provide natural ventilation during mild seasons. The enclosure and mechanical systems at the atrium lobby achieve the high-performance demands required to support the whole-building energy efficiency goals.

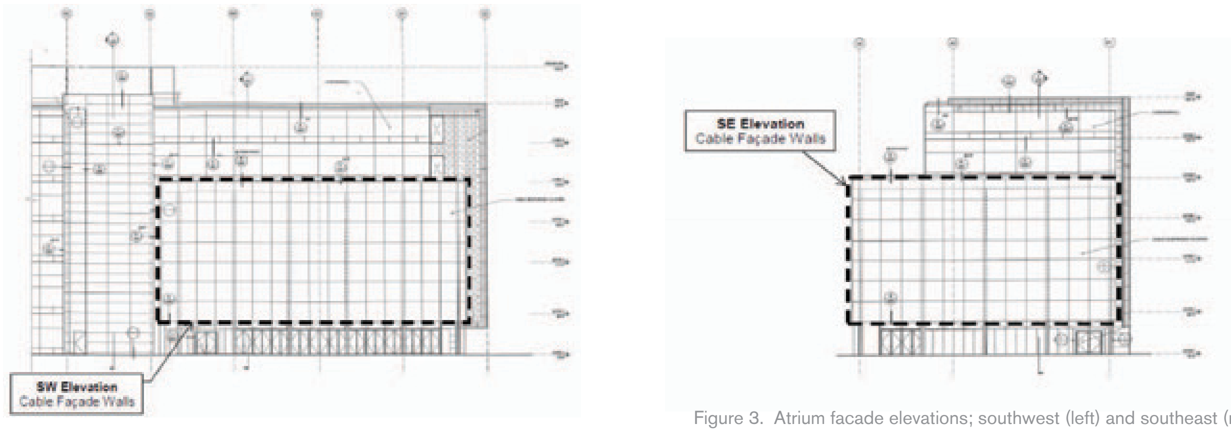


Figure 3. Atrium facade elevations; southwest (left) and southeast (right).

4 ATRIUM FACADE DESIGN

The Atrium facades include the exterior glass curtainwall and cable systems on the south-east and southwest faces of the podium, as illustrated in Figures 2 and 3.

4.1 DESIGN LOADS

The glazing system was designed for +20/-20 PSF wind loads in typical conditions and +20/-30 PSF for corner zones in compliance with ASCE 7-05 Minimum Design Loads for Buildings and Other Structures [1] and the International Building Code, 2006 with City of Seattle Amendments [4]. Seismic design forces were also considered in accordance with ASCE 7-05, 13.3 (ASCE/SEI, 2006).

Additional superimposed loads at the Level 5 roof deck by others at the atrium structure include:

- Green Roof Dead Load
  $D_{gr} = 47$ PSF
- Office Type 2 Dead Load
  $D_{of2} = 17$ PSF
- Green Roof Live Load
  $L_{r,gr} = 25$ PSF
- Office Type 2 Live Load at Level 5
  $L_{r,of2} = 80$ PSF

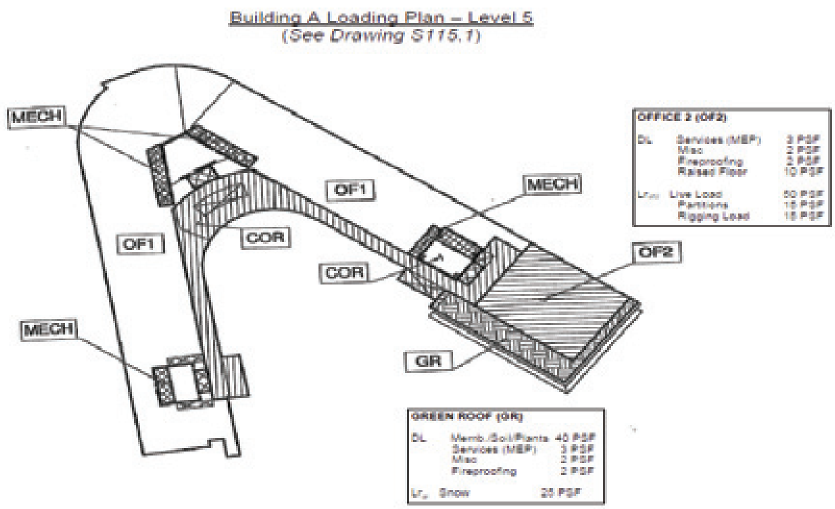


Figure 4. Superimposed roof load diagram.

4.2 GLAZING

Typical glass panels are 6’-8” wide x 7’-0” tall, fully tempered insulated units with glass edges set ¾” apart to create a joint filled with sealant to the exterior, foam backer rod infill, and a custom gasket lining the interior. These fully-tempered insulated glazing units have a 1.7” nominal thickness composed of 0.370” SB70XL outer light, 0.50” argon-filled air space, and 0.80” laminated inner lite composed of two 10mm lites with a 0.06” interlayer (Figure 5, top).

The insulated glass unit (IGU) edge deflection limit is L/140, or 0.6” along the 84” height of the typical panel. Using a finite element analysis (FEA) to simulate the composite interaction between the IGU layers and point support conditions at each corner located 5” off center, the critical edge deflection was <0.48” – within the permissible limits (Figure 5, bottom).

Atypical units along the corner and edge conditions were evaluated in a similar fashion to validate the glass units adhere to the stress and deflection criteria. The edge panel proved to be the most stressed glazing panel under design loads due to asymmetrical support conditions: continuous support along one vertical side, and one opposite corner with a relative displacement Δ=1.27” forcing the planar rectangle into a warped condition.

4.3 FITTING ATTACHMENT

The cable fitting assembly is a custom attachment designed to transfer loads from the exterior insulated glazing units to a one-way vertical support cable structural element. The cable clamp glass fitting is comprised of four primary components cast out of AISI Type 316 stainless steel: cable clamp back, cable clamp front, fitting armature, and patch plate elements. Additional connection components include neoprene pads, ¼”Ø stainless steel patch plate screws (4 ea.), ½”Ø stainless steel pin (2 ea.), 1”Ø stainless steel threaded stud (1 ea.) and 5/8”Ø stainless steel cable clamp bolts (2 ea.). The components are diagramed in Figure 6, though connection components are excluded for clarity.

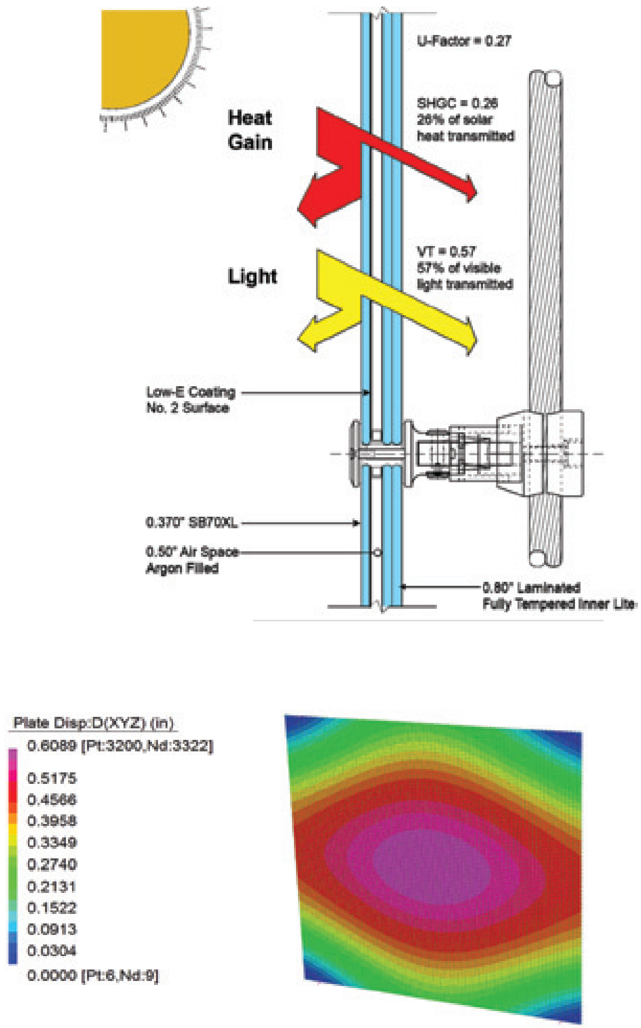


Figure 5. Atrium insulated glass unit composition (top) and FEA analysis (bottom).

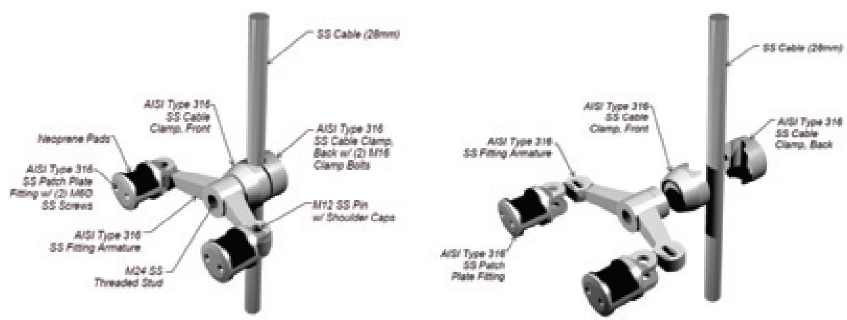


Figure 6. Fitting views; assembled (left) and exploded (right).

4.4 STRUCTURE

The atrium facade support structure consists of 29 vertical 28mmØ stainless steel cables, each pre-tensioned with 48,000 lbs of initial axial force. The top connection of the vertical member is achieved with an open swaged fitting at the cable's end, pinned to a gusset plate which cantilevers 4" outward from the primary W18 box beam structural member at the roof (Level 5, 57'-9" above ground level). The preliminary engineering for the top connection gusset plate anchor was performed by the facade contractor; however, the fabrication of the steel tab was performed by the steel contractor in a controlled shop environment prior to arrival at site. Ultimately a survey was performed in-situ to validate that the top pin locations adhered to a field tolerance of +/- 3/8" of the design location.

As the vertical cable is stretched to the bottom connection it penetrates a metal panel soffit at Level 2, 12'-6" above ground level, where the insulated glazing terminates and a series of portal doors are recessed 10'-7" (Figure 8, left). Because the cable is exposed to interior and exterior temperature ranges, the metal panel penetration for each cable is oversized to accommodate field tolerance and thermal expansion. A flexible gasket is used at the penetration to complete the weather barrier around the cable.

Approaching ground Level 1, the vertical member transitions from 28mmØ stainless steel cables to a 48mmØ high strength stainless steel threaded rod to allow it to anchor to a series of cable box terminus connections. The transition between the cable and rod occurs at a hinge connection 15" above the finished plaza level where the axial cable load is transferred through the open-swaged end fitting of the cable to the closed-swaged end of the rod (Figure 8, right). The finished stone is notched at each cable and sealed with a neoprene closure. The plaza's stone pavers at each cable serve as access panels for inspection and maintenance of a 5'-0" deep trench which houses the bottom cable box connections. Each cable box is comprised of a HSS 12x8x5/16 cantilevered element which is welded to an embed face plate within the concrete foundation. The HSS is penetrated by a 5" standard pipe sleeve which allows the threaded rod to penetrate before being fastened below with a threaded nut and a series of plate washers. The cable box is amended with steel plates and stiffener elements to form jacking seats to accommodate the pre-tensioning process during installation; this is discussed later in further detail.

Though the combined length of the cable and rod vertical member is 61'-6"+ total, the free-span for the cable member occurs between the top connection and a bracing strut at the soffit Level 2. The free-span behind the glazing is 45' with deflection criteria of L/50 permitting maximum cable deflections of 10.80" under loading. A computerized analysis model of the southeast and southwest atrium cable facades was created using the software program SpaceGASS. The previously introduced design loads were applied, after which the software determines the structural and deformational responses of the members, taking in to account the relative stiffness of

Figure 7. Interior view of the cable wall structure with stainless steel fitting clamps.

Figure 8. Construction photos; soffit (left) and bottom cable connection (right).

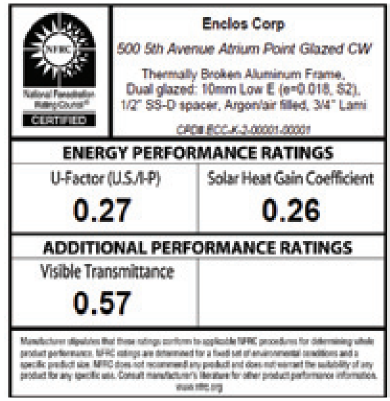


Figure 9. NFRC Label Certificate.

the primary building structure. The maximum cable deflection under loading was Δ_{max} = 8.4" occurring mid-span along the southeast facade. The flexibility of the facade support tension structure requires the boundary structures below and above to absorb large axial forces, which in turn minimizes the cable member sections to maximize transparency throughout the atrium enclosure.

5 THERMAL PERFORMANCE

The typical curtainwall systems for the project included several mockups: visual, performance and blast testing. The atrium facade included a physical mockup only for performance testing. The thermal performance of the point-supported atrium glazing was determined using computer simulation and physical testing in accordance with the National Fenestration Ratings Council (NFRC) standards to obtain the system's U-values and solar heat gain coefficient (SHGC) to validate their compatibility with target performance values utilized in energy modeling.

5.1 NFRC TESTING

The purpose for implementing NFRC certification requirements on the Seattle Foundation project was to ensure the site-built product met or exceeded target performance values established earlier in the design process by the mechanical engineer. The enclosures' role in the energy performance was fundamental in supporting the ambitious LEED targets for the project. The NFRC procedures also ensure that the values are calculated using uniform and accurate means.

The facade contractor's first step in validating the glazing system performance was by performing computer simulations in agreement with the NFRC procedures, using Windows 5.2 and Therm 5.2. Then each product and unique glass type must be tested through an NFRC authorized independent laboratory and their respective performance values loaded directly into the NFRC database. The computer simulations revealed the target performance values were met.

Following the simulation phase, two NFRC physical tests were applied to the atrium facade. They include NFRC 100 Procedure for Determining Fenestration Product U-Factors (2004) and NFRC 200 Procedure for Determining Fenestration Product Solar Heat Gain Coefficients at Normal Incidence (2004). Each of these tests utilizes an 80 in. x 80 in. (2032 mm x 2032 mm) model size for a non-residential site-built glazed wall system. Since the enclosure is a curtainwall system the model must be simulated and tested with two lites, one vertical mullion, as well as intermediate verticals for jamb conditions and intermediate horizontals as head and sill frame members.

5.2 NFRC RATING

Subsequent to successful testing, an independent inspection agency validates the thermal simulation by issuing a Certificate of Authorization Report (CAR), which is posted directly to the NFRC database. In parallel to a CAR, the independent agency generates a site-built product Label Certificate which identifies the specific product, manufacture, glass type and product ratings (Figure 9). The performance ratings for the atrium point-supported facade include a U-value of 0.27 Btu/hr-sqft°F, which exceeds the U-value of 0.34 Btu/hr-sqft°F achieved elsewhere in the project's aluminum framed curtainwall. The NFRC certificate requires the independent agency to visit the product manufacture and perform an inspection of records demonstrating that the certified product has been produced and implemented in accordance with the thermal simulations and tests.

6 INSTALLATION

The point-supported atrium facade system is backed by a series of 29 vertical cables that rely on an induced pre-tension to provide stability. The tensioning process is very similar to tuning a guitar; however, the scale of the 61'-6" long cables and the large forces make the system extremely sensitive to movements and require specialized equipment to install. The following section outlines the pre-tensioning process, including several of the inherent challenges, and a discussion of how the flexible system accommodates rigorous construction tolerances throughout installation.

6.1 PRE-TENSIONING

The installation of the cable wall commences at the top and bottom anchor conditions. The top anchor of each vertical member consists of a gusset plate cantilevering 4" outward from the primary steel box beam at the roof (Level 5). The vertical cables are attached at this location by a stainless steel clevis

Figure 10. Bottom anchor box with jacking assembly attached (left) and tension meter mounted to vertical cable during installation (right).

condition with a stainless steel pin, releasing the connection for rotation when the cable is subject to lateral load. Each of the cable's bottom end is attached to a threaded rod near the ground level. This rod penetrates the bottom anchor box, which cantilevers from a welded connection to a steel embed plate within the concrete foundation. On the underside of the bottom anchor box the threaded rod is restrained by a large nut upon a series of stepped plate washers. At this point the cable rests in place under gravity, although the system requires an induced pre-tension to provide stability.

Using the bottom anchor box as a jacking seat, a custom jacking assembly is used to mount two 20-ton hydraulic canisters to the cable (Figure 10, left). The hydraulic canisters are tied back to a control manifold which supplies the pressure required to expand the canisters, thus elongating the cable. The axial tension in the cable is monitored by a tension meter (Figure 10, right) that is tied back to an electronic interface that provides readings. The tension meter is calibrated on a project sample cable by an independent testing agency prior to being used in the field.

There is an anticipated 2 3/8" cable elongation associated with the 48,000 lbs pretension for the atrium system. This differential is marked on the vertical rod at the bottom anchor box, and is used as a visual guide to assist installation crew identify when the cable should be nearing the design forces. The cable is stretched to its target tension, taking into account an adjustment factor based on the temperature at the time of installation, and the nut beneath the bottom anchor box is tightened along the threaded rod. The tightened nut solidifies the transfer of the pre-tension forces from the cable, through the anchor box and back into the building foundation. At this time, the hydraulic pressure is released and the jacking assembly relocated to the next cable.

Several issues arise during the tensioning process of a one-way vertical cable, including member twisting and load distribution. The tendency of the one-way cable to twist under axial loads can result in undesired alignments of connection fittings. On the Foundation's atrium, the cable twisting had to be mitigated to ensure the exposed cable-to-threaded rod connection exposed above the plaza level was consistently oriented perpendicular to the elevation. Each cable was rotated 15 degrees clockwise prior to imposing the pre-tension forces. As the cable gradually received the pre-tension it began to rotate counter-clockwise towards its desired perpendicular final position. It is important to account for the effects of twisting prior to tensioning, as the large forces present challenges in rotating the cable or fittings while under loading. Modifications would require a release of the pre-tension and a repeat of the process.

Another issue that arises during the tensioning process relates to the balancing of loads as the boundary structure – in this case the roof steel – deflects and adjusts with the addition of each pre-tensioned cable. This behavior is studied using installation sequence simulations in a structural analysis tool prior to field installation. Each cable is pre-tensioned to a target pre-pretension design – pre-tension multiplied by adjustment coefficients for site temperature and the sequential location of the cable. Following the pre-tensioning of all 29 cables, the system is given a minimum of 100 hours to settle before a second round of tension meter measurements are performed to validate each cable's pre-tension is at the target 48,000 lbs, or within an acceptable variance of +/- 5%. Once verified, the cables are ready to receive the clamp fittings and ultimately the insulated glazing units.

6.2 TOLERANCES

The atrium facade's major challenge was tight tolerances required for the glass and point-supported fittings. The facade had to meet a final face of glass location within 1/8" tolerance in any direction. However, the system is designed to accommodate primary structural tolerances of 1" in any direction for steel and ¾" in any direction for concrete. The cable wall used precision surveying prior to installation, as well as built-in accommodation points at the bottom connection and within the patch-clamp fitting armature. The bottom anchor box included an oversized pipe sleeve through the HSS to allow the threaded rods to penetrate and be restrained to the underside. The oversized hole provided more than the 1.50" tolerance required in the side-to-side and in-out directions. Each clamped cable fitting with patch plate attachments for the glass provided adjustability in every direction. Vertically, the clamp could be slid up and down the cable and re-clamped. The patch plates attach to the spider armatures with a stainless steel pin at a slotted connection that also permits movement under a seismic event. The assembly provides in-out adjustability with the 24mmØ stainless steel threaded stud which joins the spider armature to the cable clamp front component. Once the in-out location is set by the threaded stud a set screw (which penetrates the top of the spider armature) is locked into place, engaging the two together. The flexibility of the tensioned cable wall exists not only under deflection, but also in its versatility in installation relative to other trades.

7 CONCLUSIONS

The Foundation headquarters feature one of the largest structural glass facades in the United States. The one-way cable facade is a high-transparency system on a highly-sustainable project which integrates innovative structural facade solutions with the latest in IGU insulating performance. The performance of the cable walls was also optimized in its consideration of the installation process during design development. The efficient termination condition at the bottom anchor boxes is just one example of leveraging the installation process and equipment as a driver in the engineered design. The atrium's point-supported approach optimizes thermal performance within the envelope and exemplifies high performance that can be attained outside the traditional curtainwall facade paradigm to achieve a transparent environment with sustainable priorities. The efforts of the architect, supported by various consultants, produced a building that is energy efficient and ultimately seeks LEED Gold certification from the United States Green Building Council. It stands as both an expression of the Foundation's commitment to green architecture and a powerful example of the opportunities presented by structural glass facades.

ACKNOWLEDGMENTS

The Foundation was completed in spring 2011 as the result of intense collaboration between many firms, individuals, consultants and contractors. Key project team members include: NBBJ (architect), ARUP (structural engineer, MEP and sustainability consultants), Gustafson Guthrie Nichol Ltd (landscape design & sustainability consultants), Sellen Construction (general contractor), and Enclos (design/assist and design/build facade contractor).

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“The beginning of building

coincides with

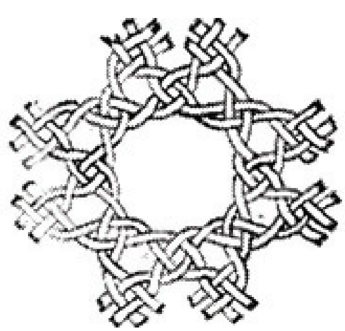
the beginning of textiles.” [2]

- Gottfreid Semper

Potential in Textiles: Space, Surface and Structure of Crochet

Alex Worden

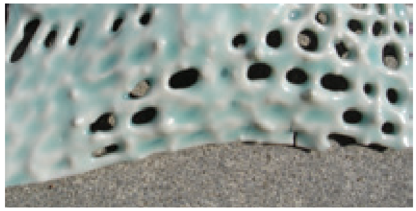
Excepts from the thesis publication *Emergent Explorations: Analog and Digital Scripting*

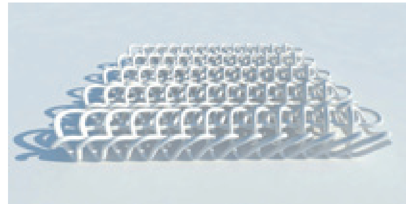


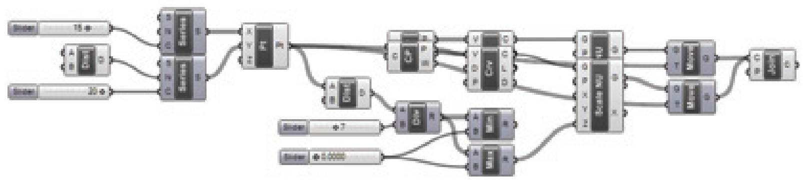
In *The Four Elements of Architecture*, Gottfried Semper proposed that textiles, or hanging rugs, were the first dividers of space. In its earliest stages, the wall was constructed from branches and plant fibers, woven together into a surface and pulled over inner supports. Though many cultures covered the woven surface with clay or mud, the textile was still the very essence of the wall.

Semper understood the historical use of textiles in defining space, writing, “All operations in the textile arts seek to transform raw materials with the appropriate properties into products, whose common features are great pliancy and considerable absolute strength, sometimes used as pliant surface to cover, to hold, to dress, to enclose, and so forth.” In *The Four Elements of Architecture*, Semper catalogs a number of textile techniques employed to develop, fasten and enclose space: weaving, braiding, pleating. But to Semper, it was the knot that promoted the greatest degree of exploration.

A knot is a means of joining. Its strength is based on both friction and by the method in which the cable was constructed. When pulled, the lateral friction exerts pressure on itself, making the knot stronger when in tension. Sailors and rope makers have developed thousands of different knots tailored for specific purposes. The combination of ropes secured to one another by knots give rise to simple nets, whilte the knotting techniques of garment making result in beautifully articulated surfaces to cover the human body.

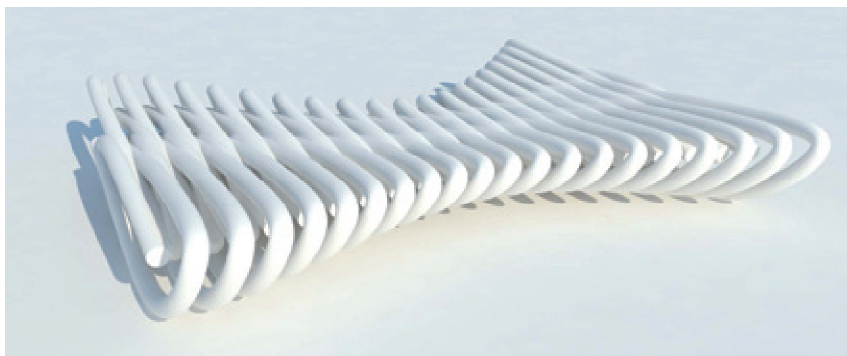




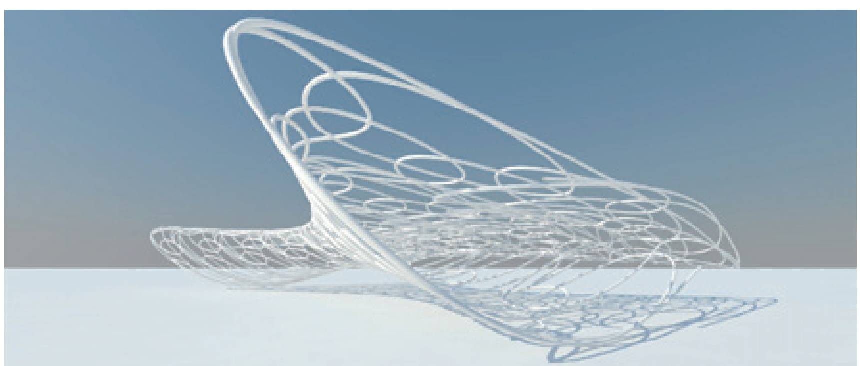


More commonly known as the slipknot, the "loop stitch" is a knot whose loosening can lead to the unraveling of the entire system. Mostly for use in garments, the loop stitch is employed in the textile techniques of knitting and crochet. The technique can be used to create many different articles of clothing from sweaters to delicate lace.

Both knitting and crochet are simple loop techniques that give rise to a great detail of variation, articulation, and ornament. Textile techniques employ a wonderful balance between bottom-up and top-down. Knitting and crocheting require a constant feedback loop of part (stitch) to whole (product). But beyond its commonly known roles, crochet has become a technique used to model complex mathematical models such as hyperbolic geometry (Daina Taimina), the Lorenz manifold (Dr. Hinke Osinka) and the Crochet Pattern Generator (Matt Gilbert). Mathematicians and designers have realized that because of its serial process in fabrication, complex formulas developed with the aid of digital computation can be executed physically in crochet to develop the physical embodiment of mathematical theories.



To learn more about what a technique can achieve, one must begin to play with and explore the technique. Explorations can lead to greater discoveries and otherwise previously unknown insights. Through exploration one begins to realize that the material employed is not defined by the technique. Any material with similar properties to thread can be used in weaving, macramé, braiding, and especially crochet. Crocheting different types and sizes of material gives rise to unexpected results.



Emergent explorations in media lead to questions of application and validity in a programmatic capacity. However, such studies are purposefully qualitative, void of any final goal or outcome. This leads to various experiments in solidifying the crochet system through the addition of hardening agents such as porcelain slip, but also the translation of the physical crochet stitch into the digital model.

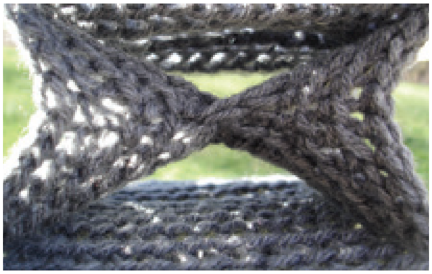
The addition and firing of the porcelain crochet model stiffens the crochet threads into a hardened, static geometry. Similarly, by carefully crafting the crochet stitch digitally through the use of NURBS modeling, the digital crochet is a simulacrum of the physical textile. Through the employment of generative modeling tools such as Grasshopper for Rhino, the digital crochet model can be developed parametrically, translating certain qualities of the physical crochet system into the digital model. By adjusting the parameters of the model, one can begin to explore quickly and efficiently. A simple change or adjustment – such as gauge of thread – can completely change the qualities of the model.

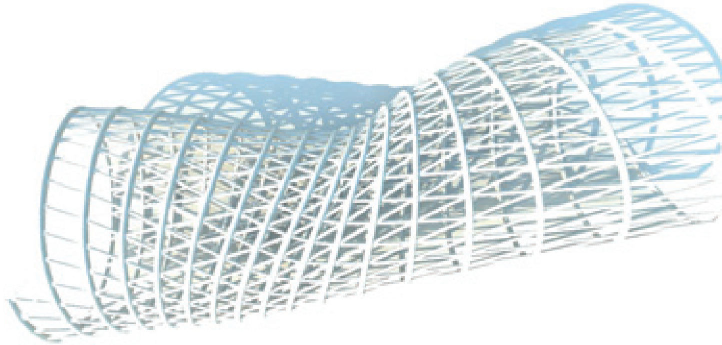
In continuing to explore the ability crochet has to stretch around most any form, a simple wooden cylinder is used in order to see the maximum elasticity of a wool thread tube using a slip stitch. Once the sleeve is stretched over the cylinder, the sleeve is pulled at both ends. This overstretching pulls the crochet to its maximum dimension. The wooden cylinder becomes visible through the openings defined by the crochet. Though the tube is overstretched in its length and diameter, the length of the tube can be also be compressed in discrete sections.

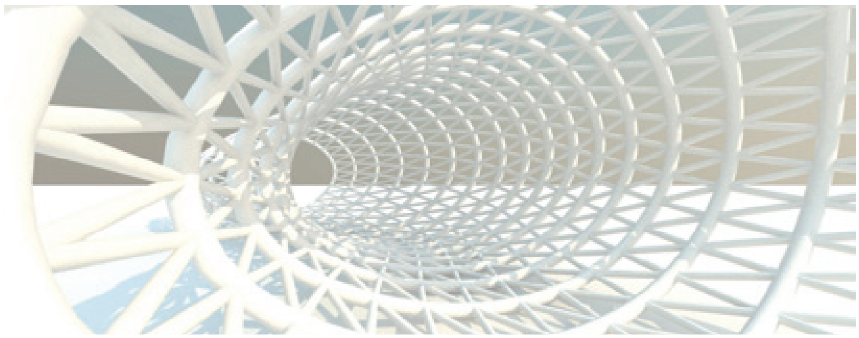
This results in a gradient change in porosity of the openings along the length of the tube. Still overstretched in its diameter, the tube remains affectual; the stitches and thread can renegotiate based on manipulations. When the tube is overstretched in its diameter and length, the process of its construction is clearly visible. A tube is constructed by the use of a single chain that is continually hooked into itself by a slip stitch. The crochet tube's internal structure is a helix.

When pulled over the wooden cylinder, the tube is overstretched and must reconfigure to maximize its stretching ability. By doing this, the slip stitch is reconfigured into diagonal restraints connecting each revolution of the optimized structure. The experiment clarifies how the looped structure of crochet can reconfigure itself into an easily recognizable structure of diagonal restraints between each helical revolution.

This discovery becomes a critical point in using crochet to execute an architectural idea. A helical structure with diagonal bracing, found within a crochet tube, becomes the base for translating crochet from a textile product into a built structure. In translating the structure of the optimized crochet tube, action, process and method deeply influence the structure. Through a difference in method and execution, this translation exemplifies Semper's statement that "the beginning of building starts with the beginning of textiles." Through the explorations in stretching, the crochet model was reconfigured into an optimized structure; a single helical beam with diagonal restraints between each revolution.







This discovery enabled the further exploration of form and space through the use of the analog model. Each crochet model secured into a jig, connecting various portions of model to nodes of the jig, resulting in an analog machine. With these analog machines, one can quickly test the variation of form and space in the physical crochet model. Each model becomes an analog computer where one force begins to affect the whole. Though the analog machine is an optimized tool in defining and visualizing an architectural space, the question of scale and construction come into play. The digital then becomes a realm for exploration where the computer aids in the process of visualization, fabrication and testing.

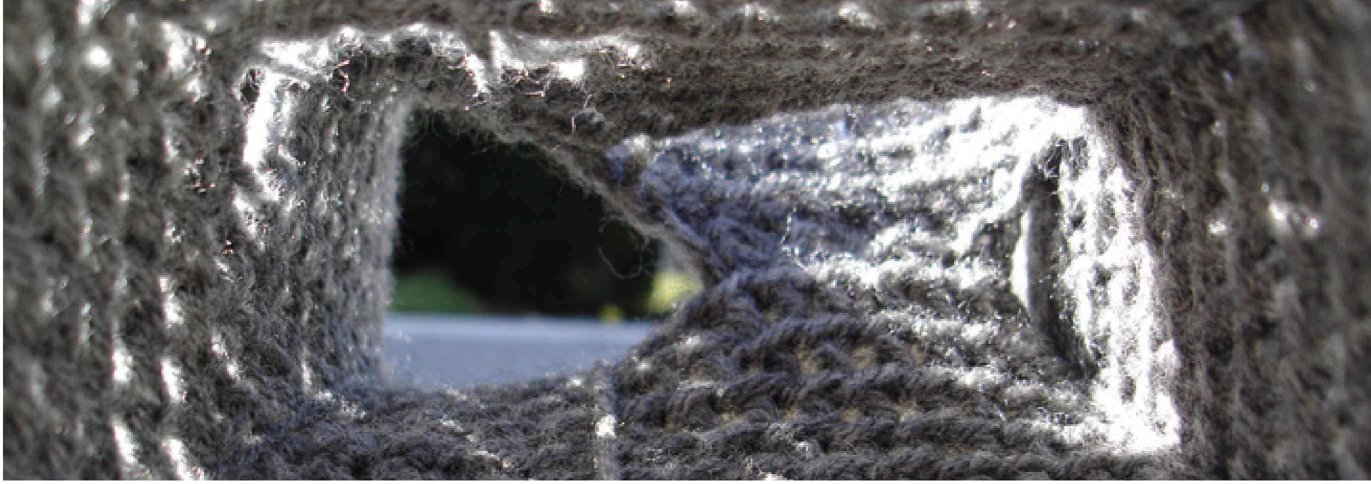
The digital model of the crochet tube is developed through the use of NURBS modeling in Rhino and the generative modeling tool, Grasshopper. In Grasshopper the helical path, formed by the crochet path, is constructed digitally by the series of relationships defined within the mathematical formula for a helix.

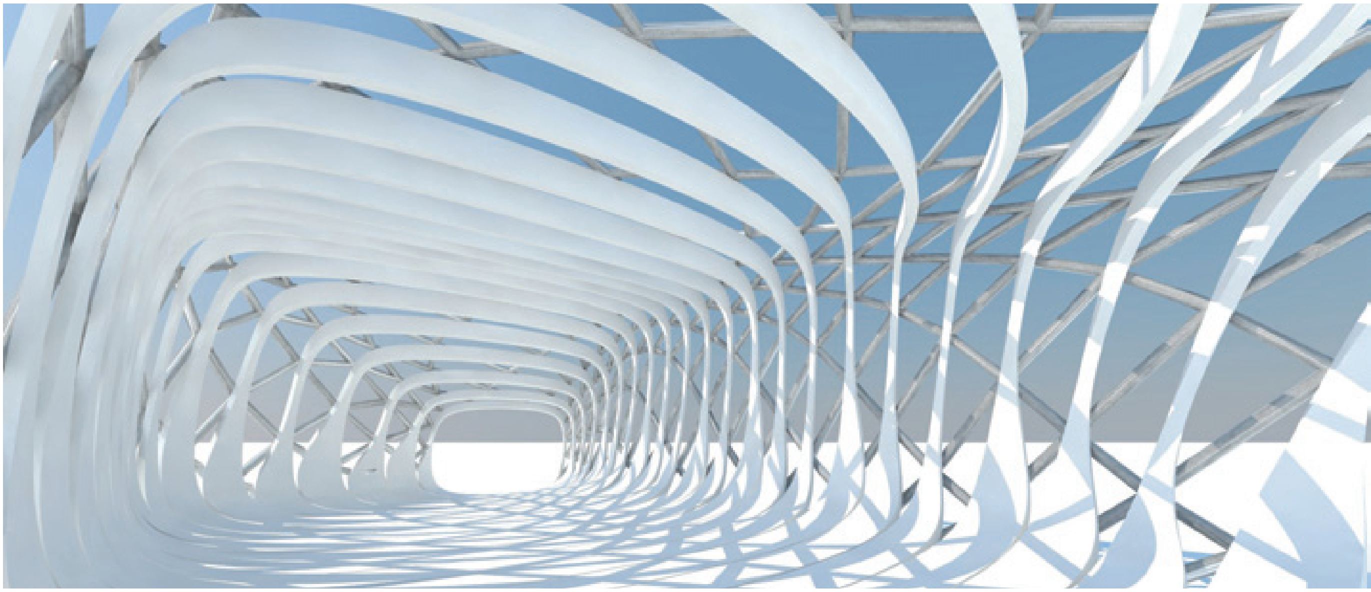
Once it is defined parametrically, the next step in reconstructing the analog tube structure is to connect each revolution of the helix with triangular bracing. This can be done manually by drafting the bracing between each helical revolution. However, if the helix is altered in any way, the bracing will have to be rebuilt. To eliminate the redundancy of reconstruction, the bracing is defined by a set of relationships within Grasshopper.

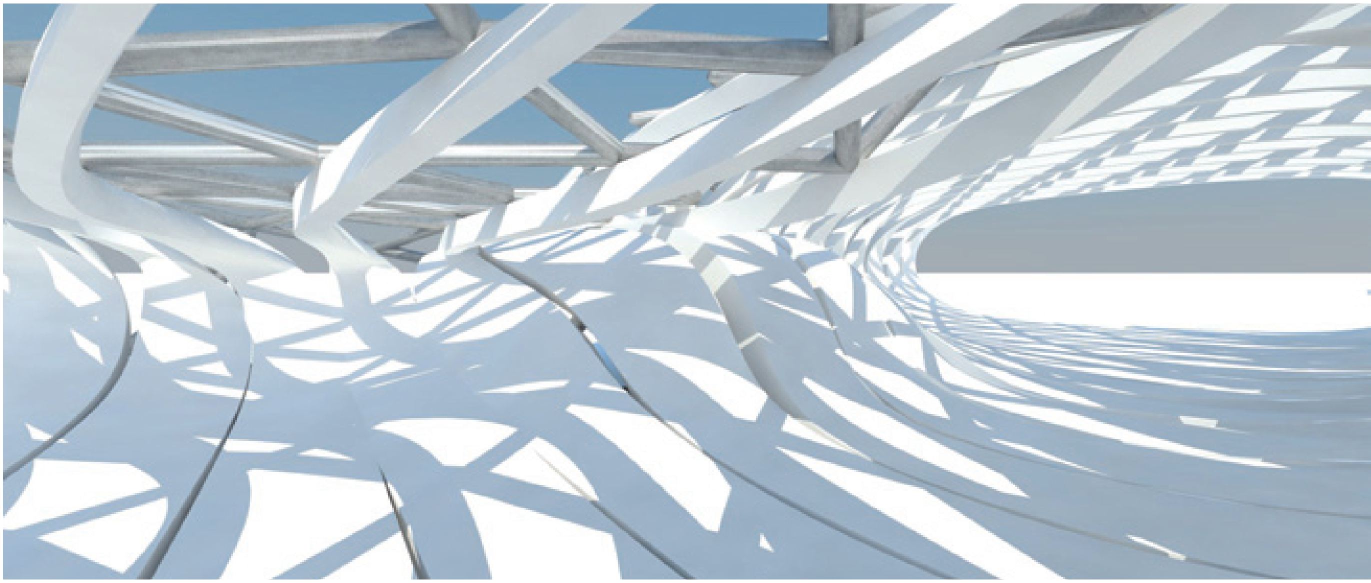
Grasshopper enables the mapping of the helix and bracing to a target surface. This allows for the manipulation of the target surface, which results in the corresponding deformation of the helically braced structure. The map to surface component takes the relationship of the base curve to the base surface and applies it to the mapped surface. The result is a curve that is modified based on the mapped surface. Any alterations to the mapped surface directly affects the resulting curve. This eliminates reconstruction of the bracing when the helical curve is altered.

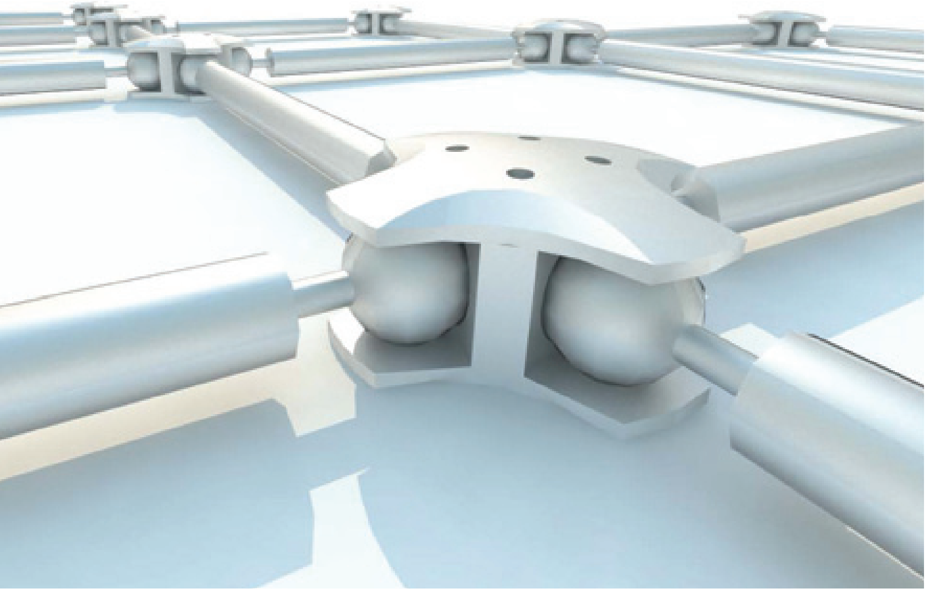
The successful completion and translation of the analog to digital model results in a digital surface. Though only the form of the crochet model is translated, the articulation occurs when the Grasshopper definition is applied to the digital surface. This digital model becomes a way to fully explore the design by refining and executing the concept. The analog model is the generator of form. The definition of an analog model is indicative of its form, structure, and its articulation of each loop. The digital model, reconstructed through the use of photography and digitized points, is not the same, but rather a translation of the analog crochet. The digital becomes a tool for visualization, exploration and fabrication.

Visualization is one of the digital model's greatest tools. It enables the objective and critical observation of space and structure. After the digital reconstruction of the analog crochet model, questions arise regarding the realistic usability of the structure. The entire structure is porous and open. In its current state, the structure is not occupiable as there is no surface to walk. This is mediated through the employment of digital tools. The helix is deformed, resulting in a surface that is walkable.







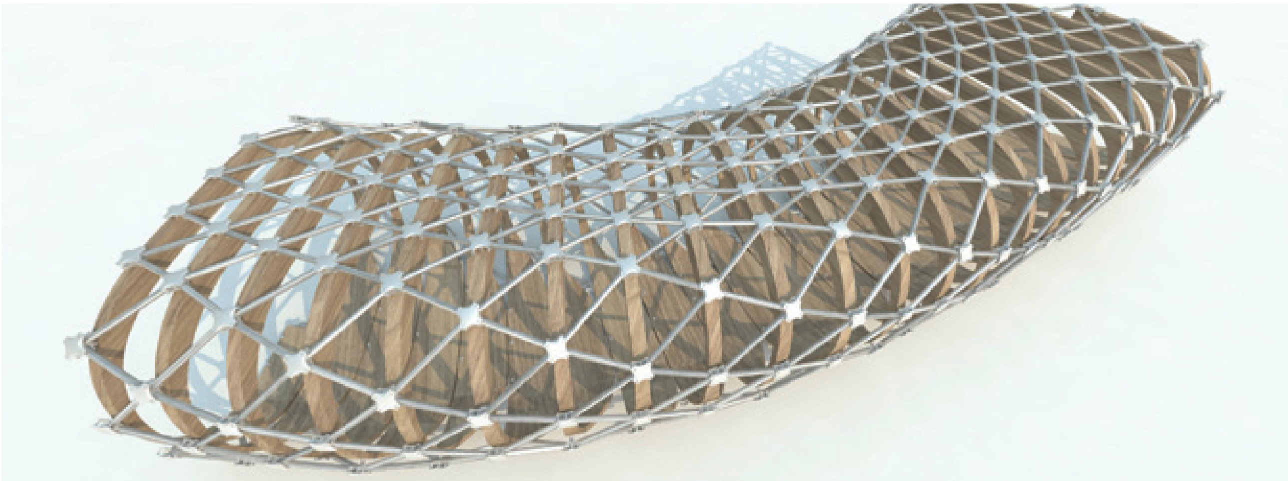


The use of prototyping and digital design through modeling can be used to illustrate relationships and aid in design decisions. A model cannot represent all details and features of the original. Models can only contain the specific features that are deemed relevant for an evaluation or test. By reducing the model to select features, this abstraction can make it easier to gain information. The selection of the represented features is important in its evaluation as their selection can lead to unforeseen opportunities. In fabricating the digital model, desired features can be determined by the method of rapid prototyping. Each prototyping technique will yield a different result and begin to influence the overall design of the digital model. The method of fabrication will define or omit details. By working with these technologies, rapid prototyping machines can lead to decisions in the overall execution of the design.

In the fabrication of the digital model through rapid prototyping, the method used directly influences the design. In fabrication, the digital never operates independently from actual reality. The dialog between the two must be constant to achieve a refined result. The testing of a design concept follows the same rules as rapid prototyping. The methods of fabrication, engineering, construction, and standardization of materials all inform the outcome.

Modeling and testing the design of the bracing system is crucial to the integrity of the structure. Though the helical beam is self supporting, the bracing aids in the stability of the system. In order to construct and fabricate these connections, it is important to identify the role that these bracing members play and how the system can be successful in its role. In the scaled physical model, simple nodes are used to connect the bracing members between the helical revolutions. There is no need to design a customized node for each discrete connection so long as the bracing member has a range of motion.

Instead of defining a static geometry that is specific for each individual connection along



the helical path, the connection allows for the bracing to adjust based on its end points between each revolution. By doing this, the standardization of the connection piece becomes an effective solution where the only customization occurs in the length of each bracing membrane. This length can be calculated through the use of digital software and then manufactured to its specific length. Unlike the analog crochet model, emergence doesn't occur within the construction process, it occurs within the connection of the bracing members. The connection configures within the designed range of motion just as its analog crochet counterpart.

The first iteration of the connection node is designed to use simple "i"-bolts to secure the bracing members. Though the "i"-bolts enable the range of motion required for the bracing, these connections can only work if the whole system is in tension.

The second iteration of the bracing connection is constructed of a ball joint. Each bracing member has a ball located at the ends, the ball fits within the connection node secured to the helical beam. This connection is loose, however, and within each node the ball joint can be tightened to result in a static and solid bracing connection. By designing the node with the ball joint connection, it allows for each bracing member within the system to have a wide range of motion. This removes the requirement for a custom connection along the helix and results in a highly efficient and effective structure. In addition to the bracing connection, each member works towards stiffening the structure. This is achieved by using pneumatic bracing members. Each member can be designed to be in tension or compression by the addition or subtraction of compressed argon. In certain segments of the structure, it is important that the bracing members be in tension and others in compression to achieve the designed result.

The helical beam, connection nodes, and the pneumatic bracing members work in unison to create a beautiful structure that can be applied to a variety of forms without mass customization. The diagonal restraints of the crochet tube have been translated into an engineered system that is a crucial component to the overall structure.

This structure, though influenced by crochet, is an abstraction. The analog crochet model is the medium to generate form, and is then translated into a static structure. This abstraction is born out of a necessity to use the analog model and digital tools to conceive and fabricate a physical structure through the use of current construction technologies. The future development of materials, techniques and technologies could remove the necessity for abstraction.

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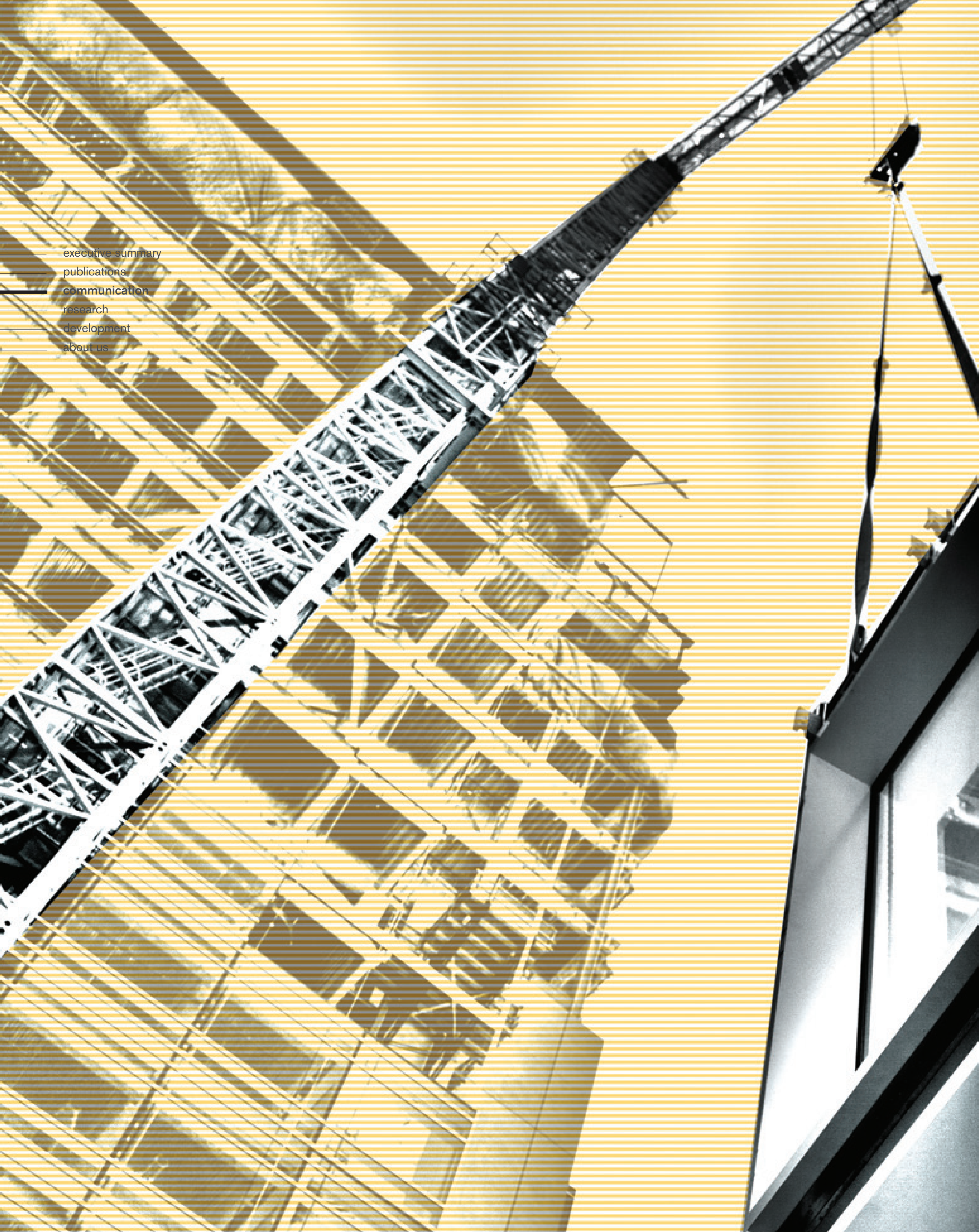
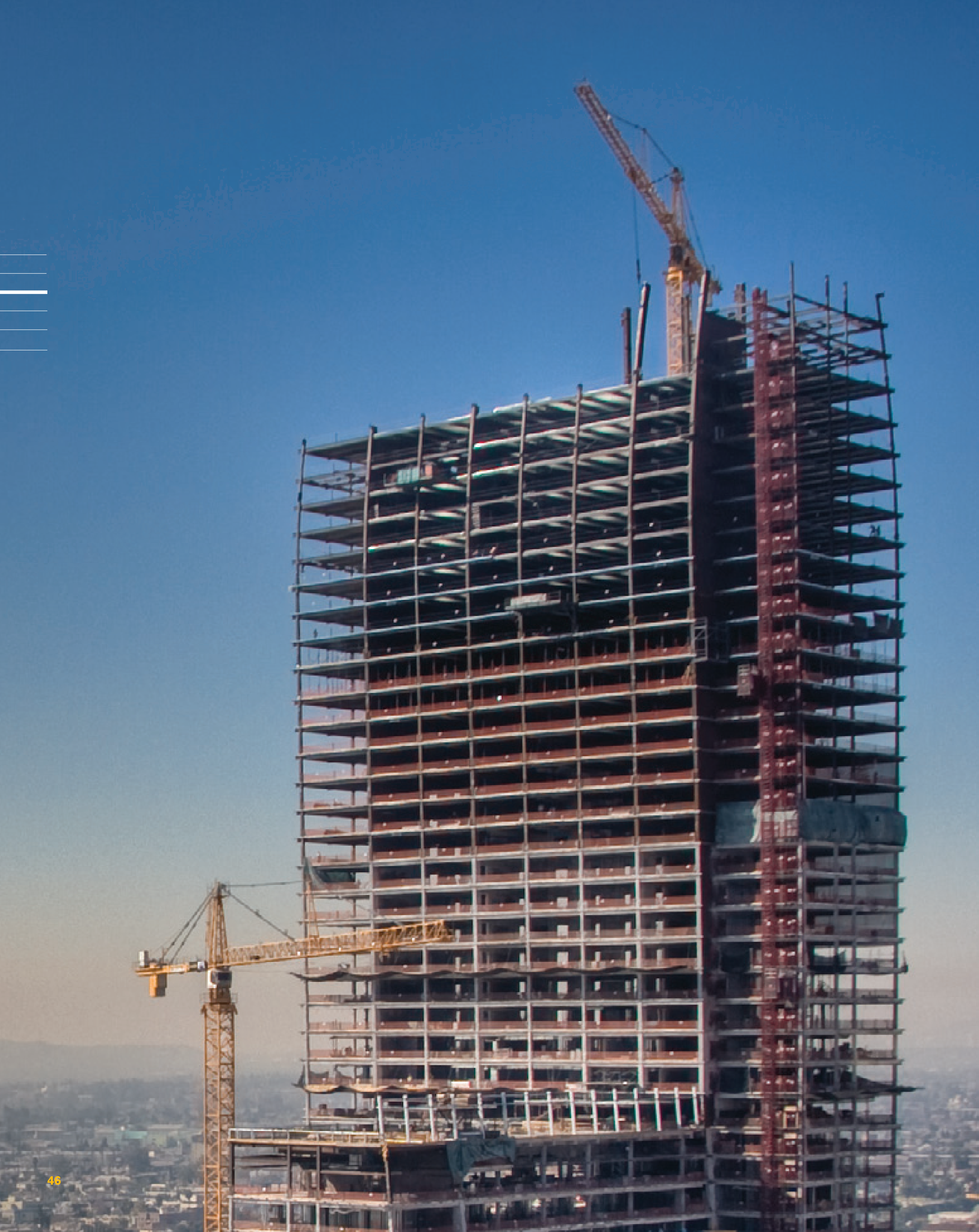
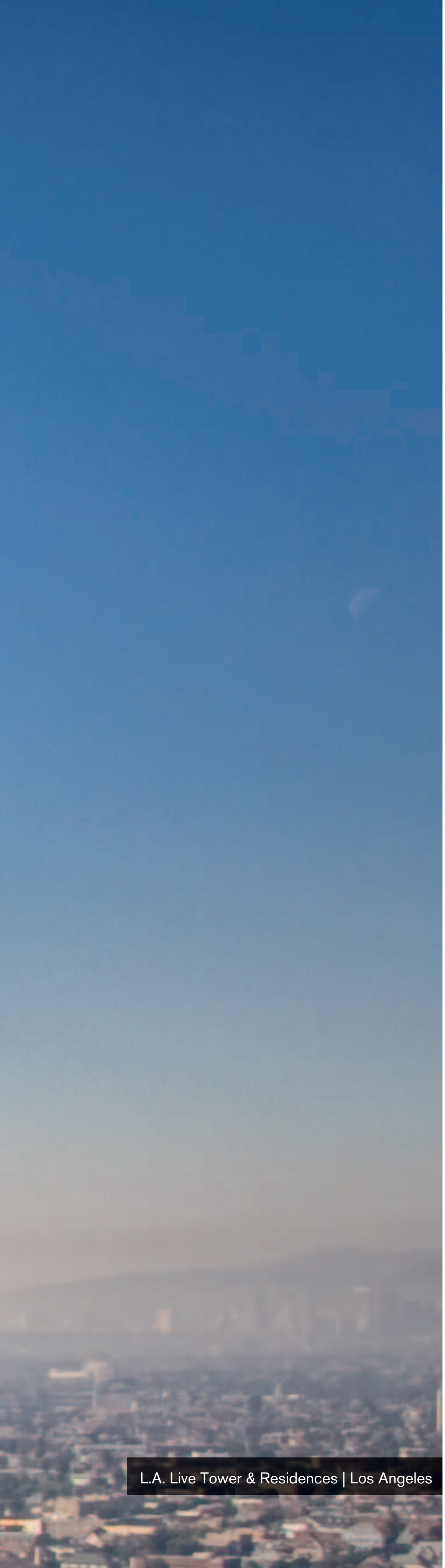
This publication can be read in its entirety at *http://www.lulu.com/spotlight/alexworden*



Communication

Explaining the complex intricacies of high-performance facades can be an overwhelming task. The physics that are integral to each design – water/vapor barrier, thermal, acoustics, structural – can be challenging to convey to architects, owners and assembly crews alike. Installation sequences, site management and other operational dynamics can also be difficult to translate from a drawing. The Studio is committed to effectively communicating the technical designs and practices of Enclos externally to owners, contractors and architects. Additionally, the same communication strategies may be applied internally to educate personnel to achieve an efficient and safe work performance.

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Field Mechanization for Cladding Installation

Matthew Lyons
Mike Padgett

***Mechanization** - Use of machine(s), either wholly or in part, to replace human or animal labor.*

Site logistics and installation planning is a particular expertise of Enclos, and a practice that starts early in the design process, often as part of pre-sale efforts. Prior to ever stepping foot on a jobsite, we develop a plan of attack intended to maximize our field processes to provide the project team the greatest opportunity for success. Drawing on over three decades of company experience, our operations and field personnel develop a streamlined process for each new venture. This article will focus on the equipment used in support of our cladding installation processes by discussing project examples in which we have employed machine tools. Because every project is different, there is no “best solution” for facade installation. Instead, here you will find a resource show-casing options for optimal success.

CRANE & MECHANIZATION OVERVIEW

The construction industry is always searching for revolutionary ways to increase field productivity and minimize project duration. The use of mechanized systems in conjunction with unique installation strategies and approaches can reduce the construction duration of any project. At Enclos, we go one step further by maximizing off-site activities of the facade system to reduce our onsite schedule. Key factors in achieving this are the design approach of the system and minimizing site activities (field installation approach). Prior to project award, the Enclos sales team, in coordination with operational and field personnel, discusses installation strategies. Central to these discussions is how we are going to install the proposed facade design. Installation by crane is usually the preferred method; however, depending upon a variety of jobsite factors, additional approaches may need to be taken. There are multiple crane types and equipment to consider, and knowing the subtle differences in categories/types – along with picking capacities, initial setup and tear down – will greatly improve each project's success.

1 MOBILE CRANES

A mobile crane is defined as "a crane that can move freely about the jobsite under its own power without being restricted to a predetermined travel path requiring extensive preparation" (Cranes and Derricks). Because the majority of Enclos' work is on the exterior of the building, mobile cranes have proven quite useful and versatile in our operations. There are two main components to a mobile crane, the base and the lattice boom or telescoping cantilevered boom. The base (or carrier portion) of a mobile crane is what defines the crane as mobile – they are the means to move and maneuver the crane around the site. There are multiple types of bases used for mobile cranes, including: crawler base, truck carrier, all-terrain carriers, and rough terrain carriers. Jobsite conditions (i.e. terrain, access, congestion) are a key consideration regarding which base is most efficient.

Once a base is selected, the type of crane that will best suit specific installation requirements must be selected. The lattice boom crane has two key components, the upper-structure, which is the rotating structure that powers the crane, and the front end attachment (lattice boom), which is attached to the upper-structure and is the lifting apparatus of the crane. The second option is a telescoping cantilevered boom crane, which consists of a boom that is made up of several tubes that fit inside one another and extend out as the name suggests. Depending on the combination, a mobile crane can arrive at the jobsite ready to work, or require multiple deliveries of components for setup. If a crane requires an extensive setup, there will be a need to allow for adequate space on-site. At the very least, the ability should exist to extend the crane's outriggers (if applicable) and be able to rotate the crane 360 degrees prior to ever picking a load. Mobile cranes will always require an operator. In addition, depending on the crane's configuration, a crane oiler may be required to lubricate machinery, change parts (i.e. jib extensions), and perform other routine machinery maintenance as required.

Beginning on the following page, examples of the more commonly used mobile cranes and carrier types are listed. Provided with the crane designation is the general capacity range (in tons), max boom reach (in feet), and additional reach with jib extensions (jibs are lightweight, boom-like structures added to the boom tip to increase the height of the crane lift). There are a variety of base and crane combinations offered, and each mobile crane listed includes its set of advantages and disadvantages with respect to the given application. The choice of the correct machinery is rooted in project specific requirements and jobsite conditions. It should be noted that as the load travels away from the crane the lifting capacity decreases.

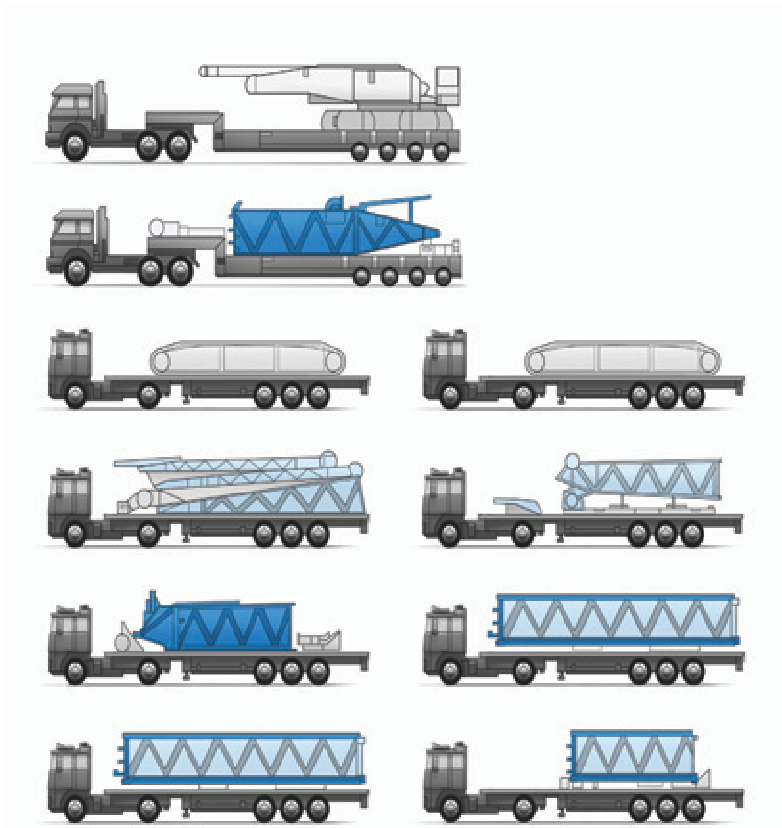


Figure 1: Example transportation requirements for a conventional crawler crane.

TYPES OF MOBILE CRANES

CARRY DECK

2-15 ton | Telescoping 50' Max Reach | +20' w/ Jib extension

Carry Decks are small telescoping cranes. Their size and configuration are similar to that of reach forklifts. They have a relative large picking load for their size, however their reach does not extend very far. Carry Decks do have the option for boom extensions similar to that of larger crane types. Carry Decks have crab steering, and drive and operate similar to reach forklifts. They will require delivery to site. We rent a reach forklift for multiple operations on almost every Enclos project, including material unloading, material staging, and other various operations. Because we often rent reach forklifts, the use of a Carry Deck is generally not needed, unless installing a heavy storefront or facade located beneath a soffit, which may require full-time use of this equipment.

BOOM TRUCK

17-25 ton | Telescoping 100' Max Reach | +55' w/ Jib extension

Boom Trucks are highly mobile cranes with the ability to pick a fairly significant load. They are flat bed trucks with a multiple-section boom crane. Their reach is very limited as their main purpose is to unload materials quickly and easily, without having to use the production crane or equipment for unloading. Enclos typically does not use Boom Trucks to install facade components, but rather for unloading facade materials.

CONVENTIONAL TRUCK CRANE

100-750 ton | Max Main Boom Reach 459' | +168' w/ Luffing Jib extension

A conventional truck crane has a truck carrier base with a lattice boom upper-structure. The upper-structure is composed of three sections: butt, insert and tip sections. Butt and tip sections make up the basic boom arrangement, which provides the crane's maximum lifting capacity. The lattice boom is lighter in weight than a telescoping boom, and has the ability of adding 'insert' sections to increase its reach. Note that there are many different configurations with regards to this crane type, but the longest booms are approximately 350 feet in length. Although the truck carrier can travel on the highway to the jobsite, the upper-structure sections are generally trucked to the site separately, requiring additional transportation and setup costs for the rental. Prior to making a rental agreement, confirm that there is adequate space onsite for the upper-structure assembly, as it is typically assembled on the ground and then lifted into place. Also, proper space will be needed in the event of an emergency (i.e. high winds) and the upper-structure has to be laid down. Another consideration that must be accounted for is the addition of counterweights. Although the machine's weight – coupled with the outriggers – provides a key role in resisting tipping, counterweights may need to be added to aid in tipping resistance.

TELESCOPING CANTILEVERED BOOM CRANE WITH TRUCK CARRIER BASE - HYDRAULIC TRUCK CRANE

35 to 110 ton | Max Reach 185' | + 25-45' w/ Jib extension

The hydraulic truck crane, or "Hydro" for short, has the same versatile features that conventional truck cranes have, with the exception that the boom is self contained. This means that the crane is ready to work upon arrival at the jobsite with only a short setup period. Adequate space around the crane will be needed to extend the outriggers, and also when rotating or "swinging" a load. These cranes also require a stable, relatively flat surface to operate from, unlike the RT or AT. There is no need for additional boom trucking as the telescoping boom extends out of itself hydraulically. There are several different sections that can be added to the tip to increase the boom length. There are also manual inserts (where the boom head is mounted on the insert and pinned), lattice extensions that are also pinned to the boom head, and various other jib types. Some of these jib sections can fold over to the side of the boom and be rotated back into place when needed, but generally they will need to be delivered separately to site. Other potential costs can include additional counterweight rentals and shipment,which depend on the load being lifted and the distance needed to reach.

Mobile cranes are not always the best solution. Selection considerations include cost, duration, jobsite access, and unique project requirements, and these considerations often **favor the use of a fixed crane.**

ROUGH TERRAIN CRANE

30-130 ton | 155' Max Telescoping Boom | +60' w/ Lattice Jib extension

Rough Terrain Cranes – or RT for short – can be driven to the jobsite, however they cannot travel at highway speeds and are generally shipped to the site instead. The carrier portion is composed of two-axels with four rubber tires, and can operate and move about jobsites with difficult terrain. This carrier drives the crane as well as powers the boom. RTs are included in the telescoping boom crane category, with a capacity that can reach upwards of 130-tons. They also have the ability to pick-and-carry loads, in addition to crab steering. These cranes typically only require a single operator, with an oiler, on-call for maintenance or repair as necessary. Again, jib extension and counterweights may need to be included based upon lifting requirements.

ALL-TERRAIN CRANE

35-320 ton | 200' Max Telescoping Boom | +275' w/Luffing Jib extension

All terrain cranes – or AT for short – combine the hydro truck and rough terrain cranes. These cranes can travel from jobsite to jobsite similar to a truck carrier, but are also capable of navigating challenging terrain similar to RT cranes. ATs can have multiple axels to allow for increased load capacity, combined with a telescoping cantilevered boom. Unlike the RT, the all-terrain crane has a cab for driving the carrier, and a separate cab for crane operation. Additional features of the AT are the ability to travel while carrying loads, and crab steering for moving in tight quarters. These driving operations can be executed while in the operator's cab to eliminate the need for multiple operators when executing pick-and-carry operations. Like the other mobile cranes, additional trucking may be required for jib extensions and counterweights.

AERIAL (HELICOPTER) CRANE

10,000 lbs

Aerial cranes are seldom used with respect to Enclos' work. The primary reason to use an aerial crane in construction is to access the top of a very tall building to install/remove heavy loads. Aerial cranes can accommodate loads up to 10,000 lbs (fuel weight has to be taken into consideration with the load). They can provide fast and efficient service to a jobsite with constrained accessibility.

2 FIXED & OTHER

Mobile cranes are not always the best solution. Selection considerations include cost, duration, jobsite access, and unique project requirements, and these considerations often favor the use of a fixed crane. This crane type is defined by a primary structure that is "fixed" in one location throughout the duration of its use. The most commonly used fixed crane is the tower crane, and it is also the most common choice for installing unitized curtainwall systems. However, there is various other mechanized equipment utilized as standalone options or in conjunction with mobile and/or tower cranes.

TOWER CRANE

2-45 ton | 275' Max Reach | Extension N/A

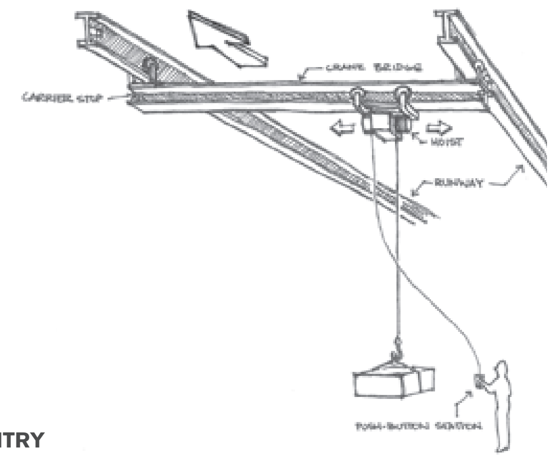
The tower crane is defined as a fixed crane because the main support base structure is fixed to the ground on a concrete pad. The primary benefit of the tower crane is that it has no height limitations. The mast (or tower) is periodically tied into the structure for bracing support, but can reach as high as 265' without bracing. The mast of these cranes are located either on the exterior of the structure, tying into the floor slabs or into a shear wall, or inside the structure (commonly in an elevator shaft). At the top of the mast is the slewing unit, which allows the crane to rotate. The main components of a slewing unit include: the horizontal jib (carries the load), the trolley (travels along the jib to move the load in and out), and the counterjib (carries the counterweight opposite the jib). Atop the slewing unit is where you will find the operator's cab.

These cranes are capable of increasing their own height, or "self-climbing." This is done using a climbing frame (a section just below the slewing unit), which raises the slewing unit up off the mast. After the climbing frame has increased to the specified vertical distance to accommodate for the new mast section, the crane picks the new mast section and inserts it below the slewing unit. This process can be repeated as many times as necessary to achieve the desired height. To uninstall the crane, this process is repeated in reverse for an externally mounted mast. For internally mounted masts, additional equipment may be required to disassemble the crane. The maximum reach radius at the tip of the jib is around 275'±. Note that as the load travels further away from the mast, the lifting capacity decreases.

For tower cranes, the lifting capacity is often rated in ton-meters. A ton-meter is a measurement of distance multiplied by force. For example, when renting a crane that has a 250 ton-meter capacity, that crane can lift a load of 10 tons at 25 meters. This would also mean that a 250-ton load could be lifted at 1 meter, which is obviously incorrect. Most manufacturers begin their ratings at a few meters away from the mast, so it is best to consult the manufacturer or vendor on exact capacity prior to renting or executing a load of that magnitude.

Tower cranes are on the more expensive end of the spectrum for monthly rentals, with associated high setup and tear down costs. Provisions and planning need to be addressed with the structural engineer-of-record to ensure that the structure can accommodate the loads imposed by the tower crane during installation and while the crane is operating. Initial setup, teardown and rental costs can be offset by the high production rates achieved by tower cranes. For high-rise building construction in particular, tower cranes are very effective because of their extremely high line-speed, which allows materials to travel long distances (vertically) in a short amount of time. It should be noted that there are other various types of tower crane mounting and jib configurations, but the static base with saddle jib configuration described above is more commonly used.

Figures 2 & 3: An overhead bridge crane (above) and a hand-held push button on an overhead crane (right).



OVERHEAD BRIDGE AND GANTRY CRANES

Capacity varies | Reach varies

Overhead cranes, also called bridge cranes, consist of a hoist, crane and set of runways. The runways are fixed where the crane bridge spans across them perpendicularly and is able to slide along tracks to move the load. The hoist mechanism, which picks the load, also travels on tracks along the crane bridge to offer additional maneuverability. There are several types of overhead cranes, but we typically see floor-operated cranes in our shops at Enclos.

The gantry crane is very similar to the overhead crane, however the bridge is fixed atop vertical legs of a specified height, which travel on a set of runways or wheels located at the base of the legs. These cranes are more applicable to our field skylight facade installation. These configurations have a large initial cost since they are generally designed, engineered, and constructed for each specific project. In addition, because gantry cranes are generally used for skylight installation, an additional crane will need to be rented to lift the gantry crane components to the top of the building for assembly. Accommodations for getting skylight materials onto the roof should also be considered. However, once the gantry crane is assembled and operating, there are no additional rental costs or fees.

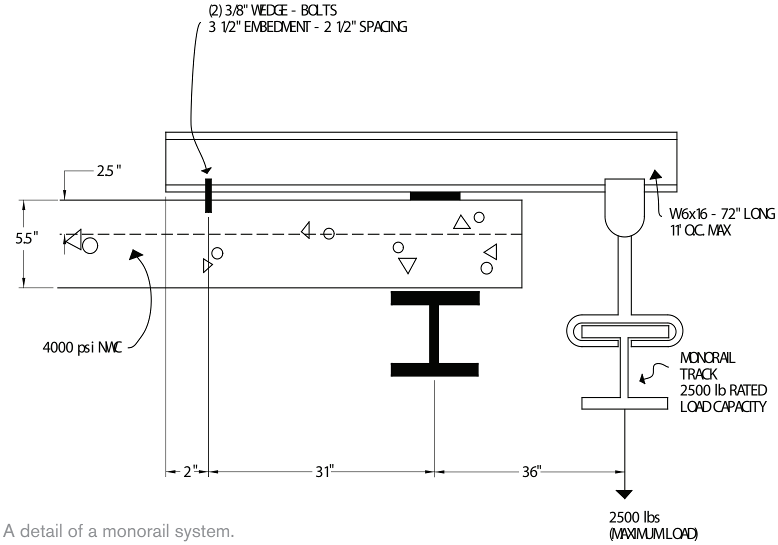


Figure 4: A detail of a monorail system.

MONORAIL SYSTEM

Monorail systems are composed of a monorail, I-beam kickers/supports, and an under-hung bridge crane. The monorail system is a highly effective mechanized system for installing single-span curtainwall units. The systems can be rented or purchased at a relatively low cost compared to a crane rental. The I-beam supports will need to be secured to the structure using anchor bolts or embeds, or with a floor-to-ceiling screw jack that holds the beam secure to the slab. If embeds are chosen, it is necessary to check with the structural engineer and coordinate with the general contractor so that embeds can be placed prior to the concrete pour. Having to drill into the slab can be very costly, especially if the slabs are pre/post-tensioned. Once the supports are secured, the monorail can be hung with the bridge crane hoist. The monorail system should always be set up as high in the structure as possible to minimize “jumps” or relocations. Jumps can take between one and two full working days, and depending on the building’s footprint, can shut down all curtainwall unit setting. In some cases, curtainwall units and monorail system components are able to fit into the man-hoist, but when they are not, other means to stock the floors with materials should be investigated. One way to stock the floor is with a Chicago boom derrick, which will be described in more depth below.

DERRICKS AND THE CHICAGO BOOM DERRICK

1/4 -35 tons | Boom length 10’ to 125’

A derrick, according to the ANSI Safety Code for Cranes, is “an apparatus consisting of a mast or equivalent member held at the head by guys or braces, with or without a boom, for use with a hoisting mechanism and operating ropes” (pg 42). The primary difference between a derrick and crane is that the crane’s hoisting mechanism is an integral part of the machine.

There are a variety of different derrick configurations, but for our purposes, the Chicago boom derrick configuration is the one that will most likely be of use. The Chicago boom, by and large, is installed on the exterior of the building, commonly on a column or building frame. Topping blocks or sheaves are located at the tip of the boom and at the pivot fitting on the support structure. The guy lines, which stabilize the derrick, are also used for the luffing operation (luffing defined as “changing the angle the main load-supporting member makes with the horizontal”). In other words, the load can be swung and maneuvered via the pivot fitting. Because of structural considerations, it is not recommended to place the derrick on the corners of the building, limiting the swing to 180 degrees.

The Chicago boom is a quick and efficient way to stock a building with materials. On a jobsite with limited delivery access, the Chicago boom can be positioned to unload delivery trucks in conjunction with stocking the building. Although this derrick could be used to perform facade installation, it is generally used in combination with a monorail, floor crane, or another installation method. The Chicago boom also may require a loading platform to land the materials depending on their size, weight, and ability to maneuver the picked load into the building.

Noteworthy is the large effort involved in setting up and relocating the derrick. The majority of this effort is involved in the pre-planning and engineering phase, but the physical setup and staging of the derrick’s components can cause issues. In some instances, an additional hoisting device may be needed to lift the derrick’s components to the installation location, as they may be too large or heavy to lift in the man-hoist. There are companies that offer both crane and derrick rentals, but depending upon the rental duration, it may be cheaper to engineer and fabricate rather than rent.

BUILD AND SLIDE

Job specific, must be engineered

The build-and-slide installation approach is more of a method than piece of equipment, however it is worth mentioning because of its use of mechanization principles. A build-and-slide operation is setup similar to that of a gantry system, and is typically used for skylight installation. All that is required for this setup are runways, several rolling platforms, and a winch. The runways are setup on either side of the opening, and the rolling platforms are positioned on the runways to build the first skylight or space frame section adjacent to the opening on the rolling platforms. Once a section is complete, the winch is rigged to the built section and rolled over the opening. The next set of rolling platforms is then placed on the runways and the next framing section assembled. This process can be repeated until the frame is complete, at which time it can be anchored to the supporting structure. Associated costs include the design and engineering of the runways and rolling platforms, as well as a winch with the capacity to pull the framing. In addition, a mobile crane will be required to stock the building materials and the build-and-slide system at the working location.

FLOOR CRANE

Up to 6,000 lbs | 3' to 7'-6" reach

The floor crane is exactly as the name suggests. These small cranes are extremely portable, capable of fitting into the man-hoist and maneuvering through doorways and other tight areas. Floor cranes can be manually pushed or electrically operated similar to a pallet jack. Their hoisting mechanism is commonly operated by hydraulics, and can pick a load up to 6,000 lbs, depending on setup and counterweight. Some have a reach of up to 7', although the bases and legs of some models may come too close to the edge of slab, thus not allowing the load to fully extend out of the building safely. As discussed, the further the load is extended out on the boom, the less capacity it has. Other considerations include the rigging equipment weight for unit and/or glass installation, head clearance inside the building, and slab capacity for equipment.

Figure 5: A mobile glass manipulator is of the mobile category, designed for field installation of large glass lites. This mobile glass manipulator can be purchased as shown; however, they are often customized to achieve the project's requirements. This particular model can manipulate a 2,000lb piece of glass 6' horizontally from the front of the machine's wheels. These manipulators are often used if 2-3 men cannot handle a lite safely, there is limited access and clearance to install a lite, or just for the sake of production. They are also designed to fit through a standard doorway (3' x 6'-8") and fit into an elevator.

GLASS MANIPULATOR

Fixed weight and reach vary | Mobile machines capacity approximately 2,000 lbs with 6' horizontal reach /14' vertical reach

Fixed glass manipulators are often set up similar to a derrick or overhead crane with a vacuum cup attachment (discussed further in the rigging section) enabling a single user to "manipulate" a large piece of glass into a frame. These types of glass manipulators are often found in a factory or shop setting for mass production.

One advantage of the manipulator is that it is not actually classified as a crane. When a piece of equipment is categorized as a crane, complex and lengthy certification and approval processes can be involved. Drawbacks to a manipulator include a large initial cost, starting around $40,000 and increasing significantly with project requirements. Counterweights must also be added to offset the large loads placed upon this otherwise small piece of equipment, especially if there is a large horizontal reach required.

WINCHES

2,000 2 Part Line

Winches also offer a significant lifting capacity while being extremely portable. It is easy to mount them to a variety of items, including carts, trolleys, concrete floors or columns, and other items. Enclos does not generally use winches for installation because variable line speeds are hard to control, ultimately complicating installation. Winches can be electrically or pneumatically operated. A common winch option is the GOLO product, which has a lifting capacity of 1,200 lbs. Another option is a "tugger," which can come as an individual winch or on rolling carts. Consideration must be given to the difference between pulling and lifting capacity. Many times winches are rated by pulling capacity, which is substantially different (upward of 10,000 lbs) to their lifting capacity (typically 10% of the pulling capacity).

> Enclos often chooses to **lift multiple units with a single pick** in an effort to decrease the total amount picks, thus **saving valuable installation time.**

3 RIGGING COMPONENTS

When lifting any item with mechanized equipment, rigging components and accessories are essential to securing and lifting a load. There are many different rigging accessories that can be utilized to lift a load, with some of the more common components used to lift facade units and components listed below.

HOOKS, SHACKLES, WIRE STRAND ROPE, FIBER ROPE, & SYNTHETIC SLINGS

Wire strand rope, fiber rope, synthetic slings, hooks, and shackles are all common elements that in some form or another, are used to rig a load in preparation for picking. Many of these items are used in conjunction with one another, or with one of the rigging accessories within this section.

Discussed following are considerations prior to using the materials for rigging and picking a load. When discussing any type of rope or sling – be it synthetic, natural, or wire – proper precautions should be followed prior to using them, including a capacity check prior to lifting any load, and inspection of the rope for any fraying, wear, or noticeable defects that could cause the rope to fail during picking. Hooks and shackles should follow a similar protocol prior to use. Check that the safe working load (SWL) is indicated on the hook or shackle. Hooks or shackles that are bent, deformed, spread, or display any other noticeable defects, should not be used.

SPREADER BAR

Most curtainwall units have two points of attachment for lifting the unit, referred to as picking points. Slings can be utilized for this operation, but the further the picking points are away from each other, the longer the sling cables need to be to reduce the sling angle. Sling angle is the angle created between the load and the sling cable. As this angle decreases from 90, the picking capacity for the slings decrease, increasing the bending forces at the picking points and creating both bending and shear forces. This is one reason for which Enclos employs spreader bars. Spreader bars are made out of steel tubing or plates, and are often engineered for each individual wall type. Because curtainwall unit sizes vary throughout a project, several sets of holes are created in the spreader bar to accommodate multiple picking point distances.

Spreader bars can also be used to eliminate the need for long sling cable lengths. Depending upon clearance issues, positioning the unit to the correct elevation with slings is often unachievable, and the spreader bar provides a means to shorten the hook-to-load distance.

Spreader bars can also be designed for picking multiple units. Enclos often chooses to lift multiple units with a single pick in an effort to decrease the total amount of picks, thus saving valuable installation time.

Figures 3 & 4: A multiple unit pick (top), and a spreader bar.

MGM CityCenter: Aria Resort & Casino | Las Vegas

FLYING JIB

Flying jibs are used to install curtainwall units on high-rise buildings with a tower crane. The flying jib employs the same principles (and general setup) as the tower crane's horizontal jib. At one end of the flying jib is a hook with which to attach the curtainwall units, and at the other is a set of counter-weights. Flying jibs are generally made of a steel I-beam with an off-center picking point for the tower crane hook attachment. The off-center picking point allows for an even balance when the curtainwall units are picked. Flying jibs are custom engineered for each project based upon the weight and quantity requirements of the cladding units.

The typical purpose for using a flying jib is to install curtainwall units in and under areas with setbacks (soffits) or when there are material debris nets on the project. The flying jib allows for clearance to keep the crane's main lines away from the structure or debris net, avoiding potential hazards. Most flying jibs are fabricated with fixed counter-weights, although some are designed with an adjustable counterweight that moves and operates similarly to a trolley. The movable counterweight provides the ability to change the balance point of the load so that multiple sized curtainwall units with varying weights can be picked without having to change the flying jib.

VACUUM (POWER) CUPS

up to 2,400 lbs, custom design

Power cups are the primary means for lifting large pieces of glass and flat metal panels. Due to the weight of these cladding materials and the difficulty in handling them, power cups provide the safest, most effective means to move these materials. A power cup is composed of a steel frame with multiple suction cups that utilize an electric-powered vacuum. The configuration of the vacuum cups can vary, but typical setups include; inline (4 cups), Quadra-tilt (4-8 cups), and a single large cup. Features sometimes allow for rotation and tilting, which give the ability to manipulate the glass precisely into place. Choosing the correct configuration depends on the weight and dimensions of the material. For example, the weight can be large for insulated glazing units, affecting the power cup configuration. For general purposes, however, an inline cup can lift approximately 600-700 lbs. There are H-bars that allow two inline cups to tie together, doubling the capacity. Quadra-tilt capacities can range from 500-1400 lbs. On some quadra-tilt models, the four legs can be adjusted to accommodate odd shaped lites. Single large-cup unit capacities are approximately 300 lbs. Orientation of the lift and set can reduce the capacity of the power cup. It is imperative to read each power cup's specifications prior to use, with particular caution when applying to curved glass or rough panel surfaces.

PORTABLE OVERHEAD HOISTS

Two of the more typical types of portable overhead hoists that Enclos uses are ratchet lever chain hoists (often referred to as chain falls) and pullers (or come-alongs). Both can be used as a means to install facades, although they are usually used in conjunction with a crane or another piece of mechanized equipment to assist in the installation. The main components of the ratchet lever chain hoists consist of an upper hook (from which the hoist is hung), a ratchet interlocking wheel, a lever, and a bottom hook. The lower hook is what connects to the load and is designed as the weakest part of the hoist. If the hook begins to bend it is a visual signal that the load is too heavy and needs to be lowered. The mechanical advantage of a chain hoist is about 22:1, and it can lift upwards of 50 tons. For portability reasons, typical chain hoists employed by Enclos generally fall into the ½ ton range. A puller is much smaller and lighter than a chain hoist. These can range from ¾ to 6 tons with a mechanical advantage of about 25:1. The chain fall is a very reliable option when needing to transfer the load from the crane. Come-alongs can also be used to transfer loads, or to pull units laterally to the correct layout location. Both rigging accessories are commonly found on Enclos jobsites.

4 FACADE TYPE & INSTALLATION METHOD

Each type of facade Enclos installs requires a custom installation method. Listed below are several categories of the more common facade types which we install, with a brief summary of the type of equipment we use to execute the installation.

CURTAINWALL: SINGLE SPAN

Monorail Installation Method

Here we install a monorail system as high on the structure as possible in order to limit the time required to 'jump' the system. Each floor is pre-loaded with bunked (crated) curtainwall units. Once the units are ready for installation they are pulled from their bunks, positioned near the edge of the floor slab using rolling carts, hooked up to the monorail system, and slid out of the building. The units are then positioned and lowered into place.

CURTAINWALL: SINGLE SPAN

Floor Crane Installation Method

A floor crane can be used where a monorail system is impractical. Furthermore, when a monorail is being jumped, floor cranes provide a means to keep installation going. The floor crane can also be used for glass replacement on large heavy lites, or in instances where a mobile crane or tower crane cannot reach the work area.

CURTAINWALL: DOUBLE SPAN

Tower Crane Installation Method

The most common approach used to install double span curtainwall units is with a tower crane. The units are shipped to the jobsite in bunks and set at the base of the tower crane (known as the “picking area”). The flexibility of the tower crane can accommodate the setting of multiple units with a single pick, decreasing the total number of picks and increasing productivity. In addition, the tower crane’s high line-speed allows for shorter setting durations. Productivity rates for setting units vary widely as a function of unit size, design, building configuration, crew size, jobsite conditions, and other factors, but generally fall in the range of 16-20 units per eight-hour shift.

UNIQUE CONSIDERATIONS

New San Diego United States Courthouse

The units cladding the new San Diego United States Courthouse require a stringent blast rating, rendering each unit unusually heavy with additional steel support and stronger materials. We were unable to access soffit conditions with a typical mobile or tower crane, and this quickly became a key consideration of our installation strategy. For this unique application, multiple options were developed, including a floor crane with a large capacity GOLO and tugger.

STRUCTURAL GLASS FACADES & GLASS STUCTURES

Crawler Crane
Howard Hughes Medical Center

The Howard Hughes Medical Institute: Janelia Farm Research Campus incorporates a very unique building footprint and challenging jobsite. Combined with custom structural glass features, the project required a complex installation strategy. A 150-ton crawler crane was used to install the facade as the optimal solution to navigate the difficult terrain and pick oversized heavy pieces of glass while maintaining a substantial reach. Lifting and transporting triple-ply glass components weighing 1,800 lbs each required a customized power cup configuration.

STRONGBACK SYSTEM

Rough Terrain Crane
O.C. Performing Arts

This project integrated a large AESS strongback system with curved glass lites for the building skin. Installation required equipment with the capacity to lift the large steel sections, and also have the finesse for flying in the curved glass lites. The equipment of choice for this demanding application was a rough terrain crane. The steel structure was rigged utilizing wire rope slings. To limit the number of crane setups, a jib extension was rented and utilized as necessary to extend the crane's reach. When setting the glass, a below-the-hook inline power cup was attached to the crane's hook to hoist the lites into place.

TRUSS SYSTEM WITH POINT-SUPPORTED GLASS

Hydraulic Truck Crane
L.A. Live Tower & Residences: Podium

Because this project's tower crane was in high demand by multiple trades, another means of mechanized equipment had to be utilized to install the podium's point-fixed glass and AESS truss system. The working surface surrounding the jobsite was existing asphalt, allowing for the use of a truck crane to install these facade elements. The steel trusses were large, awkward, and heavy, but the biggest challenge proved to be limited reach of the truck crane. A pinned lattice boom jib extension was added to the truck crane as required to set some of the steel and glass components.

CABLE NET

RT Crane
Station Place: SEC Headquarters*

An RT crane was used on the SEC Headquarters to perform various installation requirements. There were three primary installation activities that required the RTs strength and agility:

1. Installation of a 60' AESS truss, weighing in excess of 12,000 lbs.
2. Hanging two preassembled cable nets.
3. Setting individual glass panels using a power cup attached to the crane's hook.

*The project involvement was with ASI Advanced Structures, Inc. Enclos acquired ASI in 2007.

SKYLIGHTS & OTHER

Gantry Crane
Shure Corporate Headquarters*

A gantry crane was utilized to install skylights at this Chicago corporate headquarters building. Materials were loaded on the side of the opening, and the crane's rails/runways were placed back far enough from the opening to allow for material lay-down. The gantry bridge rolled down the rails to where the next row of material was stocked. The hoist then slid across the bridge to the stocked glass, picked a lite of glass, and then slid over the opening that was next in line to receive the panel.

Build and Slide
Signature Resort, Maui*

For this space frame structure, parts were delivered and staged on the roof. Runway tracks were installed along the opening in the roof. Two sets of rolling platforms/wheels were placed on each side of the track, one space frame section wide. Each section was assembled on the roof on top of the rolling platforms/wheels. As one section was completed, it was rolled over, and the next sets of rolling platforms/wheels were placed on the track ready for the next section to be assembled.

*The project involvement was with ASI Advanced Structures, Inc. Enclos acquired ASI in 2007.

All Terrain Crane
Casino Morongo*

This AESS grid shell structure was prefabricated in large ladder sections off site. The factory prefabricated sections provided a higher finish quality while simultaneously reducing field labor costs. An all terrain crane was chosen because of its practicality, capacity, and maneuverability at the job site.

Aerial Crane
Cira Center

The operations team for Cira Center created a benchmark for the installation and removal of a tower crane via the use of an aerial crane. Unique considerations for successful implementation often include street closure permits, coordination of the entire site and subcontractor operations, weather considerations at project location, and time of year.

> Because we like to **minimize our on-site activities**, we **design and engineer the largest components and units** that we can safely install.

5 SAFETY

The biggest challenge for any building contractor is the work that takes place on the jobsite, and it is on this demanding playing field that Enclos most clearly differentiates itself. In addition to training our people in the discipline of relentless diligence as a means to optimum operational safety, we fine-tune our planning, strategies and tactics to the unique requirements of each individual building project we undertake. We have developed a unique expertise over decades of experience in cladding some of the most challenging building projects ever constructed. This experience has been documented in a concise compilation of best practices with respect to the operational safety of custom facade system installation, yet we recognize that each project presents a unique scenario, requiring contextual analysis as a means to anticipate potential challenges. Drawing upon this deep accumulation of experience, we craft a custom safety plan in direct response to each specific project context.

We typically design and engineer the largest components and curtain wall units that we can safely install, as a means to reduce installation schedule and provide optimum economy. The following section includes a few key considerations for logistics and jobsite planning with respect to mechanized equipment.

6 RIGGING, SIGNALING, & OTHER TESTS

Although Enclos generally does not operate the equipment we use to install our facades, each of our field workers is trained and often certified to understand the rules and guidelines associated with rigging practices. In addition, the safety department at Enclos gives a rigging test to each employee prior to allowing jobsite access. Each of the rigging components listed above are engineered and approved prior to Enclos utilizing them on site.

Because we also use cranes for many of our facade installations, teaching field workers how to properly signal the crane is crucial. Additional training is given to site workers as a prerequisite to directing any activities involving a crane.

7 OSHA: SUBPART CC CRANES & DERRICKS IN CONSTRUCTION

The Occupational Safety and Health Administration (OSHA) enforces laws and regulations with respect to construction. To the right is a quick checklist with regards to cranes and derrick usage that was put together by the Enclos safety manager, and provides a quick survey in which to verify that the jobsite is prepared to use mechanized equipment. If the answer to any of these questions is "no", the issue will need to be addressed immediately in order to provide a safe jobsite.

If specific information is needed, visit the OSHA site below:

http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=Construction

An additional source for safety information regarding monorails and under-hung cranes is "ASME B30.11-2010 Monorails and Under-hung Cranes."

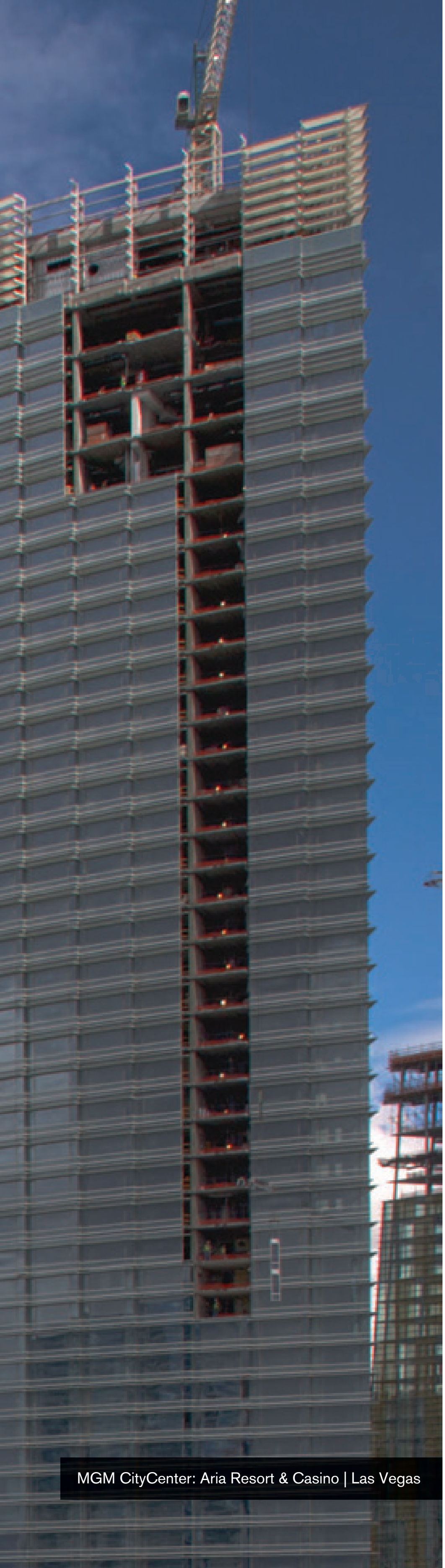
SUBPART CC-CRANES AND DERRICKS IN CONSTRUCTION § 1926.1400

This section applies to power-operated equipment used in construction that can hoist and lower by a winch and horizontally move a suspended load. Machinery is excluded if it has been converted or adapted for a non-hoisting/lifting use.

- Is assembly/disassembly being directed by a person who meets the criteria for both a competent person and a qualified person, or by a competent person who is assisted by one or more qualified persons ("A/D director")?
- Are site and ground conditions adequate to support the equipment for safe assembly/disassembly and hoisting operations?
- Is the operator licensed or certified to operate the specific crane that is being used?
- Is rigging and signaling being done by a qualified person holding a current certificate issued by an accredited agency or by Enclos? Are certification cards on site?
- Has there been a meeting with the equipment operator and other workers in the surrounding area of the equipment/load to review the procedures that will be implemented?
- Have crew members assigned to work with the equipment been trained for tasks assigned to them?
- Are synthetic slings protected from abrasive, sharp, or acute edges and configurations that could cause a reduction of the sling's rated capacity?
- Can any parts of the equipment, load line, or load (including rigging and lifting accessories) come closer than 20-50 feet to a power line during the assembly/disassembly and hoisting process? See Table "A" (§ 1926.1408) for safe operating distance.
- Has each operator and crew member assigned to work with the equipment been trained regarding the danger of electrocution in the event of electrical contact with a power line?
- Has post-assembly and daily inspections by a qualified person been conducted and documented?
- Has work area control been setup, including barricades and signage warning of hazards?
- Are all safety devices on equipment in good working order?
- Does the operator and qualified person have the authority to stop handling loads if safety is a concern?
- Has the operator, signal person and hook-on person contacted each other and agreed on the type of signals that will be used?
- Are the standard hand signal charts posted on the equipment or conspicuously posted in the vicinity of the hoisting operations?
- Has the swing radius of the crane been barricaded or roped off to eliminate the pinching or crushing of an employee against another part of the equipment or another object?

TABLE A – MINIMUM CLEARANCE DISTANCES

Voltage (nominal, kV, alternating current)	Minimum clearance distance (feet)
up to 50	10
over 50 to 200	15
over 200 to 350	20
over 350 to 500	25
over 500 to 750	35
over 750 to 1,000	45
over 1,000	(as established by the utility owner)


MGM CityCenter: Aria Resort & Casino | Las Vegas

CONCLUSION

The use of mechanized equipment and the continual evolution of equipment technology has allowed Enclos to develop increasingly innovative facade installation processes. These new approaches have optimized field performance, decreased schedule durations, and most importantly, kept our work crews safe. As building designers and developers continue to push fundamental design boundaries, the significance of the facade contractor's role will continue to grow in years to come with an increased emphasis on jobsite activity.

Image by Travis Fullerton, courtesy of VMFA.

Project Spotlight: Virginia Museum of Fine Arts

Matt Elder

When the Virginia Museum of Fine Arts set out to transform its space with a "bigger, brighter, and more welcoming" program, it did so with a very specific vision: transparency achieved through major expanses of glass. There is no better building material than glass to provide optimum transparency in the building envelope, and London based architect Rick Mather, in partnership with Richmond-based SMBW Architects, designed the largest expansion in the museum's history to bathe occupants in natural light.

"Many building materials and techniques in this project are fairly innovative – like the high performance exterior glass – that create a better environment," Mather said in a recent VMFA interview. "At the same time [they] are energy efficient…more appropriate and sustainable" [1].

Enclos provided 44,000 square feet of building facade as the central theme of the expansion program, in what the museum is calling a "virtuoso handling of transparency and natural light." The facade program was delivered under comprehensive design-assist and design-build services, in which Enclos specializes.

CLOSE UP

owner Commonwealth of Virginia

architect Rick Mather Architects / SMBW Architects

gc The Whiting-Turner Contracting Company

completion 2010

contract value $12m

program 6-stories; 165,000 sqft expansion

building type cultural

technology type Glass Fins, Large/Special Glass, Offshore Sourcing, Skylights, Special Geometry, Stick Systems

facade 44,000 sqft of exterior wall, including 20,000 sqft of unitized curtainwall with handset Indiana Limestone and 20,000 sqft of stick built custom glass curtainwall

glass oversized glass curtainwall units as large as 6 ft x 24 ft; oversized glass measuring 8 ft x 16 ft; typical glass makeup consists of 1-11/16 inch thick low-e laminated insulated glass with a custom grey frit pattern to cover insulating glass spacers; provided by Eckelt Glass GmbH

description this 2011 RIBA International Awards winning project is the largest expansion in the museum's 75-year history

BIGGER

VMFA is a state-supported, privately endowed museum whose current expansion belies its humble origins. VMFA opened the original museum in 1936 amidst the Great Depression with a brick and limestone building designed by Peebles and Ferguson Architects. The museum was founded with the mission of collecting, preserving, exhibiting, and interpreting art, and has been pursuing this mission for three-quarters of a century, experiencing steady growth in both artworks and patronage over the years. With no expansion of the facility over the last quarter century, additional space was badly needed to accommodate the growth.

Mather's renovation includes a 165,000 square foot expansion that adds to the museum's existing 380,000 square feet. The new facility doubles museum space for traveling exhibitions, adding 120,000 square feet, and provides an additional 53,500 square feet for the museum's permanent collections. It is the largest renovation in the museum's history. The James W. and Frances G. McGlothlin Wing is the largest of the redevelopment structures, and is able to accommodate up to three exhibitions at once. The McGlothlin Wing includes a 150-seat lecture hall and 4,000 square foot Art Education Center that will provide educational programs for nearly 50,000 Virginia children, or 129 of the 132 school districts within the state.

Enclos provided a diverse collection of exterior walls for the new campus style complex. The design-assist phase involved extensive collaboration between the Enclos team and the design architects in determining structural performance, materials, and system detailing of the custom unitized curtainwall with handset limestone infill, the custom stick-built systems consisting of structural stainless steel T's with oversized glass, and

Figure 1: The McGlothlin wing uses Indiana limestone to blend the new building structure with the existing 1936 structure. Image by Bilyana Dimitrova, courtesy of Virginia Museum of Fine Arts.

the skylights. Custom exterior glazed window wall systems include a combination of stainless steel and glass fins. Wall unit modules varied throughout the project, with the largest unit measuring 6 feet by 24 feet, and oversized glass spanning 8 feet by 16 feet.

"The Enclos engineering team could write a book on the design/assist phase of this project," says Bill Smith, Enclos project manager for the museum. "Especially when you consider the various wall types and complex designs."

Enclos has long been utilizing the design-assist process with leading architects on landmark projects across the nation. The service has proven to be effective in mitigating the risk posed by unique and complex facade designs, and the use of emergent materials and specialized technology, as with the VMFA facade program requirements. Prior to installation, Enclos conducted extensive mockup testing to validate the performance of the custom designed wall systems. A 16-step program tested air and water infiltration, structural, wind load, and thermal behavior. All cladding systems performed within the required parameters without incident. Through the procurement process, Enclos flexed the muscles of its global supply chain to combine highest quality with optimum economy for the materials utilized in the VMFA's extraordinary facades. Offshore sourcing included satin finished stainless steel fins incorporated into the stick-built system, typical and oversized insulating glass, patterned overhead and elevator glazing, granite skirting, and the buff Indiana limestone that wraps the exterior facade. The curtainwall units were assembled at an Enclos East Coast manufacturing facility, and shipped to the Virginia building site where they were received by the firm's field installation crews.

GONE GLOBAL

Numerous project materials had to be procured out-of-state to meet design requirements. Enclos put its global supply chain to work for VMFA.

Key suppliers include:

Accent Architectural (Baie-d'Urfé, Quebec, Cananda): Glass handrails

Bybee Stone (Ellettsville, Indiana): Buff Indiana limestone

Eckelt Glass (Austria): Oversized and typical insulated glass

J.E. Berkowitz (Pedricktown, New Jersey): Exterior glass entrances and interior glass doors

Pedras Salgadas – Corporacion Ingemar S A (Spain): Granite skirting

Shanghai Yaohua Pilkington Glass Co., Ltd. (China): Overhead and elevator glazing

Thapanin (Thailand): Satin finished stainless steel fin (featured on stick build system)

Figure 2: The McGloughlin wing includes a first floor cafe, second floor gallery, and a third floor restaurant. Each provides a view to the surrounding Sculpture Garden.

At the heart of Mather's redesign was the idea of maximized transparency. Combining expansive areas of glass in the new facade with limestone to blend the new structure with the existing, a harmonious balance was achieved between the old and new.

"Major expanses of glass allow natural light to pour into the heart of the museum," said Alex Nyerges, VMFA director, "and will welcome visitors with a look at three floors of art and activity inside." [2].

This three-story view to the interior is provided by a 40 foot tall glass wall – aptly titled the "East Window" – which overlooks North Boulevard and stands as an open invitation to passers-by. A glass-enclosed stairwell located on the north facade – appropriately referred to as the "Glass Beacon" – glows via artificial lighting at night to draw attention to the museum's entranceway. Both the East Window and Glass Beacon were initially base-loaded, with the dead load of the glass wall applied at level one. A mid-course redesign required the wall systems to be suspended from the roof structure in order to minimize the profile of the stainless steel T-section primary structural members, thereby limiting them to the resistance of lateral loads. In addition, the McGlothlin Wing's third floor includes a 9,500 square foot Conservation Center that is clad with glass windows and skylights to maximize daylighting.

At the heart of the expansion is the three-story light-filled Louise B. and J. Harwood Cochrane Atrium, acting as the museum's main thoroughfare. The atrium connects the McGlothlin Wing to two existing wings, and provides entranceways to a library, gift shop, restaurant, café and art galleries.

A glass roof distributes natural lighting throughout the atrium and into adjacent areas. Enclos also provided this unique and structurally demanding feature, along with exterior entrances and stainless steel canopies. An extensive interior package including glass doors and glass railings rounded out the scope of work.

Figure 3 (above): The "Glass Beacon" lights the museum's entranceway.
Figure 4 (below): The "East Window" displays within the museum from the exterior. Images by Bilyana Dimitrova, courtesy of Virginia Museum of Fine Arts.

MORE WELCOMING

The tie between old and new building materiality is the Indiana limestone, which blends the original 1936 building facade with the recent expansion. The use of this material, however, necessitated highly crafted work processes in both shop and field to match the unique ashlar pattern of the stone between adjacent panels. The requirement resulted in most of the stone being handset in the field by Enclos installation crews.

VMFA's expansion program also includes a 3.5-acre sculpture garden, outdoor plaza, and parking deck for 600 vehicles (partially hidden by the sculpture garden). The museum anticipates its membership to grow or surpass its all-time high of 20,000 members by 2012.

The museum expansion opened to the public on May 1, 2010, to universal acclaim. The VMFA renovation provides a dynamic, fresh public face, dramatically showcasing the artworks within. The dramatic, highly-glazed facades are integral to the achievements of this ambitious project.

REFERENCES

[1] Mather, Rick. "Architect Rick Mather Q&A." Virginia Museum of Fine Art. Web. March 8, 2011.

[2] Nyerges, Alex. "Expansion at VMFA is Largest in Museum's History." Virginia Museum of Fine Arts. Web. April 10, 2010.

Figure 5 (right): Enclos provided an extensive interior package, including glass railings.

Figure 6 (below): The expansion relocates the museum's entranceway to face the Boulevard. Images by Bilyana Dimitrova, courtesy of Virginia Museum of Fine Arts.

Figure 7: The three-story atrium's skylights shower museum visitors with daylighting. Image by Travis Fullerton, courtesy of Virginia Museum of Fine Arts.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Buy American Requirements in a Globalized Economy

John Jeske

Successful federal contracting today means navigating the “alphabet soup” of federal and other regulatory requirements that inevitably come along with governement dollars. These include a maze of FARs, VARs, DFARs, or whatever other acquisition regulations are applicable to the project; EEOC rules and other non-discrimination requirements, Small Business Enterprise (“SBE”) subcontracting plans and reports, OSHA requirements, and LEED environmental building standards just to name a few.

Among the most challenging requisites on any federally funded project is “Buy American” requirements, which generally mandates that all construction materials be purchased from the United States or a specified list of trading partner countries that have been deemed acceptable. A brief glance at the specifics of the three major Buy American statutes that contractors face often cause the head to spin with questions. More specifically, what does it mean to be “manufactured” in the United States? What if raw materials from different countries are brought together to produce a multi-component “construction material” in a United States plant? What if foreign products are specified on a project with Buy American requirements?

The good news is that by acknowledging that these questions exist, and recognizing the complex grey areas inherent in these broad-brush standards, you will already have a leg up in addressing Buy American requirements successfully. While the intricate specifics of Buy American’s various laws is well beyond the scope of any singular article, the goal here is to simply introduce its three major laws, explain why the application of those laws is increasingly complex, and recommend an effective strategy for dealing with these laws on federally-funded projects.

1 INTRODUCTION

Throughout the last fifty years, the shift of American jobs heading overseas has become an emotionally charged political issue. As both major political parties have moved towards advocacy of free trade and opening up international markets for American products, previously well-paying blue collar jobs in the American Midwest have disappeared by the hundreds of thousands, leaving permanently high unemployment rates in those areas in their wake. At the same time, American consumers have increasingly been marketed cheap goods manufactured in foreign countries, where low wages and poor working conditions often prevail.

As a result, it has become a popular issue for politicians to advocate for government purchases of American goods and services in a way that will benefit American manufacturing sector workers. A significant percentage of government purchases involve new construction projects, or renovations of existing buildings or infrastructure. Even at the state and local level, projects are often marketed to the public on the promise of employing local workers. Consequently, ensuring that American construction projects utilize American labor and construction materials has been a growing focus.

With the recession of 2008-2010, this issue has taken on an even greater importance. As President Obama took office he began to push for passage of the American Reinvestment and Recovery Act (ARRA), also known as the "stimulus bill," which included massive funding for construction projects of varying natures. Large swaths of the American public asked the justifiable question: if we plan to spend nearly $1 trillion in American taxpayer money to support American jobs, how can we ensure that this money achieves its intended aim? The answer, as it has been since the early 1930s, is to pass the newest version of a "Buy American" statute, which has become ubiquitous on federally funded construction projects today.

Here we will discuss the history of federal Buy American type statutes amongst the construction marketplace, and discuss how the increasingly complex construction industry makes application of these statutes even more challenging. Strategies addressing these requirements will also be presented. Please note that there are many Buy American type statutes on both the federal and state level that this article does not address (such as the Berry Amendment for Department of Defense spending, for example). In addition, this article is not intended as legal or compliance advice, and should not be taken as such. The intersection of every project and Buy American law (and different versions of individual laws themselves) is unique, making a generalized guidance impossible and inadvisable. Obtaining legal counsel for each individual encounter with Buy American law is a necessity.

> If we plan to spend nearly **$1 trillion in American taxpayer money to support American jobs**, how can we ensure that this money achieves its intended aim? The answer, as it has been since the early 1930s, is to **pass the newest version of a "Buy American" statute**, which has become ubiquitous on federally funded construction projects today.

2 A BRIEF HISTORY

Buy American type statutes, as the brief history below will show, are the result of economic panic. Interestingly enough, the three major laws that construction firms encounter on federal work were passed at roughly the same time as the three highest spikes in unemployment over the past 80 years. Unsurprisingly then, the requirements imposed are often unclear and have significant unintended consequences. This makes determining bright-line rules difficult to impossible. However, an understanding of the background of these statutes makes it easier to place these laws in context and to implement an effective compliance strategy.

2.1 THE 1933 BUY AMERICAN ACT

The first Buy American statute was passed during the depths of the Great Depression. In November of 1932, with unemployment rising to previously unimaginable numbers, the American people had elected new President-elect Franklin Delano Roosevelt in a landslide, rejecting the leadership of then-President Herbert Hoover.

With the economy in free fall, and banks failing almost daily, President Hoover invited President-elect Roosevelt and his economic team to the White House to discuss a joint economic strategy. Unfortunately, these sessions produced little agreement, and no productive economic policy-making.

With little to do but sit and wait for President-elect Roosevelt and a newly elected Democratic Senate to take office, a divided Congress helplessly twiddled its collective thumbs, taking the few ineffectual measures that could generate bipartisan support as the news worsened by the week. Among these measures was the 1933 Buy American Act. Sponsored by a progressive Republican Senator (and former Governor) from California, Hiram Johnson, the law was a nod towards economic isolationism and protectionism that had characterized Hoover's presidency. Hurriedly passed as Roosevelt's inauguration approached, the law was literally signed on President Hoover's last day in office, March 3, 1933, and required the use of American materials and manufactured goods in projects paid for by the American federal government.

The law has evolved throughout the last eighty years, but remains on the books to this day, Located in the United States Code at 41 U.S.C. 10a – 10d, it now affects nearly all federal government construction projects. As its rushed passage would suggest, the law was never a model of clarity. The law now contains several major exceptions, applies in some instances to construction materials from "designated countries" with whom the United States has treaties, and generally produces confusion amongst federal contractors trying to do the right thing.

2.2 THE 1982 SURFACE TRANSPORTATION ASSISTANCE ACT

Federal procurement law became even more complex with the passage of the 1982 Surface Transportation Act, or the "Buy America Act" (as compared to the original "Buy American Act"). With unemployment at its highest rate since the end of 1982, then-President Ronald Reagan and his Democratic counterpart in the House of Representatives, Speaker of the House Tip O'Neill from Massachusetts, collaborated to produce a highway-funding bill called the Surface Transportation Assistance Act of 1982 (STAA). The STAA's primary purpose was to levy a 5-cent per gallon gas tax on the American public, in order to fund highway and transit construction across the country, and stimulate the American economy.

Just as the preceding period of the 1933 Buy American Act, the American economy was in desperate shape in early 1982. The American public had endured years of high inflation, oil shortages and the resulting gas price spikes, and rapidly rising unemployment that spanned from the late 1970s into the early 1980s. The "misery index" – a measure combining unemployment and inflation – remained near post-World War II highs, where it had been holding since the late 1970s. The steel industry in particular suffered, with hundreds of thousands of Americans loosing jobs to overseas competition. Pittsburgh, Pennsylvania steel mills alone saw the loss of over 150,000 jobs during the 1981-82 recession.

The STAA was an attempt to increase government spending on American infrastructure by directly supporting American construction jobs and indirectly supporting American manufacturing. In order to ensure that the $5 billion per year raised by the gas tax levy produced a maximum impact on the recovering economy, lawmakers included a provision within the law known as the 1982 "Buy America Act."

The 1982 Buy America statute, while confusingly similar in name to the 1933 Act, addressed a completely different set of circumstances. Where the 1933 version placed restrictions on direct federal spending, much of the money raised by the 1982 act would be given to cities and states in order to fund local highway and transit projects. Thus, the Buy America language included in the statute restricts how "grantees;" i.e. state and local governments could spend money given to them for highway and transit projects, as opposed to defining how the federal government spends its own money.

The differences do not end there. With the hemorrhaging of steel industry jobs as a backdrop, the lawmakers who passed the 1982 version decided to provide separate and more restrictive steel and iron rules when compared to "other manufactured products." These steel and iron rules have been interpreted several times by the Federal Transit Administration (FTA), the agency that administers transit projects; each time causing more confusion as to what the rules actually mean. As a result, by 1982 there were two separate federal Buy America (or "American") Acts, each with completely different rules, and applicable in two different situations.

2.3 THE ARRA BUY AMERICAN ACT (SECTION 1605 OF ARRA)

The third and most recent iteration of major federal Buy American lawmaking came just two years ago as one of President Barack Obama's first acts in office. In 2009 the American stock market was again in free fall, following the onset of one of the worst financial crises in our nation's history the previous fall. The Obama administration's preferred policy response was to shock the economy into improvement, or at least slow the deterioration by infusing a massive amount of federal money into the economy. This "stimulus package," which eventually totaled $787 billion, included billions in additional funding targeted primarily towards "shovel-ready" construction projects. It is worth noting how much the United States economy has grown in the last 80 years. The total federal spending in 1932 during President Herbert Hoover's final year in office amounted to $4.3 billion – about 0.5% of President Obama's 2009 stimulus bill alone.

In any event, this large new federal spending bill, in a time of increased anxiety and job loss, produced the same reaction as in 1933 and 1982: hastily put-together legislative efforts by politicians to ensure that the new federal spending would result in new American jobs. However, by 2009, significant countervailing forces were affecting the political climate. Both political parties had developed strong strains of pro-"free trade" international trade policy, and other major economies, who were similarly suffering, posed potential retaliation threats if the United States entered into an overly protectionist stance.

These forces combined to produce an end result that was a compromised version of the now significantly modified 1933 Buy American Act. This new statute, codified as Section 1605 of the American Recovery and Reinvestment Act, changed some of the standards applied by the 1933 Act, yet kept its basic framework. Consequently, at this point, different rules will likely apply to: (1) a federal project funded from the normal yearly budgets passed by Congress; (2) a state highway or transit project built, at least in part, with federal dollars; or (3) a federal project with stimulus funding. In addition, contracting officers often have different contract clause options within each law to choose from. Thus, the first step on any job where such requirements might apply, at this point, is simply figuring out which law (and which version of a particular law) is in play on the particular project.

3 DECADES-OLD STATUTES IN A GLOBALIZED WORLD

Further complicating the task of the contractor or government contracting officer trying to interpret and apply these statutes is the ever-increasing interconnectivity and complexity of the modern economy and, by extension, individual manufactured goods. Even if the multitude of existing Buy American-type statutes had been clearly and methodically written—which they were not—it is not at all clear that they would be easily applicable in the modern construction context, for the simple reason that defining an "American" product is now a very difficult task.

For example, in the first half of the twentieth century, it was a very simple task to determine whether most products were "American." Using the automobile as an example, most, if not all, General Motors and Ford Motor Company cars and trucks were designed and developed in the Detroit, Michigan area, built with parts primarily manufactured in the "rust belt" states of Ohio, Indiana, and Michigan, and manufactured in Detroit by American autoworkers.

However, in the age of globalization, interconnected commerce, and instant communication, it can be extremely difficult to categorize products by nationality. For example, Toyota Motor Corporation, with its global headquarters in Toyota, Aichi, Japan, has for many decades been a major component of the industrial rise of modern Japan. Similarly, Ford Motor Company, with its headquarters in Detroit, Michigan (a sister city of Toyota since 1960) has been a giant of American industry for over 100 years running. Yet when shiny new Toyota Prius Hybrids rolls off the assembly line in Tupelo, Mississippi – and that fact is instantly transmitted back to Toyota Motor North America headquarters in Torrance, California – it can hardly be argued that the new gas sipping hybrid has not become an "American" car. Conversely, when the new owners of a 2010 North American Car of the Year Award-winning Ford Focus drives their gleaming new purchase off of the automobile dealership lot, they might be surprised to learn that their new "American" car was manufactured in Hermosillo, Senora, Mexico.

The construction industry is no different. An operable louver sunshade, for example, might include electrical components from Taiwan or Japan, Chinese aluminum, American steel fasteners, and be manufactured in an American plant. A specialized fabricated steel piece may be extracted and smelted down in China, shipped to the United States for fabrication, included in a larger assembly at a Mexican plant, and shipped back to an American jobsite for installation.

In any such instance, it obviously begs the question to require that the product be "American made," or "manufactured in the United States." A contractor attempting to comply with such regulations may have to make tricky judgment calls in the absence of clear guidance and with varying degrees of input and help from contract documents and the contracting officers who must implement the statutes.

Figure 1 (left): The three Buy America laws that construction firms encounter on federal work today were initiated immediately following the United States' highest rates of unemployment: the early 1930's, early 1980's, and most recently in 2009.

WHAT TO DO?
ENCLOS RECOMMENDS

1. Find Out As Early As Possible Which Law Applies

If you are working on a government-funded project, there is a good chance that some form of Buy American law applies. If the project is federally funded, the application of one form or another of Buy American law is a virtual certainty, in the absence of some sort of explicit waiver granted by the contracting officer. Often, a quick review of the bid documents will reveal a reference to specific Buy American requirements. If no such reference is found, it is important to ask whether Buy American requirements will apply. The worst possible thing that can happen is to find out that you are on a Buy American project at such a late date that it puts your planned method of designing or building the project or executing your scope of work in jeopardy.

2. Hire Legal Counsel

This point cannot be emphasized enough. The key to effective compliance with Buy American requirements is to hire legal counsel with expertise in this arena. Buy American statutes are very complicated, often coming in multiple different versions. In addition, and frustratingly enough, Buy American statutes sometimes do not mean what they seem to say, owing to interpretations on the part of the federal agencies that administer these laws.

No matter what the situation, an experienced lawyer can help navigate the complexities of complying with a particular law, and can help formulate strategy for engaging in the bidding and other project processes in the safest and most productive way possible.

3. Scope It Out

Once you have determined which law applies to the project and obtained legal guidance on the nuances and intricacies of that particular law, often the next step is to determine which scopes of work may be problematic, and begin working on those. For example, it is not uncommon for a Buy American project to include specified products from other countries. Depending on the specifics of that particular law, those products may or may not seemingly comply with the applicable law.

In this sort of situation, it is important to determine whether that product is problematic with respect to Buy American compliance, and to either switch to a different compliant product, or develop a strategy for determining compliance or pursuing a clarification or change to the specifications. No matter what the Buy American problem, it is better raised on the front end than after the project is well underway, when there may be no easy way to comply.

4. Communicate Early and Often

Making sure that all involved parties are on the same page and have the same understandings is a critical component of strategy on any Buy American project. In keeping with the old axiom that “two heads are better than one,” at a minimum, discussing the statute and various compliance issues with involved parties may lead to better ideas. Even more helpfully, it may bring to light a previously undiscovered issue, and prompt a collaborative solution that is better for the project as a whole.

5. Document Compliance

Finally, as with any government compliance issue, documentation is key. While a contractor may face challenges in procuring particular items from Buy American-compliant sources, and may also face challenges in verifying that particular raw materials or manufactured products came from the right places, proper documentation can help to mitigate those risks. We recommend not only documenting expectations from vendors and suppliers in the form of proper certifications and purchase order language, but also documenting the sourcing and transit of the materials themselves, to the extent possible. If as comprehensive a documentation plan as possible is undertaken, involved parties can reduce the risk of unpleasant future surprises.

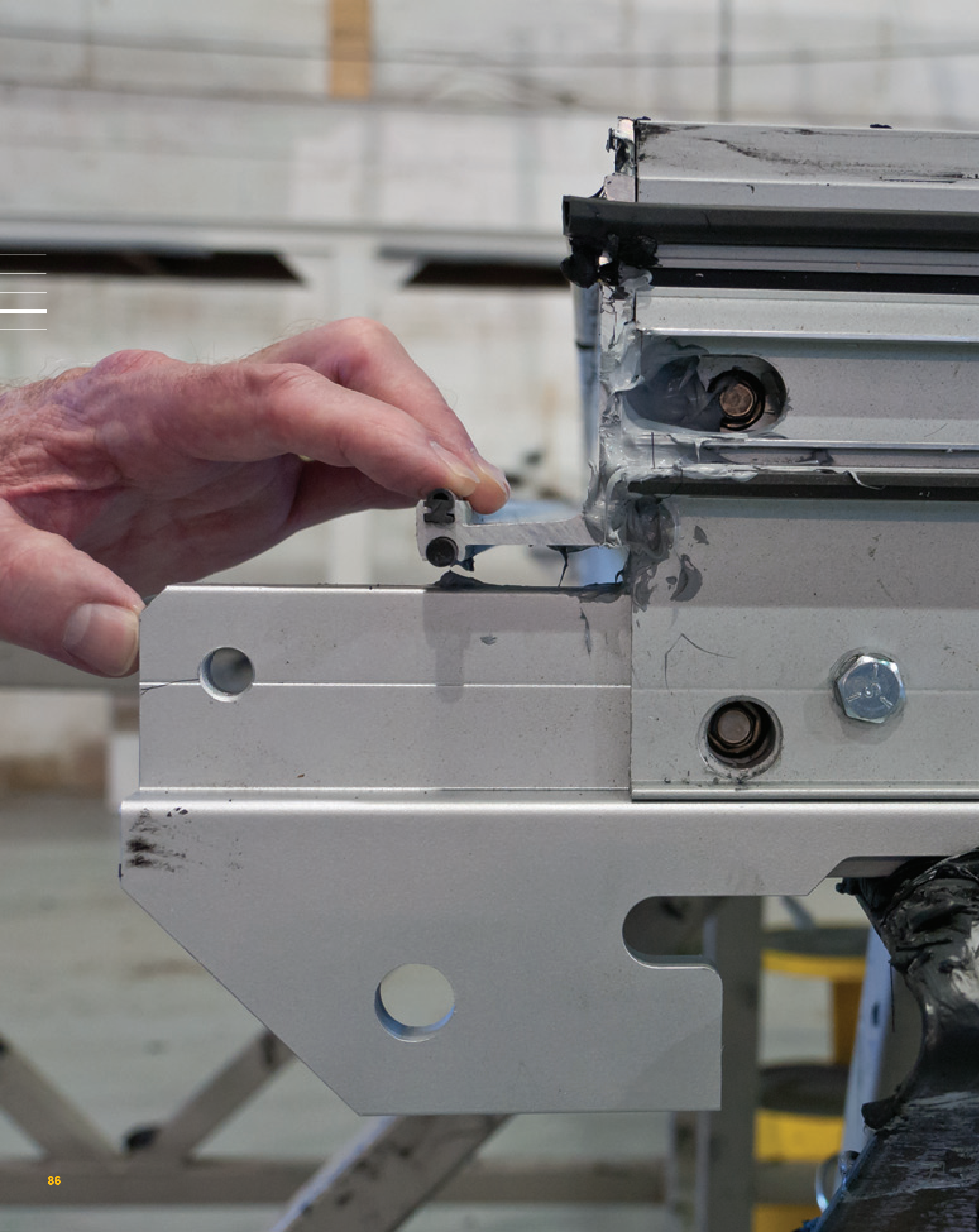
CONCLUSION

As with most project processes, doing your homework and planning ahead are the keys to navigating Buy American compliance in our interconnected modern global economy. The typical federal contractor will see these requirements on most, if not all, federally-funded government projects, yet may also be procuring products that either must be purchased overseas or can be purchased much more cheaply. The multiple existing Buy American laws, and their seemingly overlapping nature, may make it difficult to generalize simple rules or a standard compliance process ahead of time. However, with proper preparation and diligence, careful compliance with Buy American laws can become a competitive advantage, enabling confident bidding and successful performance on the large numbers of government projects that make up a significant percentage of the commercial construction marketplace today.

Figure 2 (right): Enclos' work on the new San Diego United States Courthouse closely followed Buy America requirements.

Research

The following section contains recent research initiatives conducted by the Advanced Technology Studio of Enclos. Highlights from ongoing projects are included as well.



Optimization in Component Design

TJ DeGanyar, Ph.D., PE

The process of optimization is at the core of every organic or synthetic design. Although sometimes implicit, optimization manifests itself in every step of the creative process from finding spatial fit to achieving cost effective delivery methods. The process is most applicable in the field of engineering design, where the multi-dimensional and multi-disciplinary aspect of the practice creates a vast opportunity for finding the best solution. This paper discusses the generalized formulation of structural optimization, and presents some relevant techniques for adaptation in curtainwall products. Specifically it discusses two approaches of "topology" and "shape" optimization and the potential of their application in the design of components in unitized curtainwall systems. Topology optimization is the means of creating material distribution for a given set of loads and boundary constraints. The method of Solid Isotropic Material and Penalization (SIMP) is employed to demonstrate the features of this technique in design of a typical curtainwall anchorage assembly. Shape optimization is a method for crafting the most efficient geometry to meet a set of specified conditions, while minimizing the area of the resulting geometry. To investigate the possibilities of shape optimization, the "Evolutionary Solver Method" is used, and the feasibility of this methodology is demonstrated by searching for best possible extrusion profile for typical unitized curtainwall mullions.

Over **two million pounds of aluminum** are used in the fabrication of the curtainwall system for a **typical 45-story building**.

1 INTRODUCTION

All engineering designs have the goal of achieving the best solution to a “set of variables” constrained by a “set of limitations”. This challenge is exacerbated when combined with ever increasing demands for competitiveness and the need for superior performance. Curtainwall designs follow the same requisite. Here the optimum solution is the safest, the most efficient, and the most economical product that satisfies a number of physical, spatial, and aesthetic criteria. Consider the following observations:

- Over two million pounds of aluminum are used in the fabrication of the curtainwall system for a typical 45-story building. This material costs approximately 8 to 9 million U.S. dollars.
- The annual aluminum market for the construction industry in the United States is approximately 350 to 400 million pounds. This accounts for about 13 to 15 percent of total aluminum usage in the U.S.
- Aluminum has the highest energy production ratio (44,711 Btu/lb) of all of the material used in the construction industry (glass is a close second). In comparison steel uses only 8,700 Btu per pound of steel.
- Approximately 30 percent of the price of the aluminum is the cost of the electricity used to produce it.

These statistics underline the assertion that it is both economically prudent and an environmental responsibility to aim for high levels of efficiency in the design of aluminum products. As such, the practice of reducing the product weight while maintaining structural integrity is paramount to the design of good aluminum extrusions and castings used in curtainwall systems.

In general, the following three steps are followed in the design of system components:

1. Function: This task determines the utility of the product - for example, vertical mullions are used to frame the glass and to transfer distributed lateral loads to the floor anchors and be of a sufficient stiffness to avoid excessive movement. The anchors transfer this load to the support slab and provide the required means to accommodate building movement. Primary mechanics of the element dictate the general schematics of the component. At this step the material is chosen, though the material property remains to be further examined.

2. Conceptual Design: At this stage, the design will be evaluated for fit and spatial consideration. If the parts are visual, the aesthetic aspects are evaluated in conjunction with the performance requirements. Interface with other mating components will be detailed. The result is a design with a set of specifications and constraints. In the example of vertical mullions, factors such as outer profile, unit dimensions, finish types, and thermal isolation will be established.

3. Optimization: The final step is to find the most efficient form of the component. Here several elements, ranging from strength to economy and quality to quantity, will be examined in search of the best design.

This last step is the topic of this report. Traditionally the optimization process has been an intuitive and iterative course, where the design starts with experiential or perceptive concepts, and then a series of refinements are made to converge to a more effective and robust design. However, this approach becomes less efficient as the number of variables increase and design goals become multi-objective. For example, design for both stress compliance and displacement rigidity require interrelated analysis, which is not only subject to independent specifications but also sometimes contradictory.

Let’s consider the design of a simple beam subjected to a uniformly distributed load (see figure 1). To attain lower magnitudes of vertical displacement, it is instinctive to increase the depth of the beam. But as the depth increases the cross-section becomes more susceptible to twist, hence less stable, requiring a higher torsional rigidity. This problem becomes more tedious when the number of parameters in the definition of cross sectional geometry increases (for example variables such as wall thicknesses, open and multi-cell profiles).

The following sections present a brief summary of the optimization history and its role in modern engineering practices. General formulation and representative examples highlighting the application of structural optimization in curtainwall design conclude the report.

2 HISTORY

The earliest account of an optimization process is from nearly 3000 years ago. The legend as explained by Virgil has it that Queen Dydo's fled her native Greece from the fear of being killed by her brother and landed on the shores of North Africa (present day Tunisia). Upon arrival she asked the natives to purchase a piece of land to settle. The local chieftain offered her as much land as she could enclose within a hide of a bull. The Queen accepted the proposition and proceeded to cut the hide to small strips and tie them together to make a long string. Then she laid the string in a semi-circle arc with Mediterranean shore as the straight boundary. This way she created the largest area for the city known as Carthage. The problem Queen Dydo solved, covering the largest area with the smallest perimeter, is today known as isoperimetric problem and is still a topic of study in the field of calculus of variations.

The formal solution to the mathematical problem of optimization was first introduced in early 19th century by German mathematician Gauss and leaped into an applied science in early twentieth century. Since then, thousands of problems, in hundreds of fields from economics and social sciences to engineering and genetics have been classified in one form or other as an optimization problem. The advent of numerical computation has boosted the practice to a widely acceptable means of solving complex physical and mathematical problems. Escalating needs for higher speeds and smaller sizes have made optimization the cornerstone for all disciplines in applied science.

In the field of structural mechanics, the concept has been an active area of research for the past fifty years. Methodical optimization in applied mechanics has become significant over the past two decades. A recent collection of papers by Arora [2] is an excellent source of the state of development in the subject. Other text by Christensen and Klarbring [4], Haung and Xie [5] and Bensoe and Sigmund [3] give an in-depth discussion of structural optimization techniques. In practice, most of the comprehensive solid mechanics software packages offer some type of optimization module, which can be applied to a variety of computational models.

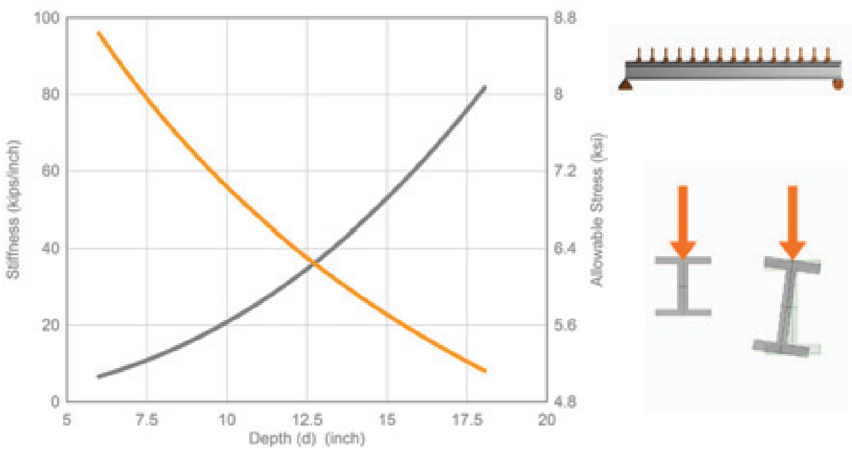


Figure 1: Effect of depth change on the performance of a simple supported beam. As depth increases the stiffness increases, and the deflection reduces. At the same time by incasing the depth, the potential for twisting of the bean increases, hence reduced allowable stresses (orange curve).

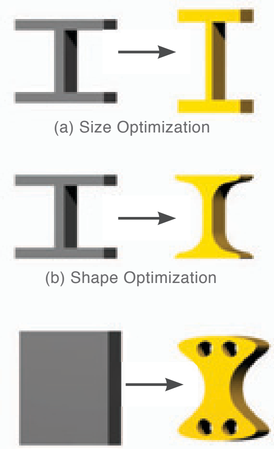


Figure 2: Types of component optimization; (a) Size Optimization: width, depth and thicknesses of flanges, and web are the design variables, (b) Shape Optimization: the outer profile of the geometry is the design variable, (c) Topology Optimization: the material distribution inside the cross section is the design variable.

3 OPTIMIZATION PROBLEM

All optimization problems in engineering design are formulated using the following four elements:

- Objective Function - J(): This is a function describing the measure of the goodness of design. Sometimes referred to as cost function, it is a single or multiple objective that needs to be minimized (or maximized). It usually refers to product weight, spatial coordinates, strain energy, material cost, or a combination of these attributes.

- Design Variables - {Vd} : These are a set of variables that form the design. They can be geometrical (such as shape or thickness) or physical (such as material strength or density).

- State Variables - {Vs}: These variables are not at the designer control; however, they will have effect on the feasibility of the final product and/or the value of the objective function. Examples might include induced stress or deformations.

- Constraints - G(): These are the limitations imposed on the design. They may be the practical range of the design variables, the behavioral restraints of the state variables or the laws governing the physics of the problem.

The problem then becomes finding the best set of variables Vd so the function J(Vd,Vs) is minimized (maximized) subject to a group of constraints imposed by functions {G(Vd,Vs)}. This framework, sometimes referred to as a mathematical programming problem (no relation to computer programming), is the simplest form of the optimization problem.

When it comes to finding a solution, the optimization problem is somewhat deceiving in its simplicity. Consider the case of a simple example depicted in figure 1. Here we have a set of two design variables {v1, v2}. The Objective function J() is surface generated by the admissible values of the design variables in their respective bounds. As it can be seen, any solution system needs to deal with a highly random nature of the objective function to reach the peak while trying to avoid any local peaks. If the cost function is definite and rational, it is possible to find a closed form solution. But in general, the cost functions are highly non-linear in nature and require advanced numerical algorithms. Furthermore, the number of variables in a problem could range in tens if not hundreds, making any form of a simplified solution insensitive to the design parameters. The study of solution techniques for solving optimization problems is outside the interest of this paper. When discussing the case study examples, a brief explanation of the solution technique will be presented.

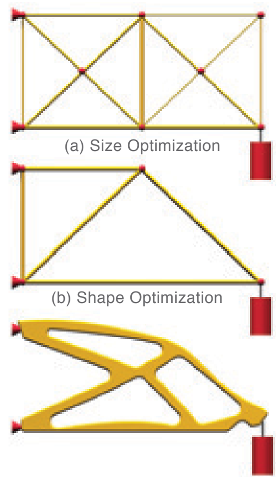


Figure 3: Types of structural optimization; (a) Size Optimization: tube diameter and wall thickness of the struts are the design variables, (b) Shape Optimization: the proper placement of the struts define the shape of the truss, (c) Topology Optimization: the optimum material placement constructs the optimal skeleton of the truss.

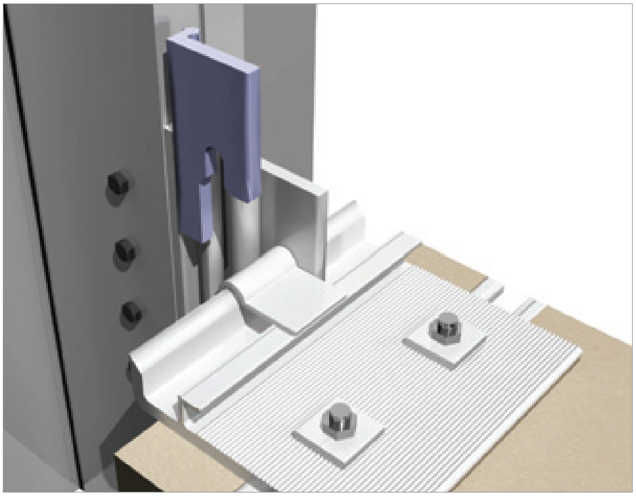


Figure 4: Typical unitized curtainwall anchorage assembly (left), and a custom anchor at the L.A. Live Conference Center in Los Angeles (right).

4 STRUCTURAL OPTIMIZATION

Structural optimization is the process involving the search for geometry to achieve the highest performance employing the least amount of material. In general the goal is to create the best design given a set of support conditions and applied loads. Prevailing literature classifies the structural optimization in three categories: *size*, *shape*, and *topology*. This categorization may be applied to the designs both at the component level (micro), or structural level (macro). This distinction is demonstrated in figures 2 and 3.

Size optimization assigns parametric data to a given geometry. In this process the overall shape and topology of the design remains constant while mollifying dimensional information. In the case of components, these could be profile thicknesses, depth and height. For structural optimization, the process usually entails the selection of the most efficient cross section from a table of allowable properties. Material properties such as strength and stiffness can also be some of the parameters being optimized.

The *shape optimization* approach aims to find the most efficient design by defining the boundary contour of the product or structure. The basic premise of the method is to represent the confines of the model with a series of curves, which can be changed to attain a superior distribution of forces. In the case of component design, size optimization could be treated as a subset of shape optimization. However, in practice, there are usually visual or functional constraints that predefine the overall profile, whereupon sizing becomes the predominant means of optimization.

Topology optimization is the progression of the previous methods into a general technique of structural optimization. This method is a process of laying material within a given space, which results in the most effective design. In component design, the outcome might be profiles with voids or hollows; in structural design, the result will be a demonstration of load paths through the model. This scheme is the most complex scenario to implement. However, it is the most robust with the most efficient solution.

Applying all or some of these techniques may optimize curtainwall systems. Different parts tend to match unique approaches for obtaining the right solution. For example, shapes using extrusion processes benefit more from shape optimization, and components made using casting or machining solid blocks tend to be better suited to topology optimiziation.

5 ANCHOR HOOK DESIGN: EX. 1

To demonstrate the utility of the optimization process, let's consider the example of a typical anchor system used to attach unitized curtainwall system to building floor, in particular the part that engages into mullions and hooks to the anchor assembly attached to the slab (see figure 4). This component transfers gravity loads as well as lateral horizontal loads to support structure while accommodating movements due to thermal effects, live loads, and in plane seismic and wind loads. This element is common to almost all unitized systems in a variety of configurations. The fabrication methods include machined aluminum extrusions, cast or forged aluminum or steel.

The objective of this optimization process is to design the most effective anchor system that minimizes the amount of the material used while maintaining full structural integrity and load transfer mechanisms of the element. To this end, a topology optimization technique known as Solid Isotropic Material with Penalization or SIMP is introduced here.

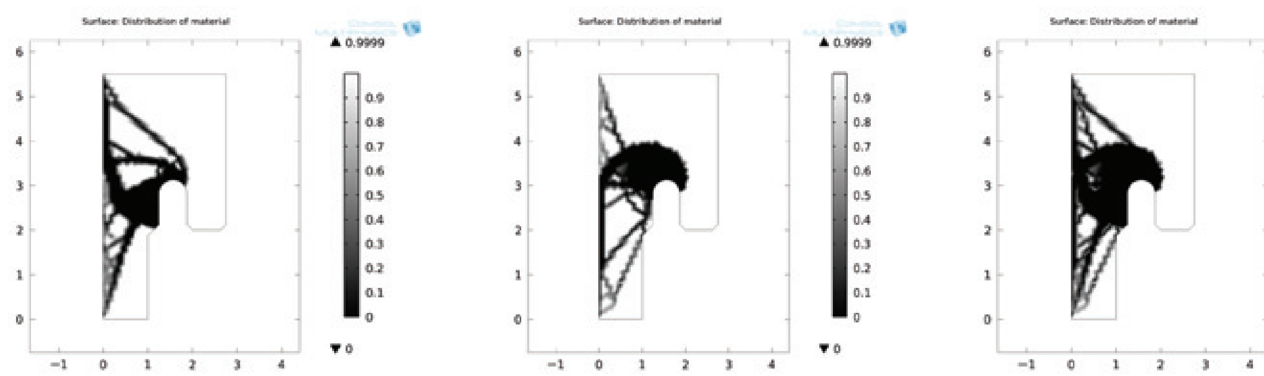
The basic premise of SIMP is to distribute material mass to achieve an efficient stress distribution within the part. One approach would be to assume that the perimeter of the component is to remain constant, while the thickness of material is varied to obtain the optimum topology.

Computationally this scenario can be implemented by defining the concept of "effective" modulus of elasticity, which is defined by the following relation:

$$E_e(x,y) = \rho^q(x,y) \cdot E$$

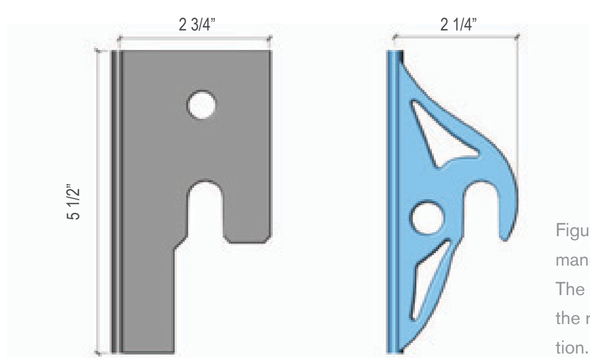
In this equation (E_e) is the effective spatial modulus of the elasticity, (ρ) is the distributed material density ranging between 0 and 1, and (q) is an integer constant greater than one (usually assigned a value of 3).

Substituting this equation into the formulation of minimizing strain energy principals,



Pressure Suction Superimposed

Figure 5: Results of SIMP mass distribution of typical anchors.



Design A Design B

Figure 6: Design A is the original anchor profile, manufactured by machining a longitudinal extrusion. The final product weighs 3.2 pounds. Design B is the revised shape using SIMP topology optimization. The part weighs 1.4 pounds, a reduction of 56 percent.

a non-linear finite element analysis can be formulated to be solved iteratively. The implementation details are discussed by Christensen and Klarbring [4] and Haung and Xie [5].

This methodology is applied to the anchor hook. Figure 5 depicts the mass distribution in a typical hook design for both negative and positive applied lateral loads combined with the gravity load. The mass density is then depicted in grayscale images, after which these images are combined graphically into a single image that can be used as a template for a new design (see figure 6).

The stress analysis of this new design is compared to the original element in figure 7. It can be seen from the results that the new design has a more efficient distribution of stresses while reducing the weight by 60 percent. Table 1 compares the statistical average and peak stresses of the two solutions, indicating a dramatic distinction between the two designs.

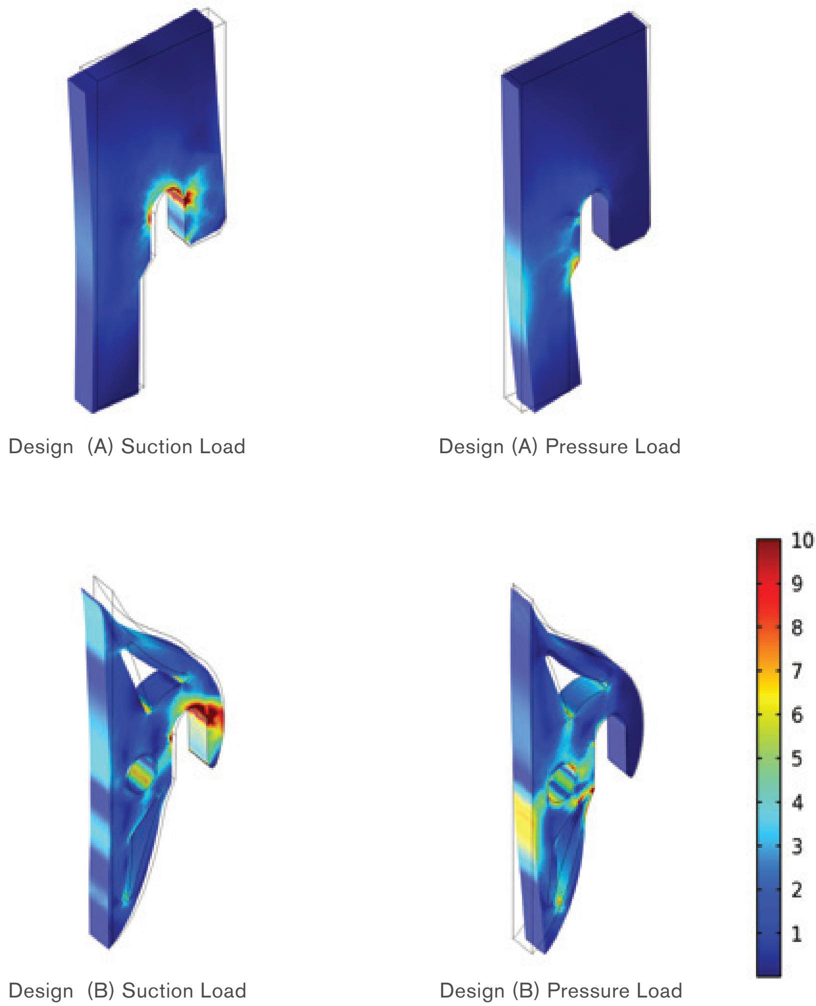


Figure 7: Finite element analysis of a typical anchor A, and the optimized version for pressure and suction loads. Von Mises stress distribution.

Loading Type	Evaluation Metric	Design A Weight = 3.2 lb	Design B Weight = 1.4 lb
Pressure (+)	$(s_{vm})_{max}/s_y$	0.36	0.67
	$\int_V s_{vm}\, dv$	328 ft-lb	361 ft-lb
Suction (-)	$(s_{vm})_{max}/s_y$	1.09	0.68
	$\int_V s_{vm}\, dv$	472 ft-lb	438 ft-lb

Table 1: Comparison of average and maximum stresses between a standard anchor (Design A) and the optimized version (Design B) for pressure and suction wind loads.

6 VERTICAL MULLION DESIGN: EX. 2

Consider a vertical aluminum mullion of a typical span, where the target cross-sectional profile is to follow an outside shape as depicted in figure 8. It is the objective of the optimization process to achieve the highest capacity with lowest material weight (smallest cross-sectional area). We can define the efficiency index as the load carrying capacity of the mullion per unit length divided by its weight per unit length. This index is defined as our cost function to be minimized. The optimum design is considered to be a function of two primary state variables, center span deflection ($\delta < L/175$); and the maximum allowable stress in the compression fiber of the cross section (F_c). The design variables are the various wall thicknesses of the extrusions, which define section properties such as moment of inertia, section modulus and torsional constants. The constraints are defined by the following equations:

$$\delta = \frac{5wL^4}{384EI_{xx}}$$

$$\delta = h(I_{xx}^{-1})$$

$$\alpha = \frac{L(I_{xx}/d_c)}{C_b\sqrt{I_{yy}J/2}}$$

$$F_c = \begin{cases} \dfrac{F_{cy}}{n_y} & \alpha \le S_1 \\ \dfrac{1}{n_y}\left(B_c - 1.6D_c\sqrt{\alpha}\right) & S_1 < \alpha < S_2 \\ \dfrac{\pi^2 E}{2.56 n_y \alpha} & S_2 \le \alpha \end{cases}$$

The detailed description of the various variables defined in the above equations is available in the Aluminum Design Manual [1]. The answer to this optimization problem is obtained using an evolutionary solution technique, common to problems with multiple variables and relatively simple cost evaluation schemas. Evolutionary algorithms perform well in approximating solutions to a variety of optimization problems when there

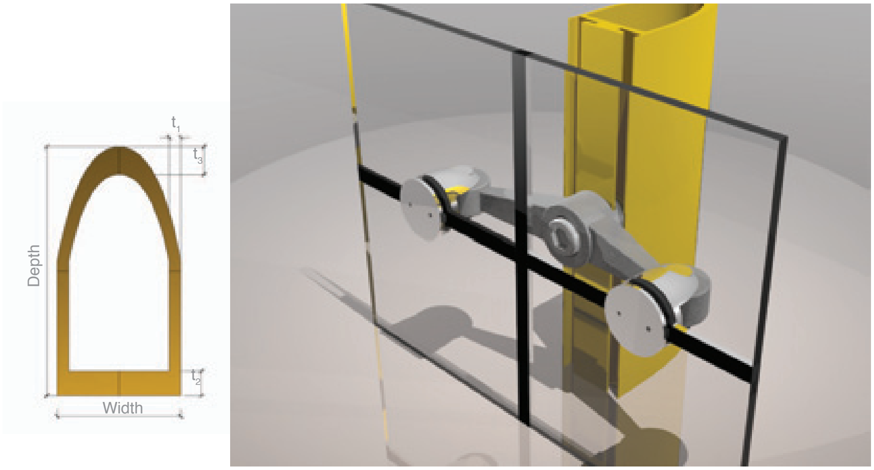


Figure 8: Shaped vertical mullion system and its parametric description.

Capacity (plf)	250	200	150
Depth (in)	6	6	6
Width (in)	3	3	3
t_1 (in)	1/8	3/16	1/8
t_2 (in)	7/32	1/4	5/32
t_3 (in)	1/2	9/32	1/8
Wt (plf)	3.48	2.66	2.33
Efficiency Index	73	77	62

Table 2: Cross section dimensions and mullion properties for optimized profiles, for different applied loads.

Parameter	Design (A)	Design (B)
d_0 (in)	6.00	6.00
d_1 (in)	1.19	1.00
d_2 (in)	0.75	1.44
w_1 (in)	2.00	1.50
t_1 (in)	1/8	3/16
t_2 (in)	1/8	3/32
t_3 (in)	1/8	1/16
t_4 (in)	1/8	7/32
t_5 (in)	1/8	3/32
t_6 (in)	1/8	1/4
Area (in^2)	1.81	1.49
I_{xx} (in^4)	6.95	6.97
I_{yy} (in^4)	0.97	0.42
J (in^4)	0.40	1.56
S_C (in^3)	1.87	1.85
w_d (plf)	123.6	123.6
w_f (plf)	166.8	152.4
Efficiency Index	58	70

Table 3: Cross section dimensions of split vertical mullion and efficiency index for Standard design A and an optimized version B.

Figure 9 (opposite): Typical split vertical mullion (blue). From left to right: actual mullion; parametric description; original design; optimized design.

are weak postulations of underlying fitness of design variables, and the solution can converge into multiple possibilities that can be manually redirected. Apart from their use as mathematical optimizers, evolutionary computation and algorithms have also been used as an experimental framework within which to validate theories in biological evolution and natural selection. The mathematics of this solution technique is beyond the scope of this paper; however, there are numerous publications exploring the fundamentals and the implementation techniques of the concept.

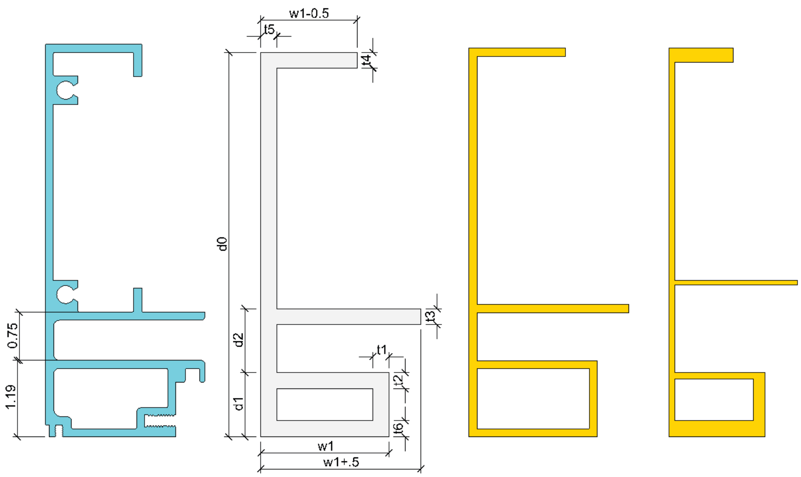
Table 2 shows the results for three different applied load conditions, and the corresponding optimized parameters. The wall thicknesses are constrained to remain within a 1/8" – 1/4" dimension, with a resolution of 1/32". It is interesting to note than that the efficiency index is reduced for the lower applied loads (150 pounds per linear feet). This indicated that the sensitivity of the design parameters are reduced at this load level. To gain a more efficient solution we need to consider adding additional design variables such as profile depth and width.

A similar process is applied to a split mullion of a unitized curtain wall system. Figure 9 shows the split mullion and a simplified model with a selection of design variables. The state variables are again the mid span deflection limitation (span divided by 175) and maximum allowable stress in the mullion. Table 3 presents the properties of the original designs as they compare to the optimized system. As expected, the optimization process moved mass away from the center of the mullion and placed it in the extreme fibers. The resulting design attained a 21 percent increase in the efficiency index of the cross section while maintaining the utility of the extrusion.

A more general consideration would be to include the depth and the width of the profile in the design variable set, or further including entire unit information such as horizontal and stack mullion parameters as well. Moreover, the cost function can be augmented to include parameters such as fabrication and finishing costs in addition to the efficiency index.

7 SUMMARY

In this report the concept of structural optimization was explored and its relevance to façade designs were examined. The potential value of the concept was demonstrated through descriptive examples. The next step in development of this topic is to create simplified algorithms that can be easily incorporated into the course of day-to-day designs. This streamlining approach should remove complex and cumbersome technical obstacles from creating efficient, economical and elegant designs.



Original Design | Design variables | Design (A) (Wt = 2.14 plf) | Design (B) (Wt = 1.76 plf)

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Sealed Cavity Walls

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DOUBLE-SKIN FACADE SYSTEMS

The advent of the double-skin facade (DSF) has provided several advantages over conventional single-skin designs. The second facade layer and intermediate space created by its introduction provide additional possibilities for the control of physical interactions that occur between the maintained conditions of the building interior and the uncontrolled external environment. By increasing reflection and dampening of external noise, double-facade configurations provide greater sound attenuation of problematic urban sources. Configurations can also be implemented for cooling climates, where the intermediate space serves as a conduit by delivering natural ventilation to cool upper building levels at which high wind prevents effective implementation of operable venting. In heating climates temperature driven heat-loss is reduced by the insulating action of the intermediate space. Heating climate systems can be further enhanced by integration with mechanical systems to achieve heat recovery of HVAC system exhaust air. In addition, shading systems that would typically be vulnerable to external conditions can be housed in the intermediate space.

In order to achieve the aforementioned benefits in cold weather climates, the management of humidity becomes a paramount design consideration due to the fact that the temperature of air contained within or flowing through the intermediate space can deviate appreciably from the controlled set point of the building interior. For each application the unique combination of fluid dynamics, heat-transfer and water vapor transport (mass-transfer) must be appropriately assessed, typically involving more rigorous analysis and testing for validation of performance than conventional single wall systems.

Figure 1: Testing for a compartmentalized wall system.

COMPARTMENTALIZED DESIGN

The focus of this article is to discuss systems which may be implemented to mitigate the potential for condensation in a specific, "compartmentalized," or *box-window*, double-skin facade application. Compartmentalized systems are easily realized as unitized systems where single framed vision areas contain both inboard and outboard glazing, as seen in figure 1. In this configuration there is no uncontrolled communication of the intermediate space between framed units.

CONDENSATION OF WATER AND DEPOSITION OF FROST FROM HUMID AIR

At a surface of liquid water, the rates of evaporation and condensation have a net effect of producing a vapor pressure over the surface. Similarly, ice also exerts a vapor pressure owing to the rates of sublimation and deposition. With sufficient time, and under conditions of uniform temperature, equilibrium of these rates is achieved and the vapor immediately above the surface is said to be "saturated". The thermodynamic quantity prescribed to represent this condition is the saturation pressure of water vapor (p_{ws}) (Eqs.1 & 2) and any subsequent increase or decrease in temperature will respectively result in net evaporation or net condensation until a new saturated pressure is obtained. Equations 1 & 2 (Hyland & Wexler 1983b) provide a correlation for determining the saturation pressure as a function of temperature over a surface of water or ice.

Air removed from a source of water also commonly includes a component of water vapor proportional to its fraction in mass of the total gas constituents which comprise air. Such air is said to be humid with a partial pressure of water vapor (p_w) that varies proportionally with the temperature and pressure of air. Condensation of dew or deposition of frost will occur on a surface under the condition that air immediately exposed to that surface achieves a partial pressure equal to the saturation pressure at that location, and subsequently, it is convenient to express the quotient of the partial and saturation pressure of water vapor as the relative humidity φ (Eq. 3).

In observation of these quantities, as they apply to the design of exterior wall systems, several simplifications become apparent. The range of air pressures encountered as internal and external environmental conditions are of the range of temperature and pressure that the ideal gas relation (Eq. 4) provides a suitable equation of state to determine partial pressures. Furthermore, fluctuations in pressure are sufficiently small to have an unsubstantial effect on partial pressures. Over the range of temperatures observed the saturation pressure exhibits a much stronger dependence on temperature than the partial pressure such that decreasing temperature acts to increase the relative humidity of an air mass from its initial state towards unity at which point a change of phase is initiated. In light of this observation, the goal of analysis is typically to determine the lower temperature that this condition is achieved. The dew point t_{dp} (Eq. 5) and frost point t_{fp} (Eq. 6) correspond to the respective temperatures of condensation and deposition. Equations 4 and 5 (Peppers 1988) may be employed to determine the quantities for a range of temperatures typical to architectural design.

Inspection of equation 3 provides two independent variables that can be utilized to condition the relative humidity of air within

Equation 1

$$LN(p_{ws}) = \frac{C_8}{T} + C_9 + C_{10}T + C_{11}T^2 + C_{12}T^3 + C_{13}LN(T)$$

Equation 2

$$LN(p_{ws}) = \frac{C_1}{T} + C_2 + C_3T + C_4T^2 + C_5T^3 + C_6T^4 + C_7LN(T)$$

Equation 3

$$\varphi = \left.\frac{p_w}{p_{ws}}\right|_{p,T}$$

Equation 4

$$p = \rho RT$$

Equation 5

$$t_{dp} = C_{14} + C_{15}Ln(p_w) + C_{16}Ln(p_w)^2 + C_{17}Ln(p_w)^3 + C_{18}(p_w)^{0.1984}$$

Equation 6

$$t_{fp} = 90.12 + 26.142Ln(p_w) + 0.8927Ln(p_w)^2$$

a building. The mass fraction air attributed to water vapor is proportional to p_w implying that the concentration of water vapor is one such variable. A second variable is provided by the dependency of the water-vapor partial pressure on temperature.

Subsequently, systems which mitigate condensation of water or deposition of frost on internal surfaces of building enclosure systems must effectively control the humidity or temperature of air that is exposed to interior surfaces. For the purpose of discussion, these strategies will be addressed broadly as passive or active systems.

When considering the compartmentalized double-facade it becomes apparent that some humidity and temperature control strategies will not be effective. Channeling and delivering air flow from existing HVAC facilities to the cavity of each individual unit for the purpose of maintaining temperature or lowering humidity will likely exceed the acceptable cost to achieve the added benefits of the design versus a conventional single-facade system. Local treatments, such as the use of electric fans or desiccant require periodic maintenance or may be technically difficult to achieve. Historically, the use of pressurization or external ventilation has been successfully implemented. For instance, the enclosure system developed by for the Bibliotheque Nationale de France (Dominique Perrault Architecture, 1994) utilizes a combination of pressurized and passive systems to maintain the multi-story unitized compartmentalized double-facade. High-rise systems feature a distribution network to provide dried air to each cavity from a central pressure source. Ground level systems are passively ventilated to the building exterior, but remain accessible for periodic cleaning of contaminants.

DESIGN OF PASSIVE SYSTEMS

Passive systems operate on the principle that the ambient external temperature is both greater than the ambient dew or frost point temperature and less than that of the cavity. As a consequence, the cavity humidity achieves equilibrium with the external water vapor pressure by either diffusion or convection from the ambient. Since the saturation pressure is greater corresponding to the warmer cavity condition, relative humidity is diminished from the external ambient preventing the formation of water or frost on internal surfaces.

The major benefit of passive systems is cost effective implementation; however, designers should be aware of some inherent limitations to the technique. If rapid fluctuations in external temperature and humidity from proceeding storms or changes in weather occur more quickly than conditions within the cavity can equilibrate, it is possible for the cavity temperature to be lower than that of the ambient – thus presenting a condensation potential. In addition, external pollution or contaminants may be introduced by orifices used for ventilation. Large openings should feature filters to prevent contamination and to provide access to the intermediate space for cleaning. Passive systems should not be applied where periodic cleaning is difficult.

DESIGN OF ACTIVE SYSTEMS

While pressurized active systems differ in operation from passive systems, both are comprised of a common set of components. A source of pressurized air is typically supplied by a pressure vessel, but may also be provided by motorized blowers. Distribution of air flow and communication of the pressurized air source to each double-facade cavity is most commonly achieved with polymer conduit hoses. A controlled orifice for relief prevents the possibility of excessive cavity pressure and establishes the system's operating point with regard to volumetric flow rate and pressure. The assembly of these components is depicted schematically in figure 2.

The primary source of variation that affects operation of the components discussed is the size of the orifice that establishes the operating point of the system. A small orifice will exhibit a large pressure loss coefficient and subsequently will result in a cavity pressure that is close to that of the supply with minimal mass flow through the cavity. A large orifice will inversely result in a cavity pressure that is close to the external surroundings with a high rate of air flow through the cavity. Throughout the remaining discussion the former mode of operation will be referred to as

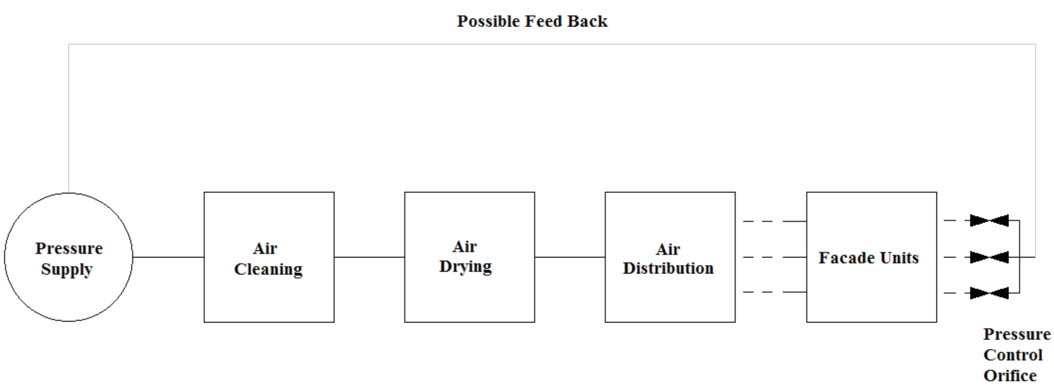


Figure 2: Schematic of Components

TEMPERATURE CONTROL STRATEGIES

Passive:

- Polymeric thermal breaks or discontinuous features in metal framing.
- Integration or replacement of metal components with fiberglass, vinyl, wood or other materials exhibiting low thermal conductivity.
- Placement of loose-fill or rigid thermal insulation.
- Insulated glazing and glass coatings.
- Paints and surface treatments that affect radiation heat transfer.

Active:

- Heating of air or increased convection by mechanical integration of facade elements with HVAC systems or local equipment.

HUMIDITY CONTROL STRATEGIES

Passive:

- Passive ventilation of voids and internal spaces to external ambient humidity.
- Placement of vapor and weather barriers.
- Application of desiccant materials.

Active:

- Maintenance of HVAC system set-points at specified humidity and perimeter zoning.
- Active displacement of humid air with dried air from a controlled source.

(continued)

pressurized and the latter will be referred to as *displacement*. It is important to note that pressurized and air displacement strategies are not distinct modes of operation, and in fact are the extremes of a spectrum of possible operating modes. Figure 3 illustrates these potential modes of operation.

In practice, actual DSF systems have multiple openings introduced by imperfections in manufacture in addition to the control orifice; gaps in gaskets used to seal the glazing, and voids at the interface of framing members. Some common sealants, such as structural silicone, are permeable to water vapor over time. From these avenues water vapor may be introduced to the cavity space by diffusion from the ambient. Unabated, this diffusion would achieve an intermediate cavity humidity that is characteristic of the building exterior and interior, in addition to the openings present.

PRESSURIZED SYSTEMS

The pressurized system relies on the pressure difference of the cavity and ambient to produce an outflow at openings with sufficient flow rate where the advection of dried air from the cavity has a stronger effect on water vapor transport than the opposing action of water vapor diffusion that occurs in accordance with the increasing gradient of vapor pressure in the flow direction. In order to produce a quantitative assessment of this behavior, it is appropriate to observe the Peclet number *Pe* (Eq. 7), the product of the dimensionless Reynolds and Schmidt quantities, that correlates to the ratio of advection to diffusion of water vapor.

Equation 7

$$Pe = Re * Sc = \frac{\rho U D}{\mu} \frac{\mu}{\rho \mathfrak{D}} = \frac{UD}{\mathfrak{D}}$$

With increasing *Pe,* diffusion of water vapor becomes less significant than advection.

While specific knowledge of external humidity, opening geometry, and system operating point are required to correlate internal conditions to *Pe,* it can be stated in general that increasing the opening size at fixed cavity pressure increases *Pe* due to the fact that air flow velocity and opening diameter are proportional to *Pe*. All other quantities, with the exception of the binary diffusion coefficient that exhibits a mild dependency on temperature, are fixed by the properties of air. For the purpose of illustration figure 4 portrays air flow through a circular orifice between two zones of differing water vapor concentration with $Pe = 144$. The color contour diagram indicates the variation of concentration and the overlaid stream lines show the path of fluid motion. In this scenario, which corresponds to a mean air flow velocity across the orifice diameter of X, diffusion is inadequate to produce any upstream presence of humid air within the cavity.

DISPLACEMENT SYSTEMS

The displacement system gains its effectiveness from the process of mixing humid air that enters the cavity with dry air and displacing it. Even in the absence of a positive pressure difference between the facade cavity and ambient, or even with a negative pressure difference, sufficient advection of dry air will mix with potential inflows of humid air to maintain greater than dew point conditions within the cavity. In this mode of operation, the rate with which the concentration of any inflow diminishes is of significant interest. Zones of recirculation or stagnation within the cavity rely greatly or solely upon diffusion to facilitate mixing, and may be susceptible to local condensation near openings. Even in the case where advection is significant it is highly improbable that air flows within the cavity will be uniform. Due to these facts, the variation of water vapor concentration and air flow within the cavity must be determined either experimentally or by computer analysis.

PRACTICAL CONSIDERATIONS

The primary practical consideration which motivates the use of one mode over the other is the ability to seal the cavity space. If the design is sufficiently simple and manufacturing can minimize uncontrolled openings, the pressurized facade will benefit from the minimal flow rate required to maintain dry conditions within the cavity space, and subsequently both desiccant usage and fluid moving requirements are minimized. For more complicated scenarios, air displacement systems may prove to be more reliable, but at a cost of increased air flow from leakage introduced by manufacturing defects. This will be small in comparison to orifices purposely introduced.

A practical consideration which also warrants attention is the design of open versus closed loop systems. In a closed loop system, the air is returned from the control orifice to a zone of controlled pressure or possibly the pressure supply. In this scenario dry air can be conserved and the inlet and outlet pressures may be controlled independently of local pressure at the control orifice opening. Fluctuations in ambient conditions may also have less effect on operation in this mode. Implementing such a solution requires additional equipment and the cost of that equipment must be considered in design.

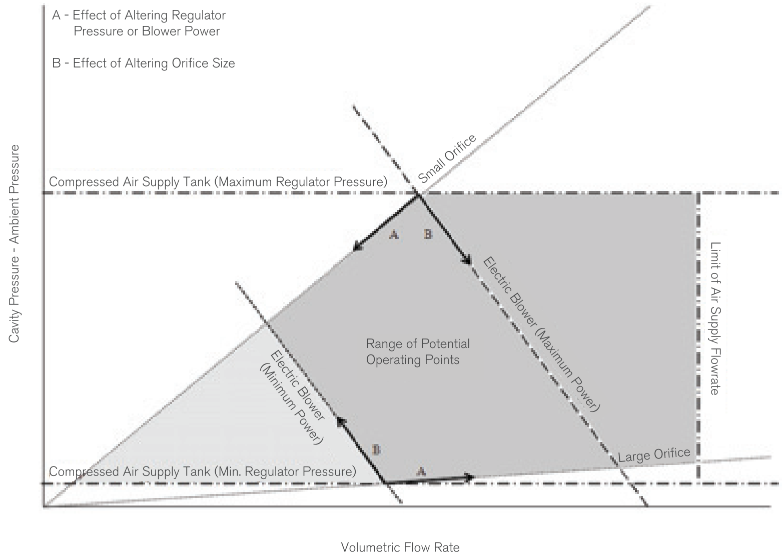


Figure 3: Potential Range of Operation

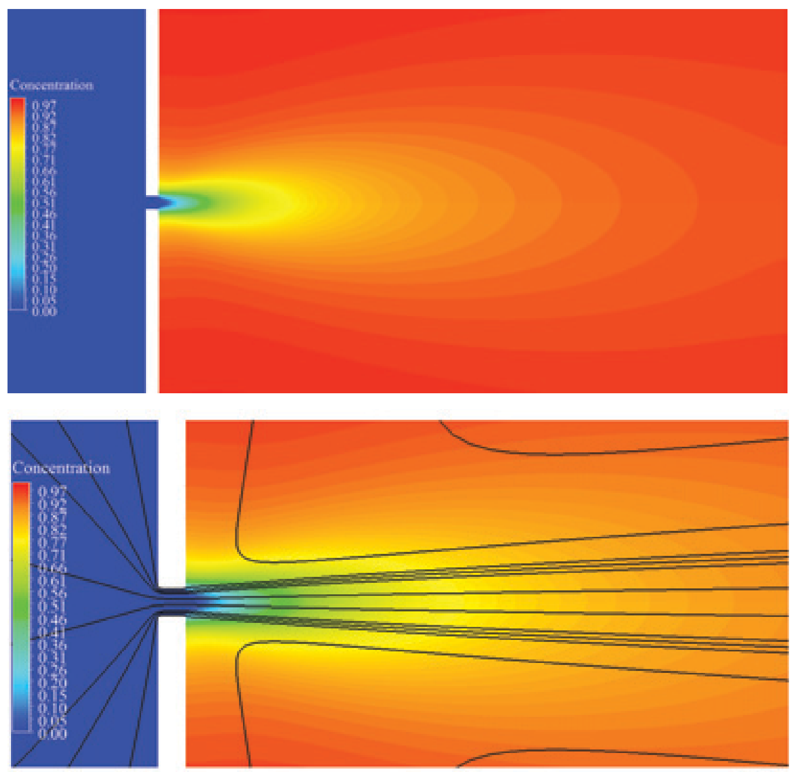


Figure 4: Contour Distribution of Water Vapor Concentration and Air Flow Stream Lines.

CASE STUDY

In order to access the performance of a typical compartmentalized DSF to resist condensation, the following discussion of conducted tests will provide some insight to typical sizes and conditions observed in actual systems. The appartus used is explained in figures 5-7.

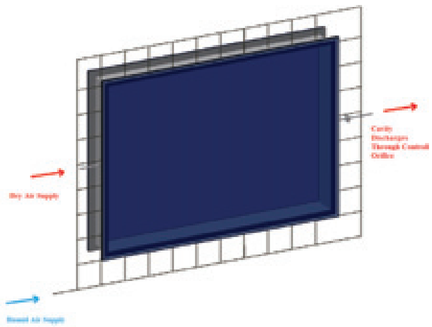


Figure 5
The specific system evaluated is rectangular prismatic, has an aspect ratio of height versus depth of 7.2 and width versus depth of 9.9. Infiltration of humid air at saturation corresponding to ambient temperature and dry air are introduced by separate fluid flow circuits as indicated above. The inner and outer lights are typical 1" insulated glazing units held by an aluminum frame.

Figure 6
This configuration simulates a worst case scenario for an open system operating in the air displacement mode, with positive external pressure such that the mixing rate of humid air infiltration and dry air controls the cavity condition. Since relative humidity and saturation pressure are strong functions of temperature, the outer surface of the glazing is cooled in some tests to produce a temperature field that corresponds to winter conditions. The actual test piece and cold chamber utilized to produce this effect is depicted to the right.

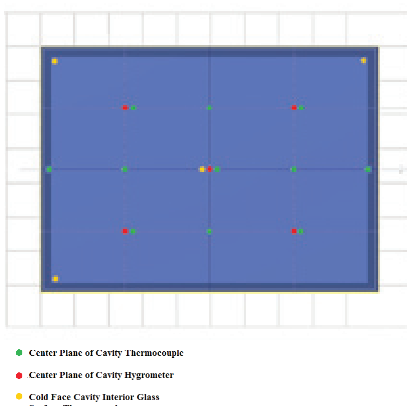


Figure 7
Cavity conditions are monitored by an array of thermocouple temperature sensors and hygrometers suspended within the cavity by thin nylon wire. Interior surface of glass temperatures were also monitored by thermocouples.

COLD CHAMBER TESTING

The cold chamber test simulates a winter temperature environment and provides the most accurate representation of actual conditions. Gradients in vapor pressure associated with temperature may affect diffusion of water vapor. Natural convection currents will also affect advection and actual condensation or frost deposition that can be observed at the limit of performance.

In order to assure an initially dry state the cavity was purged of humid air by the dry supply at a high flow rate until the hygrometer used indicated a condition of dry air. The cold chamber was allowed to equilibrate for several hours until steady state heat transfer was achieved.

The test is initiated by reducing the dry air flow rate to a value typical of operation and increasing the saturated humid air flow rate to a value characteristic of infiltration that may be expected to occur under worst case conditions. After sufficient time, conditions within the cavity equilibrate and variation in humidity and temperature are observed. The dry air flow rate can then be reduced until a new steady condition is observed and the minimum required flow rate is determined.

WARM CHAMBER TESTING

It is also possible to assess cavity conditions with a warm chamber test. Warm chamber tests neglect the aforementioned effects of temperature on water vapor transport, but may be employed for longer periods than would be practical for cold chamber testing. In this test the reduction in cavity water vapor pressure can be determined for various combinations of saturated infiltration and dry air flow rates.

COLD CHAMBER RESULTS

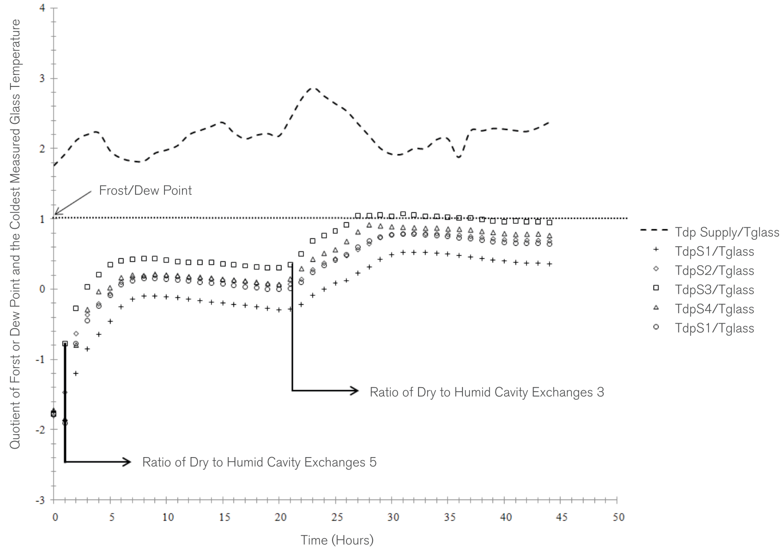
Figure 8 depicts the results of cold chamber testing at two flow rates. At each hygrometer the quotient of the measured frost point temperature and coldest measured cavity-interior glass surface temperature on the cooled glazing are plotted against time. The quotient corresponding to the humid air supply is also measured. Fluctuations are associated with the warm ambient temperature, which varied daily to some extent. Under the conditions in which the glass achieved the frost point, some deposition was observed and is indicated in figure 9.

WARM CHAMBER RESULTS

Warm chamber tests were conducted to evaluate the effect of daily variations in ambient temperature on the performance of the system. Figure 10 displays the balance of flow rates required to maintain a relative humidity and temperature within the cavity at conditions typical of most office buildings and residences. The mode of operation and test facilities are similar to those of the cold chamber tests, but absent of the refrigeration unit.

CONCLUSION

Strategies for condensation management in compartmentalized double-skin facade cavities have been discussed with attention paid to the physics of condensation, both passive and active control strategies, and testing to evaluate the performance of systems. The best application for any specific system ultimately depends upon a multitude of factors, including access to the double facade cavity, the ability to seal the facade space, and the severity of exterior conditions. In any scenario, analysis and testing are appropriate to determine parameters of operation, and facade contractors throughout the United States will increasingly be asked to put forth an effort to adopt the sophisticated analysis and testing capabilities required by this emerging architectural trend. Enclos is committed to addressing the needs of our contractor and architectural clients by developing innovative strategies for condensation management in double-facade systems so that their benefits may be realized independent of winter conditions inherent to the project.



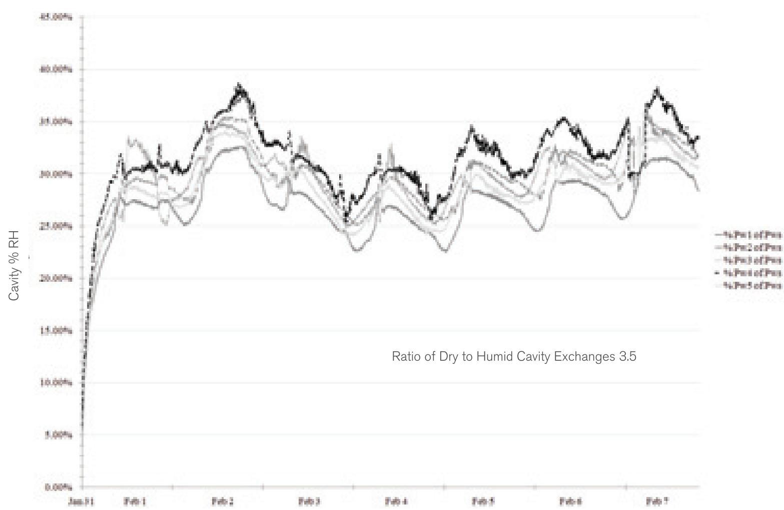


Figure 8 (top): Cold chamber test quotient of dew point and glass temperature at various flow rates of dry and humid air versus time.

Figure 9: Frost on glazing.

Figure 10 (bottom): Warm cavity test humidity versus time.

Enclos contributed materials and curtainwall units for the blast testing of Momentive's two-part structural elastomeric adhesive/sealant product "UltraGlaze SSG4600".

Blast Performance of Structural Glazing

James Casper, PE, SE
TJ DeGanyar, Ph.D., PE

Original paper and presentation for the Glass Performance Days 2011 international conference in Finland.

Typical analysis procedures for blast resistant glazed framing members fall into two categories, finite element multiple degree of freedom analysis and single degree of freedom (SDOF) analysis. Finite element analysis is not always economically feasible, and simple SDOF analysis results in unnecessarily conservative sections that may not be able to meet the architect's design intent. Conservatively sized sections have the additional detriment of increasing the load to structure, due to the "glass fails first" methodology required on a vast majority of projects. Significant gains/savings can be achieved by sequentially performing a SDOF analysis of each system element, starting with the glazing. Each successive element is then loaded with the response of the previous element, until the load is resolved into the structure.

INTRODUCTION

Events of the past decade have made blast resistant structures and blast resistant curtainwall a serious consideration for projects that in the past would have balked at the cost or aesthetic impact resulting from hardening the structure. Typical curtainwall analysis usually consists of segmenting the system into floor to floor spans and performing a single degree of freedom analysis. SDOF analysis can be done quickly, but is quite conservative. Conservative analysis in turn results in a large and costly cross section, and due to the glass fails first methodology, increases the load to structure. The other end of the spectrum is hydrocode analysis and finite element analysis. These analysis techniques can be quite precise, but are costly due to the time required to construct and analyze the models. In additional to being time intensive, specialized modeling software and modeling expertise are needed to get precise results. Sequential single degree of freedom (SSDOF) analysis offers a compromise. SSDOF analysis utilizes a series of SDOF analysis to predict the response of the system as a whole. SSDOF analysis provides less conservative analysis for a modest increase in time, allowing the structure to be hardened more economically and provide more options architecturally. Below we will discuss SSDOF methodology, its advantages, limitations, and comparison with SDOF analysis results.

SEQUENTIAL SINGLE DEGREE OF FREEDOM (SSDOF) ANALYSIS METHODOLOGY

SSDOF analysis decouples each component of the curtainwall system and analyses each component separately, but recognizes each component is a part of larger system. Each component is loaded by the response of the component immediately preceding it on the load path. The series of decoupled analyses for curtainwall begins with the prescribed overpressure and impulse being applied to the glazing. Specifications typically require specific government developed glass analysis software program to be used to analyze the glazing. These programs produce a glazing perimeter load functions that then may be used to load a beam model of the curtainwall system. The response function of the curtainwall system is then used as the load function to the curtainwall anchor. Finally, the curtainwall anchor response is used as a load function for resolving the loads to the building structure.

SEQUENTIAL SINGLE DEGREE OF FREEDOM (SSDOF) ADVANTAGES

The first and largest benefit to using SSDOF analysis is the use of existing experimentally validated glazing analysis software. Significant performance gains can be realized by taking advantage of the glazing's ability to dissipate energy due to glass breaking and how the glazing response changes the shape of the load function to the curtainwall framing system.

In addition to reducing the amount of energy impinging the curtainwall framing, the load function shape differs from the typical idealized linearly decaying load function that impinges the glazing. The glazing response loads the curtainwall with a lower peak and longer duration, resulting in a less impulsive

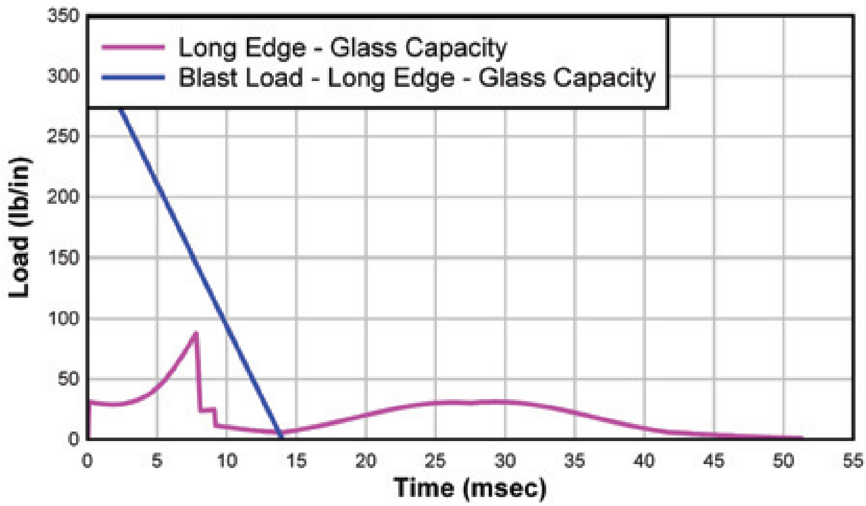


Figure 1: Pressure Tributary Load Function and Glazing Response Load Function

Figure 1 illustrates the differences between a pressure and tributary loading and the loading results of glazing analysis software. Linear decaying pressure and tributary loading (blue line) has a higher magnitude and much shorter duration. This results in a highly impulsive load. Glazing analysis software results (magenta line) incorporate glass breakage and flexibility of the glazing. The glazing response load function illustrates the breakage of the outer and inner lite of an insulated glass unit with only the membrane providing final load resistance. The peaks of the load function are followed immediately by sharp drop offs, which represent the glass breaking. Load applied to the curtainwall frame after the inner lite has fractured is provided by the inboard lite's interlayer. Conservation of mass and energy principles dictate that the drop offs represent energy and momentum being dissipated, therefore requiring the curtainwall system to store or dissipate less energy.

load (see figure 2). Due to curtainwall's low mass, reducing the impulse and increasing the load duration allows the curtainwall system to mobilize the mass and stiffness to resist the load.

Limited gains can be found in using SSDOF over SDOF for the curtainwall framing system. SDOF already includes the strain energy dissipated due to the formation of plastic hinges. A source of performance gains for the curtainwall framing system is using a high strain rate stress strain curve in lieu of using load and mass approximation [1]. A high strain rate stress strain curve is used to allow elements to behave according to the strain induced rather than assuming an elastic or plastic behavior. A series of model comparisons using load mass factors and stress strain curves were ran. Models using a stress strain curve returned a 4.7% decrease in maximum deflections.

Curtainwall anchors are much stiffer than other curtainwall components and frequently required to behave elastically when subjected to the full capacity of the framing system. With these restrictions, anchors contribute minimal gains and may be assumed to be a rigid member transferring load directly to the structure without alteration. SSDOF analysis returns similar results as a SDOF analysis.

SEQUENTIAL SINGLE DEGREE OF FREEDOM (SSDOF) LIMITATIONS

SSDOF analysis loses fidelity due to the decoupled nature of the analysis. Each decoupling replaces the flexibility of the sup-

Sequential single degree of freedom analysis provides **less conservative analysis** for a modest increase in time, allowing the structure to be hardened more economically and **provide more options architecturally**.

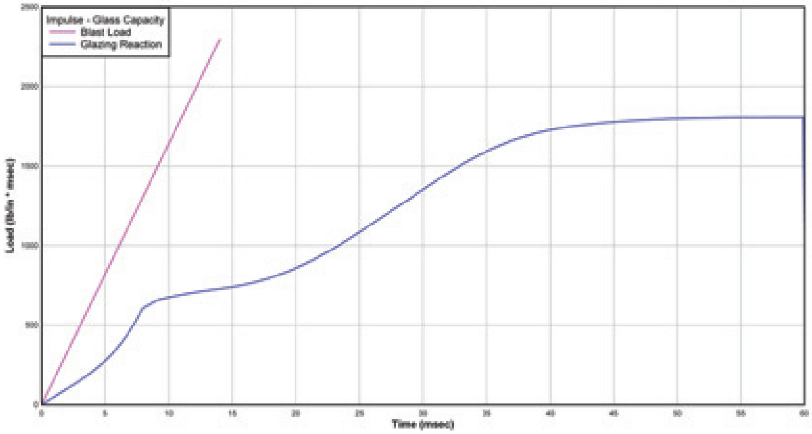
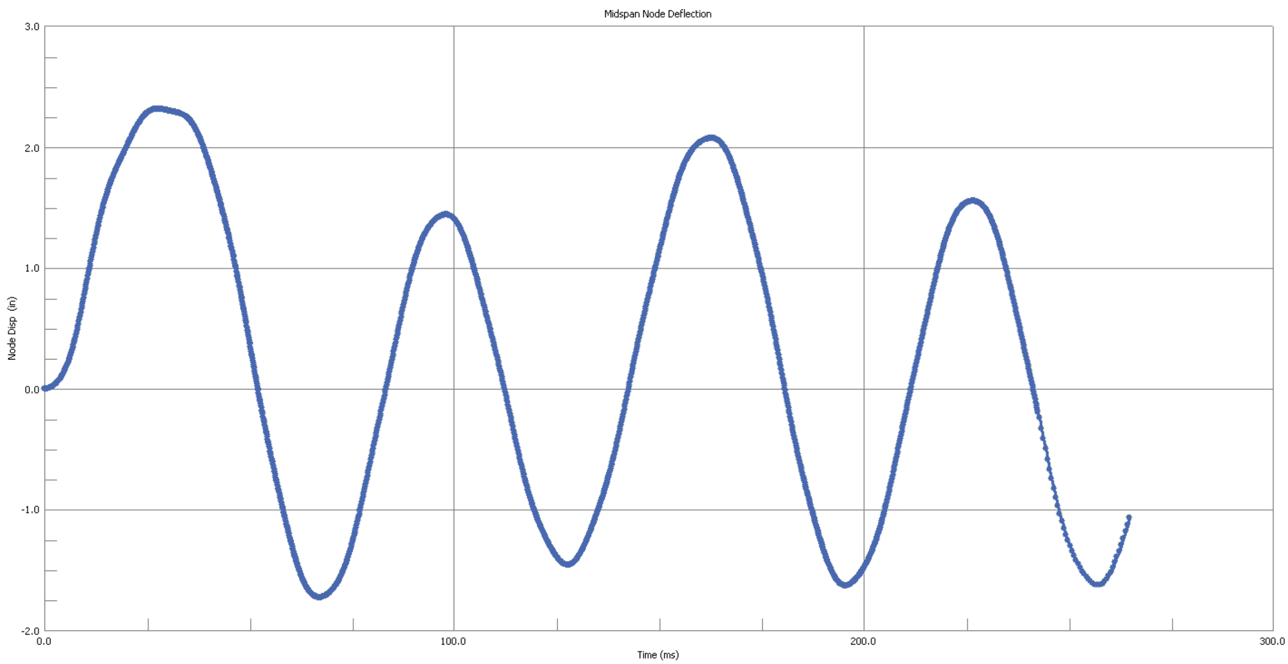


Figure 2: Impulse Comparison - Glazing Response Capacity (blue) and Blast Pressure (magenta)



SINGLE DEGREE OF FREEDOM MULLION RESPONSE		
Ductility	Support Rotation (degrees)	Maximum Displacement (in)
2.669	5.29	5.56

SEQUENTIAL SDOF		
Ductility	Support Rotation (degrees)	Maximum Displacement (in)
1.14	2.26	2.33

Figure 3: Mid-span Results – SSDOF and SDOF

porting elements with a rigid simple support. Removing the flexibility alters how the components and system behave. This change in behavior can be an issue when the negative phase of a blast load coincides with the rebound response of the curtainwall system. This results in a larger rebound response than provided by either SSDOF or SDOF. This is seldom an issue for typically specified blast loads and common curtainwall system geometries. The constructive rebound response is typically an issue with a punched window system, where the natural frequency of the system is closer to overpressure blast duration.

COMPARISON

Figure 3 illustrates how the mid-span deflection of a representative mullion varies with time using SSDOF analysis. The maximum SSDOF deflection calculated is 2.33 inches.

	Ultimate Resistance (lbf)	Sequential SDOF 9lbf)
Reaction	5169	4020

Figure 4: Load to Anchor – SSDOF and Ultimate Resistance

Per SDOF analysis, based upon the methodology outlined in industry standards references [1] and [2], the mid-span deflection is 5.56 inches. SSDOF maximum deflection is 53% less than the SDOF maximum deflection.

Reactions for SDOF [2] and maximum reactions for SSDOF, shown in figure 4, indicate the reaction of SSDOF is 1149 lbf less than the typically required mullion flexural capacity. The difference reflects a missed 28% potential savings in loads to anchor.

CONCLUSION

Sequential single degree of freedom analysis utilizes the energy dissipating and actual strain properties of the major curtainwall components to provide a less conservative analysis of the performance of a curtainwall system. The obvious implication is the specified level of blast resistance may be realized using a lighter and smaller framing cross section, thereby helping to reduce the cost of hardening and providing more freedom to meet the design intent.

REFERENCES

[1] Task Committee on Blast Resistant Design of the Petrochemical Committee of the Energy Division of the American Society of Civil Engineers, 2010, *Design of Blast-Resistant Building in Petrochemical Facilities.* 2nd Ed., American Society of Civil Engineers. Reston, VA., pp 87-88

[2] Mays, G C and Smith P D (eds), 2001, *Blast Effects on Buildings*, Thomas Telford Publications, London, pp.102-105

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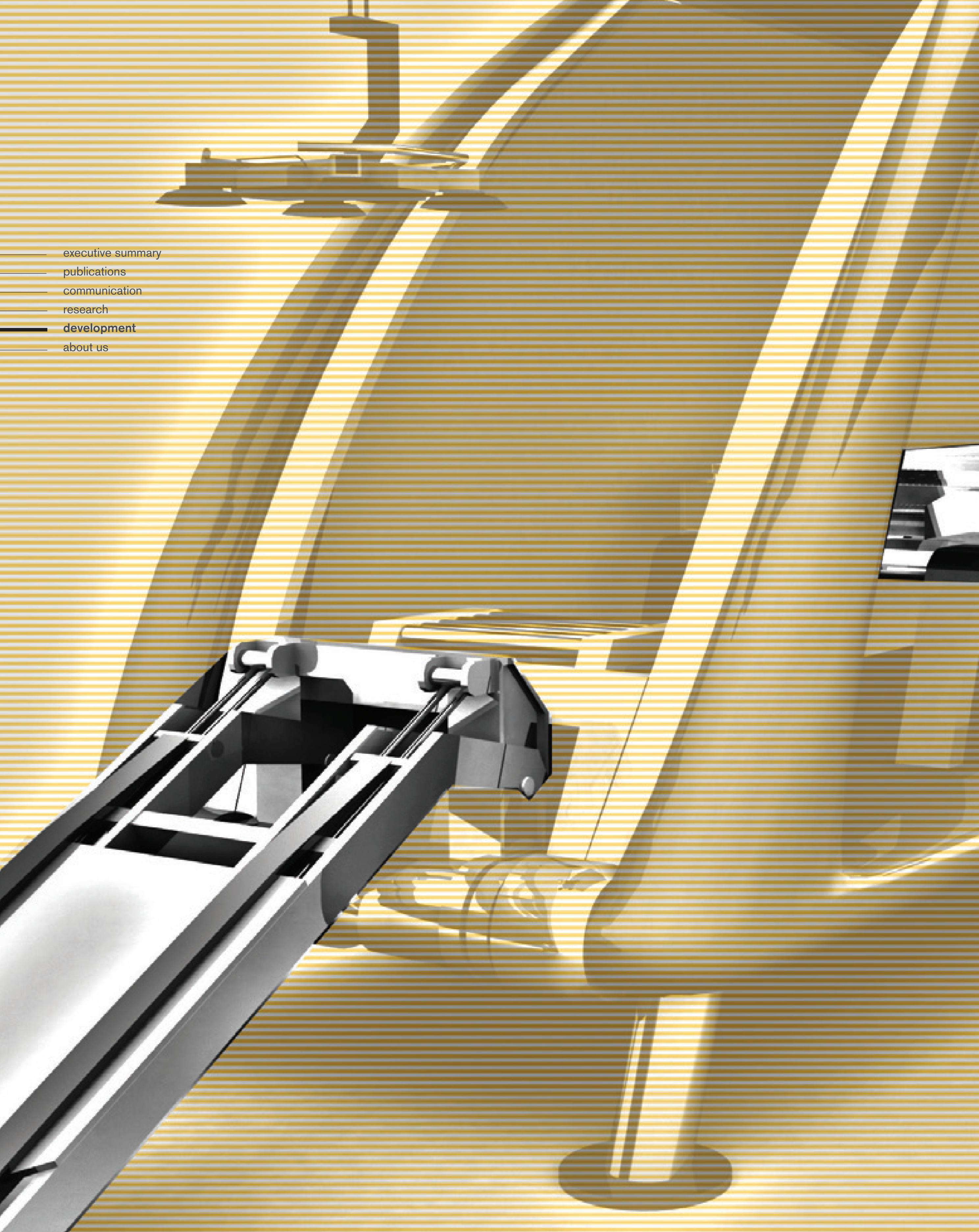
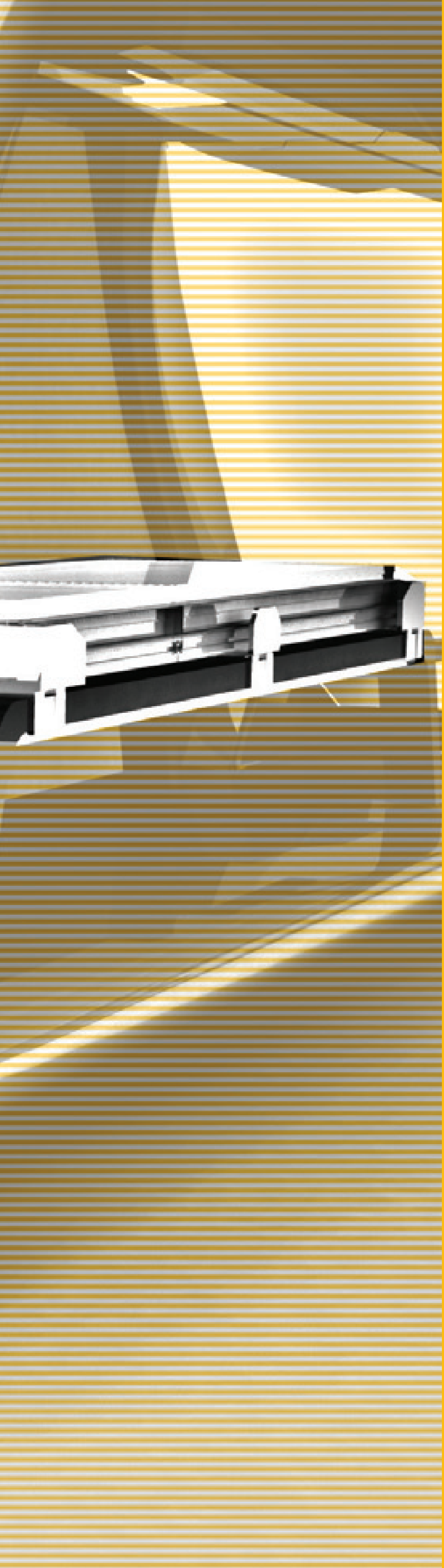




Development

Enclos has been able to remain at the forefront of advanced facade engineering through a continual commitment to core principles while redefining internal processes to leverage the power of sophisticated tools. This section documents several projects the Studio is currently undertaking to improve our process. These projects include in-depth evaluation of near future applications including cassette wall systems and phantom modeling in BIM.

Cassette Wall System

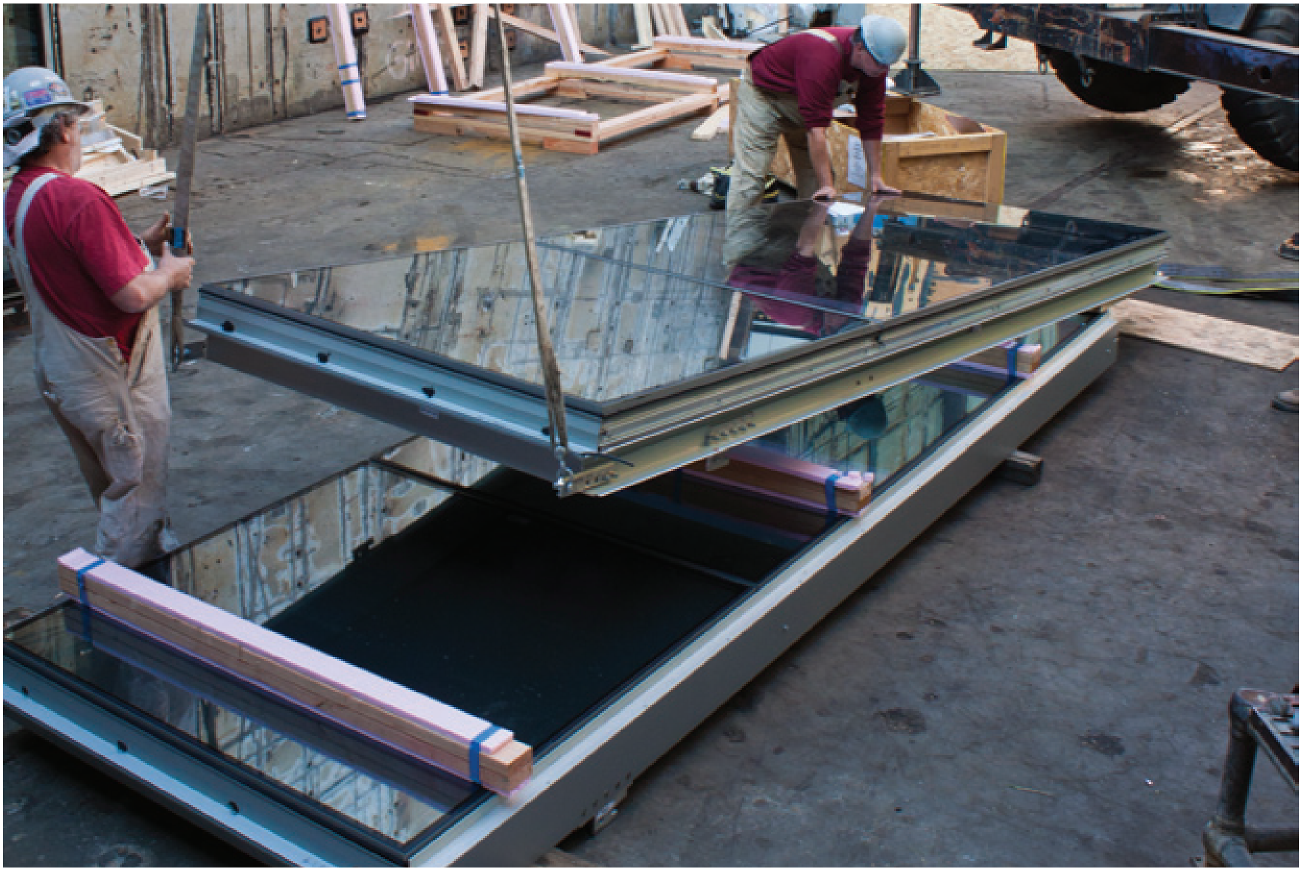
Michel Michno, LEED AP
Kevin Tan
Jeff LaNasa
TJ DeGanyar, Ph.D., PE

Modular facade systems represent one attempt to optimize the final assembly of unitized components delivered to the construction site. This facade system – also known as cassette walls – is pre-assembled in modules, ultimately simplifying the final assembly process, easing the inspection of completed units, facilitating just-in-time assembly by synchronizing manufacturing and field activities, and introducing a greater flexibility in the location and size of the final assembly facility.

Curtainwall assembly and glazing processes are constrained by sealant application and structural glazing. These processes dictate the type and size of facility required. They also influence lead times, the amount of work in process, and completed product inventory. The Cassette Wall is designed to de-couple silicone sealant application from the final assembly process.

Completed units maintain the appearance and the behavior of traditional unitized facades but do not require exceptional installation methodology. Cassette systems do not impose design limitations, rather they allow for full customization in size, shape, and finish in interior and exterior applications.

The Cassette Wall (patent US2008/0066402 A1) has been fully designed and engineered by Enclos, including a full size mock-up manufactured and tested. This document presents engineering and test data from our own in-house research.



Enclos conducted a full scale cassette wall system mockup.

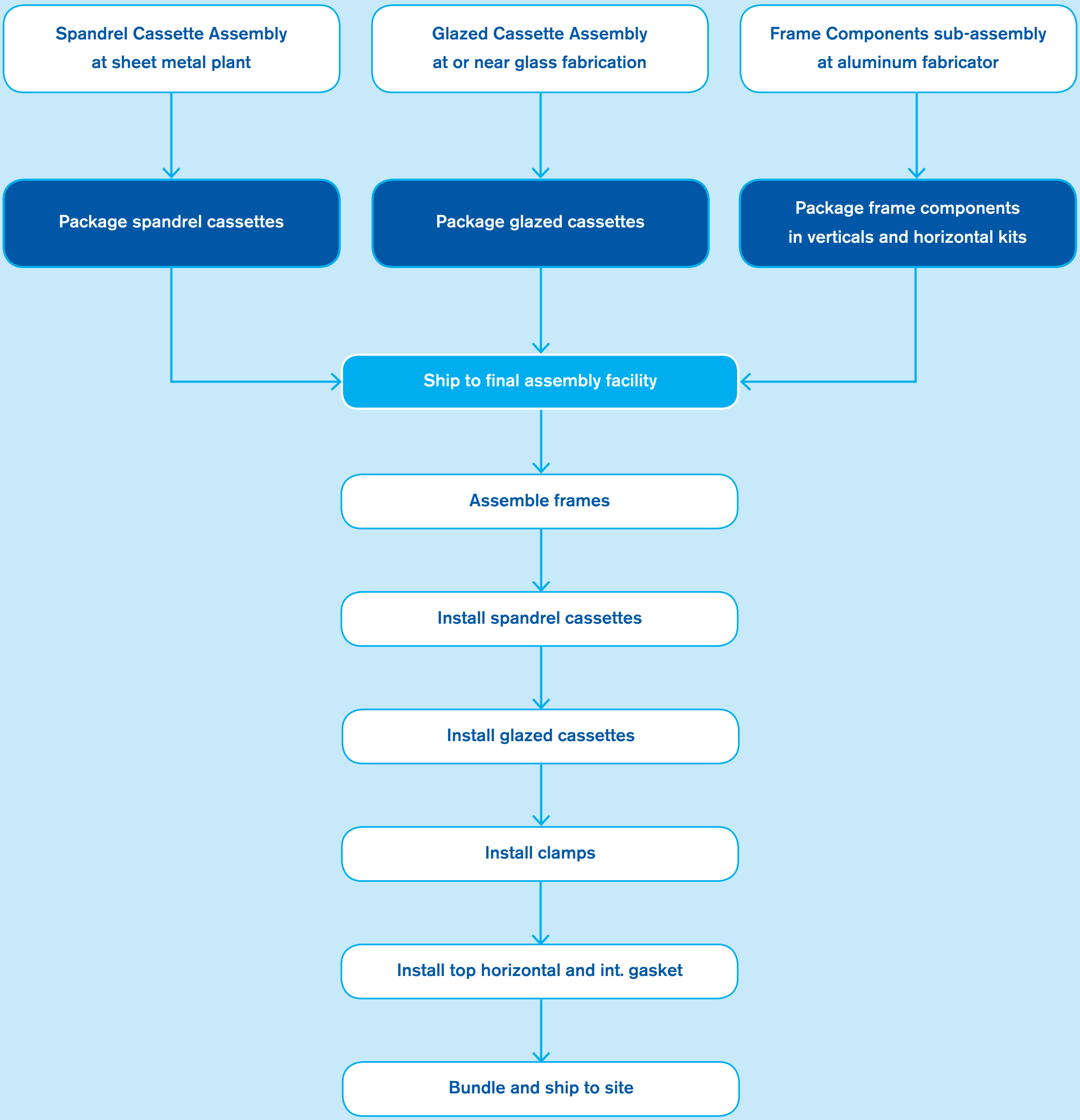
INTRODUCTION

It is generally accepted that construction has lagged behind other industries in productivity improvements for the better part of a century. The combination of engineered to order (ETO) products and the fragmented nature of the construction industry typically results in waste and inefficiencies along the supply chain involving products and services from several industries.

Recent developments in 3D computer modeling, especially the emergence of processes such as Building Information Modeling (BIM) and clash detection, have created opportunities for reducing lead times, thus increasing efficiency and reducing costs on complex construction projects. The ability to compare digital models, check interference and reduce the number of RFIs have increased contractor's confidence that engineering and design data will match field conditions, leading directly to an increase in the pre-fabrication and pre-assembly of components delivered to the jobsite. This has been especially noticeable in the electrical and mechanical trades in recent years. In contrast, facade contractors have practiced pre-assembly of units since the 1980s because of the building skin's interface with interior trade work. If the glazing industry was not impacted by the BIM revolution in terms of pre-assembly, it has undoubtedly changed the way information is managed by using graphics (rather than or in conjunction with data) to manage projects. With unitized curtainwall being a 30-year-old concept, it has since become a commodity to the construction industry.

The facade concept presented herein primarily targets processes ahead of field installation: procurement, fabrication, sub-assembly, final assembly and glazing. Our Cassette Wall research is based upon sub-assembling major framing components and producing pre-glazed, pre-assembled glass and infill systems that can be later assembled without the use of sealants at a final assembly site. This extended pre-assembly process dramatically reduces unit assembly time and space requirement, something especially effective when the facade incorporates numerous materials from multiple sources. For example, glass can be pre-glazed to aluminum cassettes in or near a glass fabrication facility while insulation is being pre-applied into spandrel cassettes at a sheet metal facility. An early eye on the quality control of modular components and reduction on assembly time also facilitates just-in-time final assembly, reducing storage requirements while improving flexibility and change management.

PRODUCTION FLOW CHART



Because **modular systems** separate cassettes and kitted framing components, **freight can be reduced by more than 500%**.

Figure 1 (opposite): The "dry" cassette system reduces labor costs and insures better weather performance.

MODULAR DESIGN

The type of modular assembly described in the previous section has been common practice in the aerospace, automotive and ship building industry for many years. Through unique design concepts the practice can also be extended to the facade industry by using the principles of modular design: the product is partitioned, various modules have well defined interfaces, and components can be separated and recombined (to increase flexibility). As a curtainwall application, the focus is on optimizing final assembly – reducing the number of components and designing processes around known interfaces, thus reducing motion waste. As a result, transportation waste is also minimized.

OBJECTIVES OF THE CASSETTE WALL

Shipping fully assembled and glazed units can be expensive, especially if units are shipped from overseas. Compounding this is the fact that shipping containers limit the size and number of units that can be delivered. Because modular systems separate cassettes and kitted framing components, freight can be reduced by more than 500%.

Large, heavy and bulky components should be handled as little as possible. The cassette wall design offers the possibility of performing assembly tasks in line with the manufacturing of infills. Cassettes can be attached to glass, terracotta can be attached to an infill panel, and insulation can be installed on sheet metal backpans at the sheet metal manufacturing facility. This reduces material handling and motion waste at the curtainwall assembly plant.

Final assembly only requires screw guns, reducing labor to1-2 man-hours, minimizing the need for multiple assembly lines and work-in-process. Final assembly is closer to the field erection sequence, where specialized, mobile assembly facilities can be designed with minimal space requirements. Pre-assembly can then be performed in low labor cost areas.

Cassette Wall design is particularly adapted to facades using a large number of infill types, and a "dry" final assembly insures better weather seal quality. However, with major components being pre-assembled during throughout the process, the need to inspect components early on increases to reduce the risk of disrupting quality issues and rejected components.

CURTAINWALL TYPOLOGY

The AAMA Aluminum Curtainwall Design Guide Manual classifies wall systems by five different types. As far as field installation is concerned, Cassette Walls fall under the Unitized Systems classification.

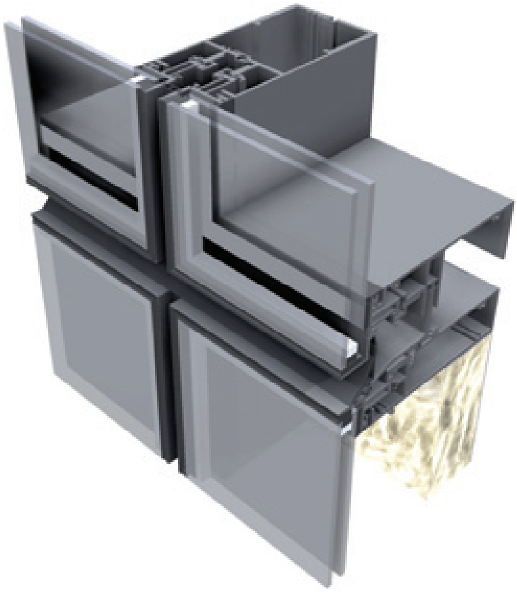
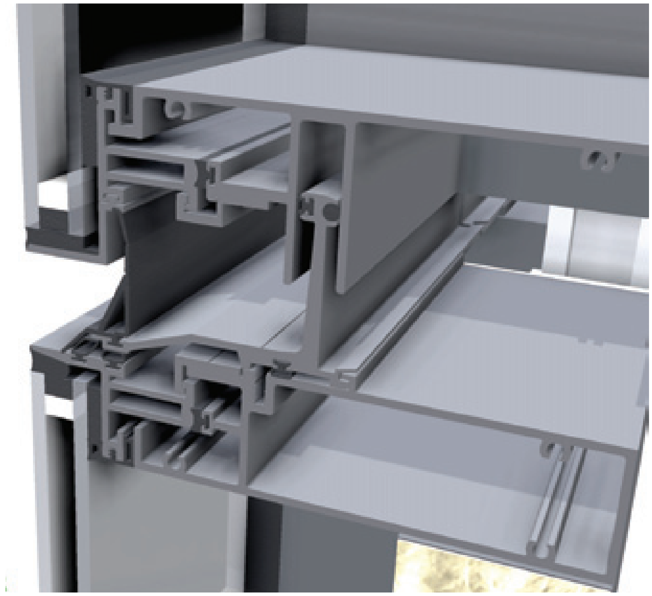
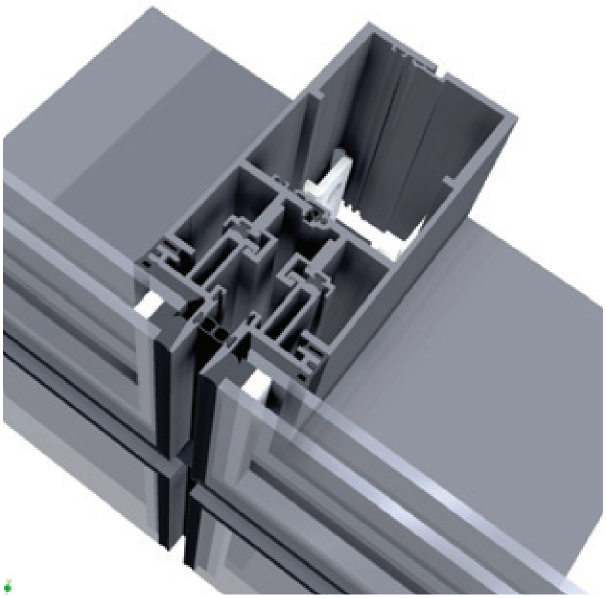
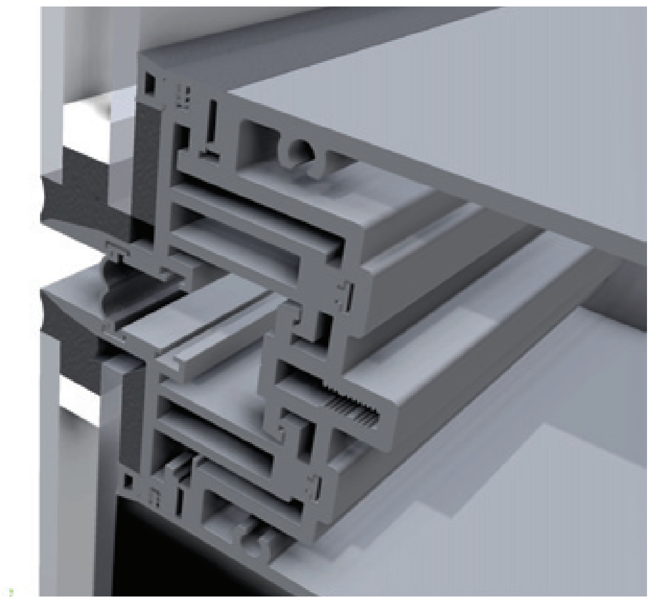
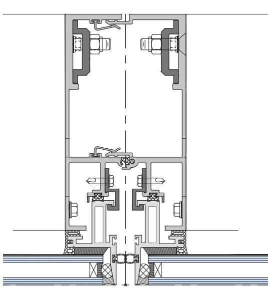
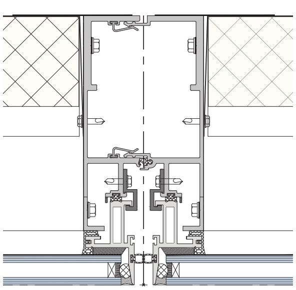
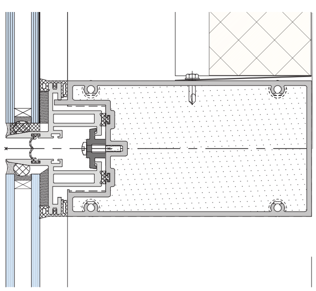
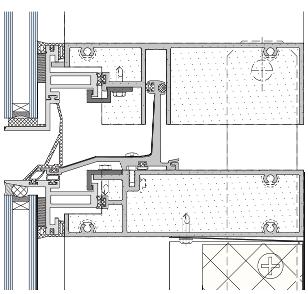
Stick Systems: Individual fabricated components and infills are installed on site with no or little pre-assembly.

Unitized Systems: Facade modules are shop assembled and glazed to the highest level of quality, with complete panels being shop built.

Unit & Mullion Systems: Hybrid compositions consisting of sticks (mullions) that are erected as a first layer with pre-assembled and glazed units later attached.

Panel Systems: A variation of the unitized system with sheet metal or castings replacing the unit frame.

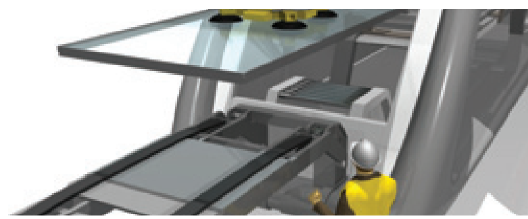
Column Cover & Spandrel Systems: Pre-assembled units used to cover columns and spandrel areas, with glass units or stick systems installed at the vision areas.

FLEXIBLE MODULAR ASSEMBLY

CONCEPT ONE: MOBILE ASSEMBLY FACILITY

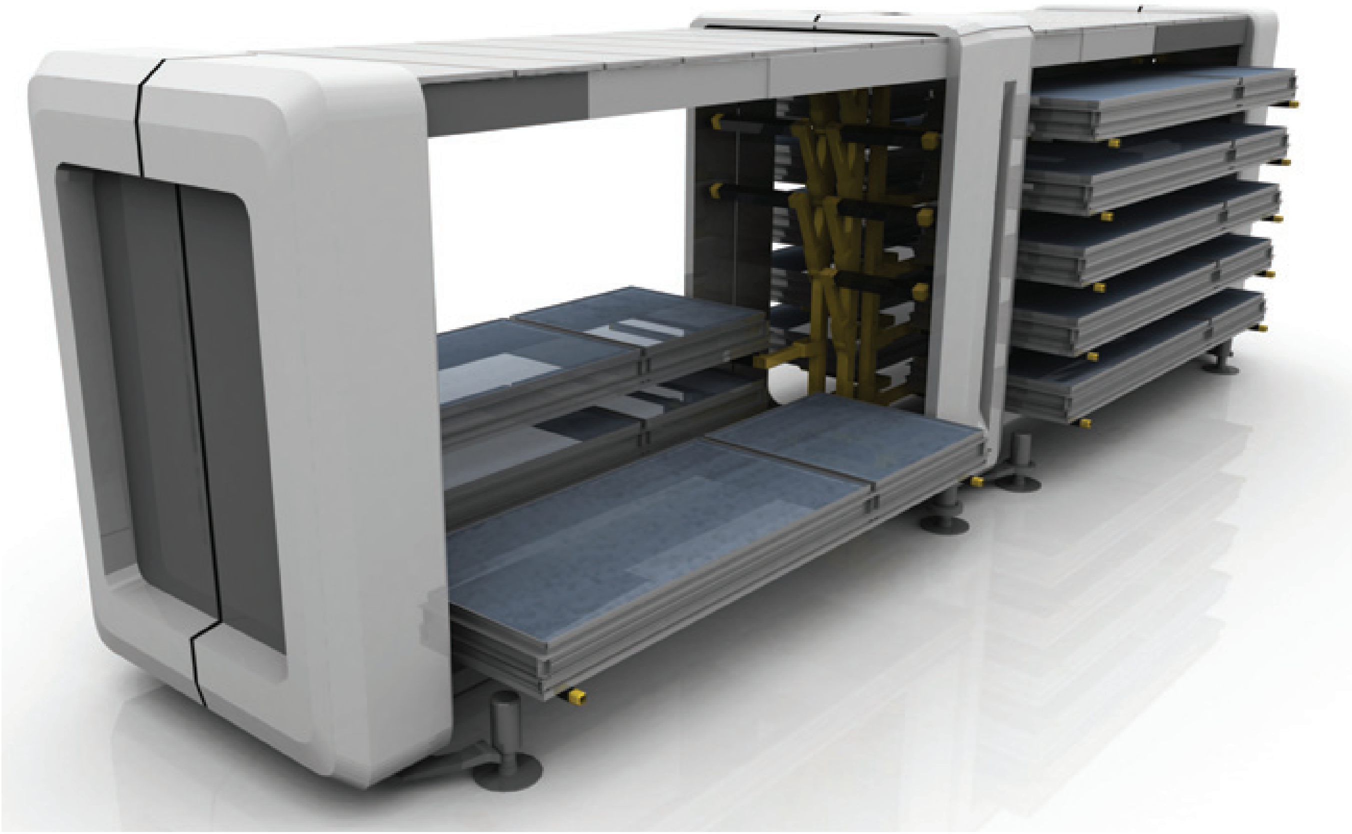
CONCEPT TWO: SINGLE MODULE FACILITY



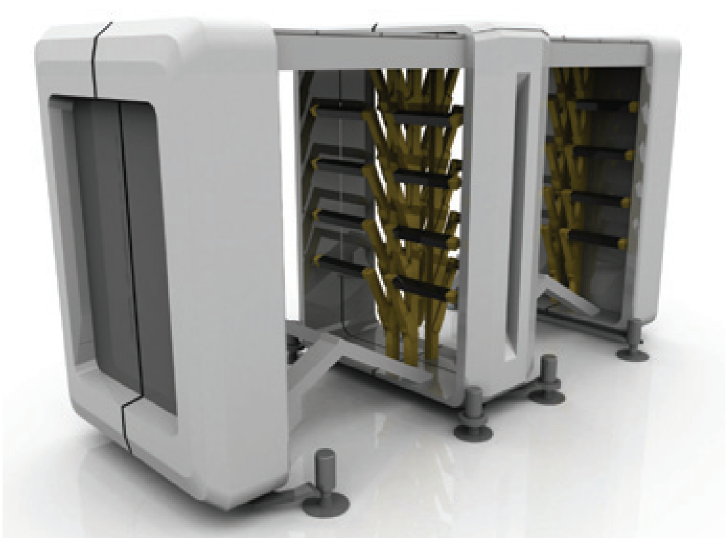
CONCEPT THREE

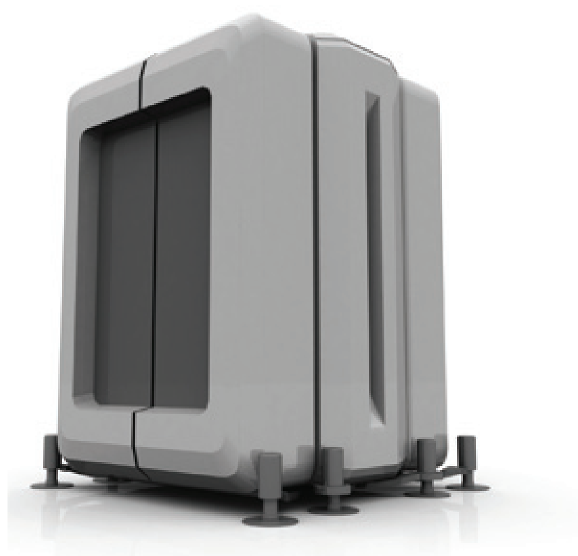
Concept three offers the option to expand the assembly station's work area by linking additional modules together.

MODULAR FACILITY STORAGE UNIT



The modular assembly is compacted for initial transport and expands upon arrival at the job site. The assembly has a maximum storage capacity of 20 units.





Phantom Modeling in BIM

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TJ DeGanyar, Ph.D., PE

Fluency in the alphabet soup of 3D modeling is becoming increasingly more important in ensuring optimal interoperability.

Generally, buildings require multiple 3D models for their full design, engineering, construction, and integrated practice. At the core of an integrated practice lies the intimate collaboration between the design team, construction team and a digital 3D model. *Phantom Modeling in BIM* will illustrate varying collaborative approaches to understand how we can maintain “Phantom” links of shared 3D models between architects, contractors, and sub-contractors alike to incorporate design changes with greater efficiency.

INTRODUCTION

A basic tenet of American law is that construction trades cannot be held responsible for errors when they have properly followed contract documents. Known as the Spearin doctrine, this legal case serves as a safe harbor for contractors by implying a warranty from the design documents provided by the owner. This doctrine suggests that if the contractor follows design documents provided to them, there is no liability for performance failures or defects in the construction arising from the design.

Under traditional construction contracting paradigms, the construction trades are required to follow the contract documents, which commonly include 2D drawings and specifications. However, the design and construction industry has recently undergone a significant shift away from the use of two-dimensional CAD and paper drawings for three-dimensional, semantically rich, digital models.

In contrast to exchange plans – via drawing files like dxf or dwg – **the IFC exchange is strictly model based**; a wall is not a set of lines but **an object with specified attributes and relations.**

This trend has reached a point where this technology, generally referred to as Building Information Modeling (BIM), is being used by the majority of the industry. Additionally, the push for the 3D model to be used as a contract document – binding parties to the same extent as drawings or specifications always have – is currently increasing.

In a BIM design, the designer can select pre-programmed objects embedded with information about all of its relevant characteristics, not just its shape. Moreover, software such as Revit allows any change in plan view to automatically update any section affected by the change. In Tekla Structures, changes in dimension or geometry automatically update details and related documents.

The gap that exists today arises from each stakeholder maintaining his or her own 3D model. When an architect or engineer releases updates or addendums to the design documents (for example, if a column is removed to create a larger bay from one of the models), the architect releases a new set of drawings, making contractors and sub contractors responsible for manual reconciliation and model synchronization. Manual changes in the drawing sheets and re-detailing the connections increase the likelihood of human errors, with potential to "break" the existing model. As projects grow and file structures get more complex, this style of coordination also becomes increasingly complex, making traditional project management methods ineffective when exchanges need to be processed rapidly and accurately.

This paper provides preliminary ideas for how to use BIM/Industry Foundation Class IFC 2x3 and/or XML based IFC file exchanges to bridge the gap by creating phantom links between an architect's model and user's 3D phantom model, which will update all rapid changes without human-error; thus creating "phantom modeling".

OBJECTIVE OF THE IFC

Efforts throughout the past decade have been directed at using a central repository or model server that acts as a base for interoperability between various architecture, engineer and construction disciplines and their software applications. Recently an international standard for information exchange of BIM data – the industrial foundation class (IFC) – was developed by the International Alliance of Interoperability to facilitate interoperability in the building industry [3]. The goal of IFC is to enable interoperability between building information systems.

The IFC provides a specification of a data model that covers the domain of building information. It can be used as a shared data model or integrated data base by many groups, allowing any participant involved with the planning and construction process to use the same model, thus increasing transparency of changes and the ability to let other players know of the actual change in the planning. In contrast to exchange plans – via drawing files like dxf or dwg – the IFC exchange is strictly model based; a wall is not a set of lines but an object with specified attributes and relations.

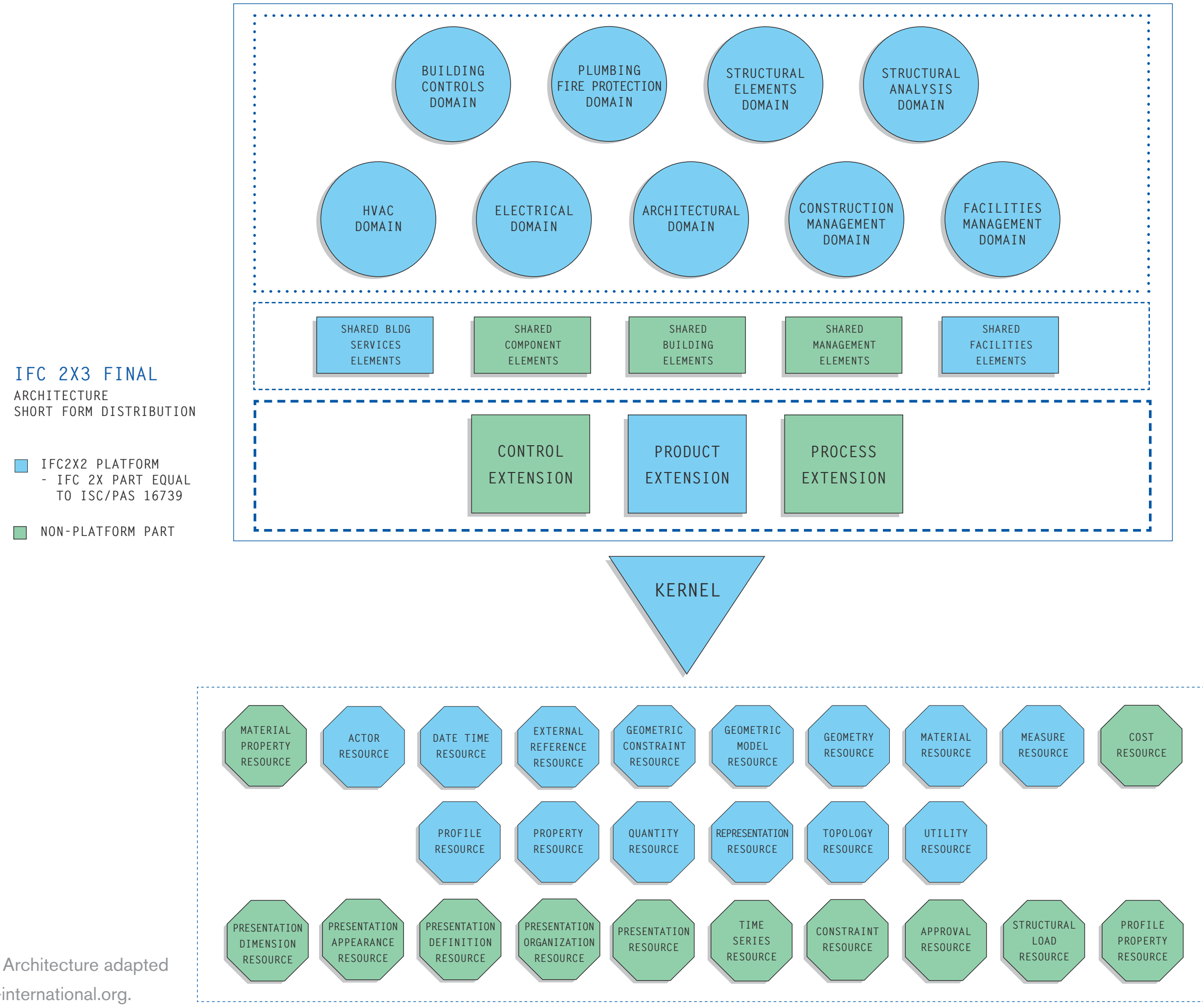

Figure 1: IFC Architecture adapted from www.iai-international.org.

ARCHITECTURE OF THE IFC

There are four layers in the IFC Model. The layers follow the "gravitation" concept, where elements of a certain layer can only refer to entities of the same or a lower layer.

1. *Resource Layer.* This layer contains the fundamental concepts expressed as entity types such as geometry (point, line and curve) topology (vertex, edge, face and shell), geometric model (CSG, B-Rep, and Geometric Set). The elements of this layer can be referenced by elements of all other layers. In figure 1, the resource layer is symbolized with octagons.

2. *Core Layer.* This layer declares abstract concepts that are specialized by the layer above. There are abstract concepts like object, group, process, property definition, relationship or root. There is no instance of an abstract entity type. An abstract class provides an interface to the derived (specialized) entity types. In figure 1, the core layer is symbolized with triangle and rectangles.

3. *Interoperability Layer.* This layer defines basic concepts for interoperability between different domain extensions. Shared building elements like beam, door, roof, window or ramp are defined in this layer. In figure 1, the interoperability layer is symbolized with rectangles and squares.

4. *Domain Layer.* The entity types of the domain layer extend the concepts of the interoperability layer. Elements of one domain are not allowed to reference elements of any other domain. Domains include architecture, facility management, electricity or structural analysis. In figure 1, the domain layer is symbolized with circles.

The latest IFC release is IFC 2x3 TC1. Version 2x3 has introduced the ifcXML specification by using XML schema to define the IFC models in parallel with EXPRESS [4]. IfcXML offers a combination of advantages, first using XML technology as the mainstream technology for information publication and exchange, whilst reusing a well established, internationally recognized and supported data standard. It is recommended for architects whose partner's applications cannot read the original IFC format, but can manage .xml databases (such as budget, energy calculations, etc.). This is an uncompressed format, with larger file sizes than the normal IFC format.

COMMON TERMS

XML: Extensible Markup Language (XML) is a simple, very flexible text format derived from SGML. Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere.

XLINK: Defines the XML Linking Language which allows elements to be inserted into XML documents in order to create and describe links between resources. It uses XML syntax to create structures that can describe links similar to the simple unidirectional hyperlinks of today's HTML, as well as more sophisticated links.

XPATH: Notation that can be used by XML Style sheet Language Transformations (XSLT) to "flatten" the XML tree structure in an XML instance file by providing a unique path definition to data contained within an XML instance file.

XSD: XML Schema (XSD) is the schema definition language used in ifcXML to describe the structure of ifcXML files. The XSD is automatically generated from the IFC source definition, the IFC EXPRESS.

IfcXML methodology: The methodology to automatically convert the IFC source definition into the ifcXML schema and to convert data sets into ifcXML documents.

IfcXML schema: An XML schema defines the set of rules that the model should follow, such as the hierarchy of the building elements, required properties that have to defined based on their tags, etc. One can add more rules to the schema in addition to the ones given by IAI. The most recent ifcXML schema is ifcXML for IFC2x3.

IfcXML file: An XML document that can be validated by an ifcXML schema. Each ifcXML file should be well structured and validated against a valid ifcXML schema.

EXAMPLE

Structure of a building storey element and its properties in an ifcXML file

```
<IfcBuildingStorey id=”bs1”><GlobalId>3XjaeTTcDeDeeddVPFcs98</
GlobalId>
 <OwnerHistory>
                  <IfcOwnerHistoryxsi:nil=”true” href=”enclos1 “/>
      </OwnerHistory>
<Name>First floor</Name>
<ObjectPlacement>
<IfcLocalPlacement xsi:nil=”true” ref=”i20”/>
</ObjectPlacement>
<CompositionType>element</CompositionType>
<Elevation>350.0</Elevation>
</IfcBuildingStorey>

<IfcRelDefinesByProperties><GlobalId>1fvr_56SS7jsK_vrADYHZ</Glo-
balId>
<OwnerHistory>
<IfcOwnerHistory xsi:nil=”true” ref=”enclos1 “/>
</OwnerHistory>
<RelatedObjects ex:cType=”set”>
<IfcBuildingStorey ex:pos=”0” xsi:nil=”true” ref=”bs1”/>
<IfcBuildingStorey ex:pos=”0” xsi:nil=”true” ref=”bs2”/>
</RelatedObjects>

<RelatingPropertyDefinition>
<IfcPropertySet><GlobalId>1lpBu^kBSSWM7r$$xnE1xi</GlobalId>
<OwnerHistory>
<IfcOwnerHistory xsi:nil=”true” ref=”enclos1 “/>
</OwnerHistory>
<Name>PSet_BuildingStoreyCommon</Name>
<HasProperties ex:cType=”set”>
<IfcPropertySingleValue>
<Name>AboveGround</Name>
<Description> Indication whether this building storey is fully above
ground (TRUE), or below ground (FALSE), or partially above and below
ground (UNKNOWN) - as in sloped terrain.</Description>
</IfcPropertySingleValue>
</HasProperties></IfcPropertySet>
</RelatingPropertyDefinition>

</IfcRelDefinesByProperties>
```

Figure 2. Example code from an ifcXML file.

METHODOLOGY

This section suggests a methodology for implementing phantom modeling process using ifcXML. It is not fully developed and merely acts as introductions to the examples, which are for illustration purpose only.

WORKFLOW

The process to maintain phantom links consists of six steps:

1. Determine what information needs to be read or written from architect's and other user's model(s) for synchronization.

2. Review the IFC schema to see which entity definitions are relevant.

3. Design and document a global mapping table such that there is a one-to-one mapping of all the elements between both models.

4. Write application code for "import" and/or "export" that use an XML parser, such as Xerces, and generate an ifcXML instance file; use DOM or SAX application programming interface(s) to parse the XML instance file to get or set information into the mapping file.

5. Run step 4 with the architect's model and store the global IDs of model elements in the first column.

6. Repeat step 4 with user's model and store the corresponding global IDs in the second column, which will in turn give you the Xpath to the element in the ifcXML schemas that match the data item(s) you want to compare.

Note: If architect and/or specialty contractor uses Revit, export the model to IFC 2x3 and then convert it to ifcXML (since Revit doesn't support ifcXML).

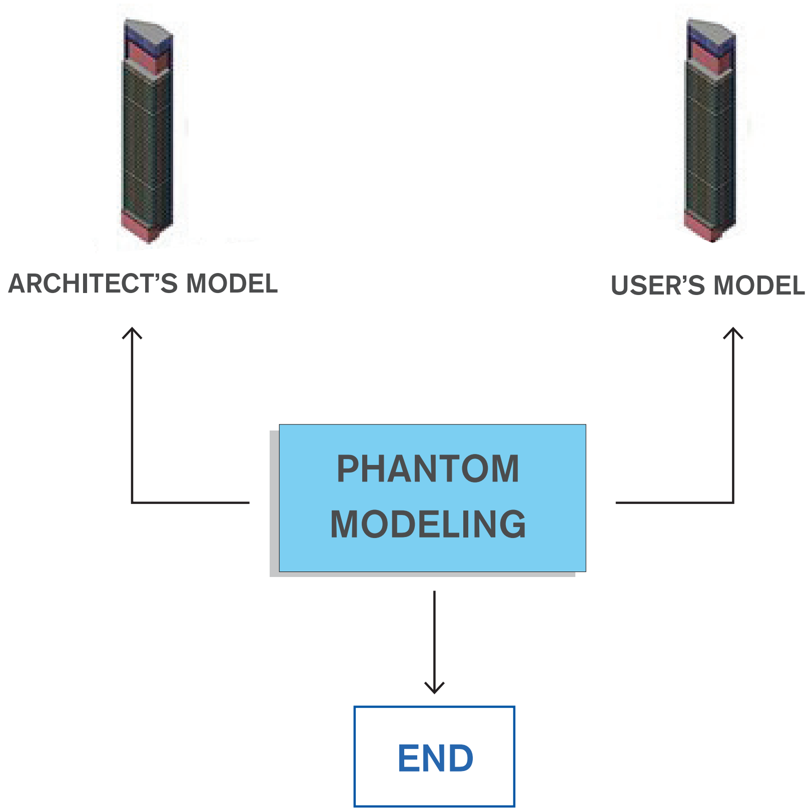

Figure 3. Conceptual interface relationship of phantom modeling.

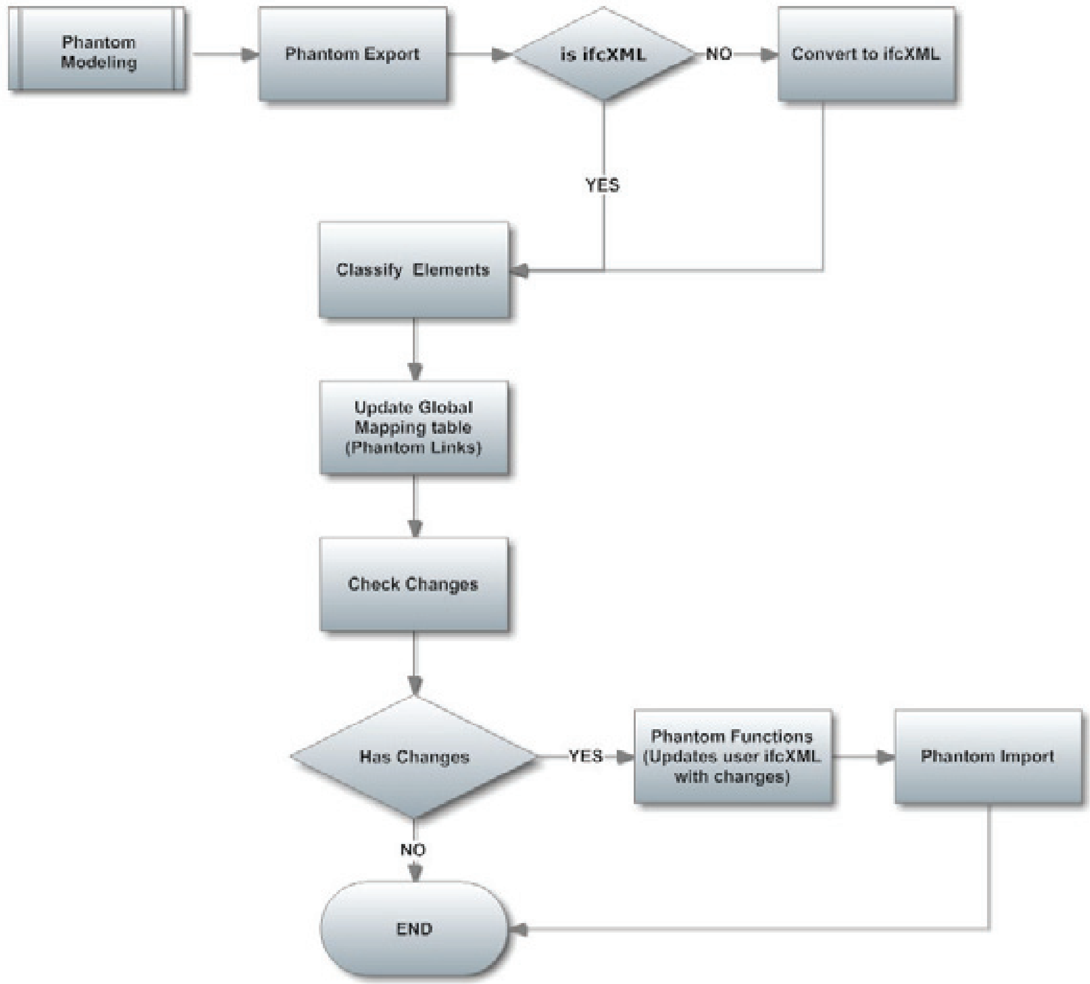

Figure 4. Internal process of Phantom Modeling.

INTERNAL PROCESS OF PHANTOM MODELING

1. *Phantom Export:* Export the models to ifc/ifcXML. The IFC model obtained from the architect's application is always transformed into native ifcXML, which will be validated against user defined XSD. Filtration can be done by selecting only the required building elements that you wish to synchronize, such as curtainwalls, interior walls, slabs, columns, beams, etc.

2. *Element Classification:* For more accurate model mapping, you can define your own XML schema that contains all the rules, such as hierarchy and property definitions of various elements (in addition to their default "IFC type" definitions).

3. *Phantom Links:* The mapping table contains all the intelligent links, which includes version information and history of the links.

4. *Phantom Functions*: Phantom Manager allows you to list the eligible set of element classifications that are to be checked for changes, and to detect IFC model version changes between the architect and user's model as a part of phantom model-based data exchange workflow.

5. *Phantom Import:* Once changes are made to the XML file, the new file is imported to the application, which will in turn synchronize the user's model. Since the incoming elements or modifications are converted into native format they become an active part of the architectural model, while retaining their properties (material, profile, etc) assigned to them before synchronization.

The transition from a paper-based exchange of design models to digital represents a substantial change in the design and construction industry. **Digital models open the door for abundant automation possibilities**, including large portions of the analyses done during the design phase.

CONCLUSION

The transition from a paper-based exchange of design models to digital represents a substantial change in the design and construction industry. Digital models open the door for abundant automation possibilities, including large portions of the analyses done during the design phase. With this comes potential critical consequences in regards to the speed and efficiency of future design processes that must be considered — ultimately, the quality of the resultant designs.

From a technical perspective, IFC and its use in the design and construction industry represents an interesting study for a number of reasons. The domain is challenging because of its breadth, and because of the size of its models. With the AEC industry being historically paper-based for information exchange and analysis, the opportunity for digital techniques to automate and streamline processes is significant. Working in such a highly collaborative environment makes interoperability a key issue, and the industry finds itself in a situation similar in many ways to the software engineering, where visualization-level interoperability has reached some level of maturity and semantic interoperability continues to develop.

The principal semantic interoperability challenges revolve around the quality and consistency of the models produced. Efforts are underway to provide for consistent modeling both through technical solutions and through the engagement of stakeholders to determine what constitutes good modeling practice. The success or failure of these efforts will go a long way towards determining the extent to which BIM succeeds in transforming the industry.

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The Studio studies the physics of wall systems to optimize the impact of environmental factors, it designs advanced and sophisticated computer applications (creating custom tools when applications are not commercially available or insufficient), and explores new and experimental approaches to facade digital design thru 3D modeling, advanced graphic representation, design simulations, BIM and Integrated Project Delivery.

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