THE SIGNIFICANCE OF THE WIREFRAME: A DISCUSSION OF COST DRIVERS FOR MODULAR CURTAINWALL CONSTRUCTION

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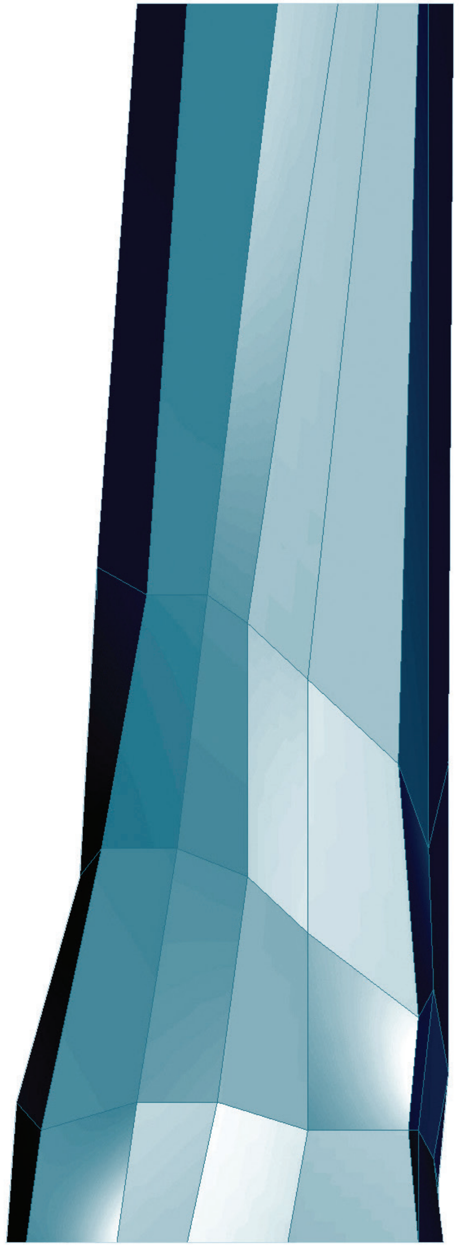
Imagine a glass-clad highrise office building in a large city like New York. Imagine it has 50 floors and each floor has a perimeter which takes one hundred 5'-0" wide curtainwall units in order to create a complete circumnavigation of the floor plate. If the building is relatively simple, each one of the building's 5,000 curtainwall units might cost as little as a high-end road bicycle. If the project is very complicated or some simple cost drivers are not considered early, it is possible to end up having a building clad with the equivalent of five thousand mid-sized sedans. The next time you look at a complicated highrise facade, try to imagine for a moment that each curtainwall unit is a brand new, four door car.

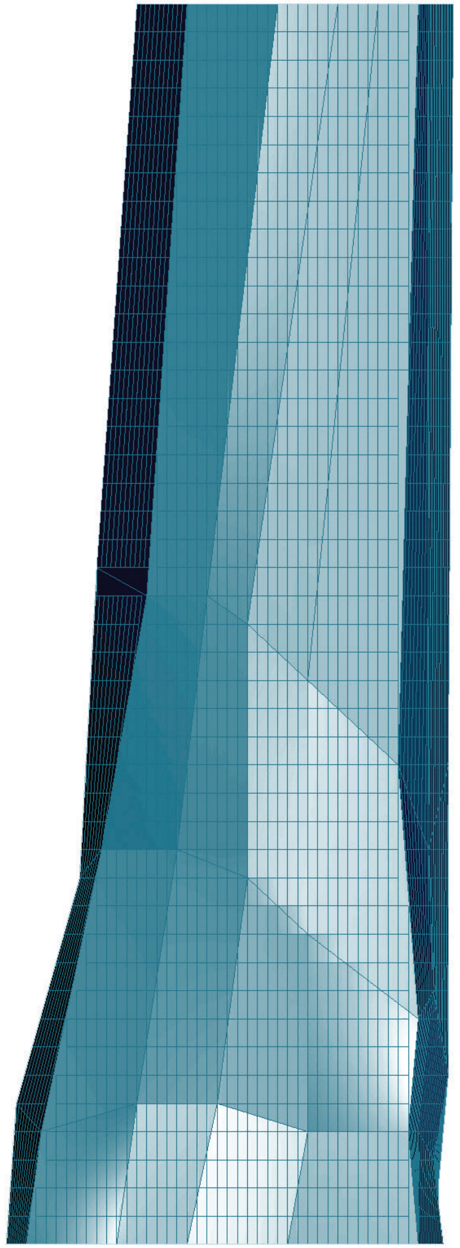
Here at the studio, we often find ourselves involved in the design stage of monumental curtainwall projects. Frequently this involvement is prior to an architect issuing final construction documents and our task, in part, is to help the design team and ownership group reduce the overall cost of the facade while maintaining the architectural intent. At this stage there is often a computer model of some kind and generally these fall into the category of massing models or surface models (i.e. a Sketchup or Rhino model of the overall form), or if the project is a bit further along, models which were used to generate an "Issue For Bid" set of architectural drawings (i.e. a Revit model). Many times, the first step a member of the studio group will make is to attempt to use these architectural models to create a simple wireframe containing the precise layout of the individual unitized modules which will form the completed facade.

Over the last few decades, highrise buildings have gone from being rational forms—essentially rectangular or cylindrical masses—to being forms which flow, twist, warp, bend, push, pull, crack and facet. As a result, their skins have gone from being easily identifiable repeating patterns to highly variable, non-linear, and patternless. In all these emergent and divergent forms, the essential first step to defining the curtainwall is to define the modules and to rationalize the resultant wireframe as much as possible without impinging on the architectural intent. Often this step is left until too late in the design process and rationalizing the facade to reduce costs and meet schedules has a disappointing impact on the form and ultimately the project.

Unitized curtainwall design, at its core, is a technique which employs modular construction and assembly practices in order to reduce both the field construction schedule of the facade and the cost of field labor. These costs (field labor and field schedule) truly are the primary drivers behind unitized curtainwall design. There are, of course, myriad other benefits regarding performance, but



CONTROL SURFACE



UNIT MODULIZATION "WIREFRAME"

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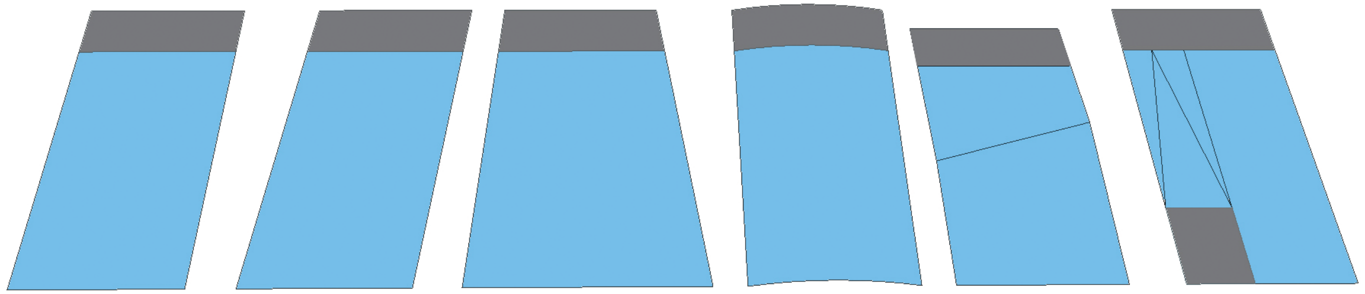
FIGURE 1
On the left, a complex faceted massing model for an unspecified high-rise in New York. On the right, a wireframe mesh applied over the surface mass.

FIGURE 2
A series of possible wireframe unit configurations, each with a spandrel zone to hide the building structure.



an understanding of what drives the square foot cost beyond simple material choices, and ultimately, how much of that cost relates to the modular wireframe of a building facade, should give an architect more control over their design. No one at the studio enjoys stripping a building of its unique architectural features in order to meet a budget. Our hope in sharing some insight into often overlooked drivers for the cost of a facade is that architects might come to better understand and control a building's skeletal wireframe to better understand the project costs.

Every individual curtainwall unit on a building has a skeletal wireframe which connects the workpoints or module points shown in the framing details. On a typical unit, these wires define the location of the left and right mullions, the unit sill, the unit head and typically an intermediate horizontal which breaks the infill between vision and spandrel zones to hide the building's primary structure. On simple units, these lines are typically rectilinear. On more complex units, the perimeter wireframe (mullions, head and sill) can be sloped, they can form a trapezoid or a parallelogram, they can be folded or curved or can be compound curved. The geometry of the wires and the shape of the area they define have a large impact on unit costs. The more complicated the geometry of the area and the surface defined by the boundary of the wires, the more expensive that individual curtainwall unit will be.

In addition to the perimeter wires of the unit, the intermediate wires (horizontal or vertical) can have the same properties – linear, folded, curved or compound curved – and again they have the same implication on costs. Finally, each skeletal wireframe has a connection point to the building structure where the self loads (e.g. unit weight) and imposed loads (e.g. wind load) are applied back to the structure through the unit anchorage. The location of this connection point can also have implications on overall cost.

The workpoints which define the nodes of the skeletal unit wireframe are like the control point of a NURBS surface, with each surface cell contained by the control points representing a curtainwall unit. In building a wireframe model, a curtainwall designer is looking initially for a couple of things. First — do the surfaces of an architect's model "close" — that is, do adjacent surfaces meet exactly at the same control points. Second — there is an analysis of the surface cells ("units") contained by the nodes that looks for repetition based on size, shape and, if the information is known, infill materials. The more modular cells which repeat, the better costs can be amortized across the facade. Imagine again our 5,000 curtainwall units on the highrise in New York City. If 85% of those curtainwall frames are the same modular unit, the costs of everything from engineering to setting units will be lower for the project. If 85% of the curtainwall units are each unique, there are increased costs associated with almost every aspect of the building process.

Related to repetition, it is also worth mentioning the effect of volume. Any project, no matter the size, requires allocating a certain number of resources in terms of design, engineering, project management, shop labor and field labor. This is part of what makes it challenging to produce complicated facades on a very small scale. If the 'startup' costs are only spread across a small overall square footage, the cost per square foot of a project can appear very high when compared to a job of similar complexity with a larger overall facade.

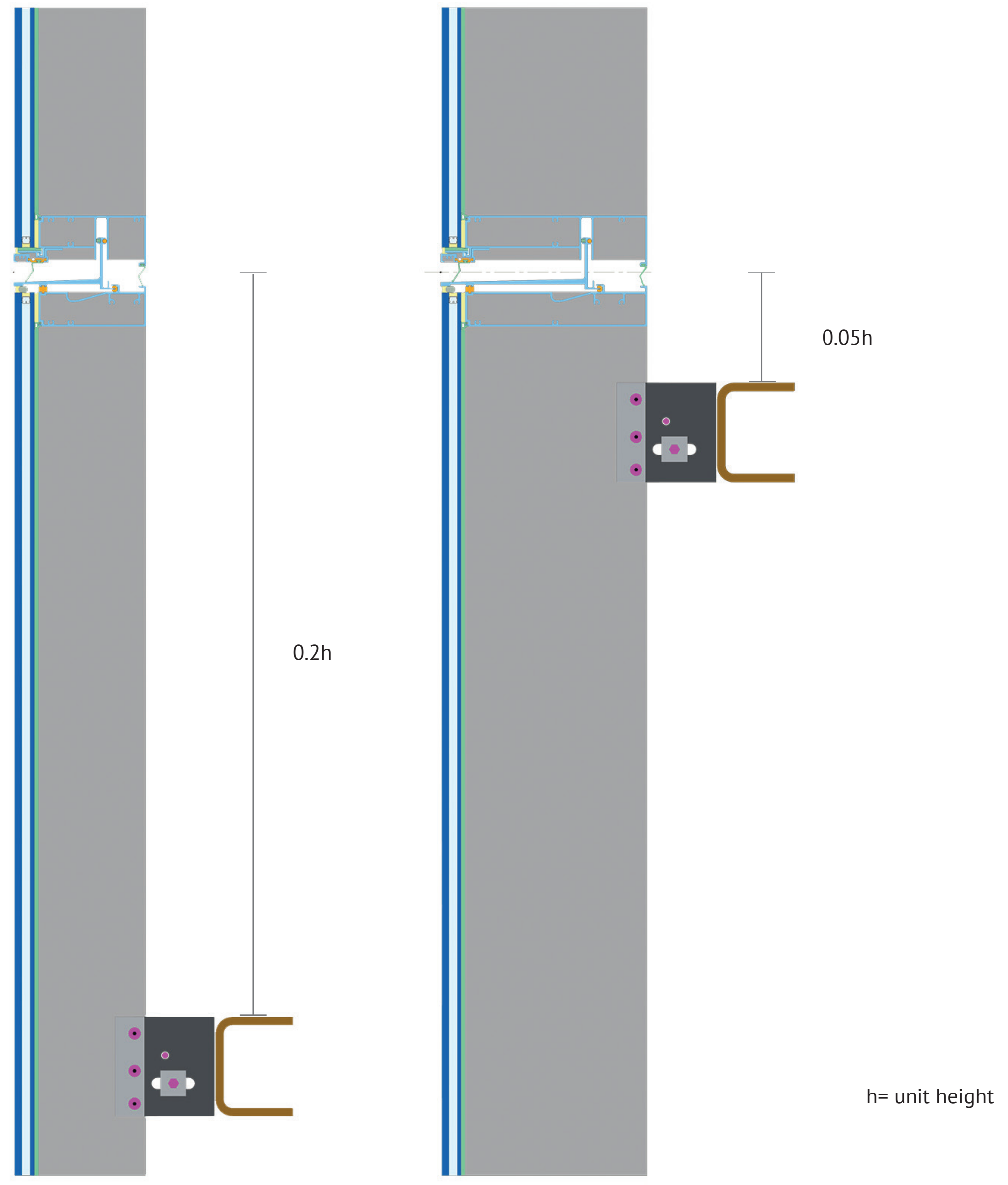
Once a wireframe is established and unit sizes can be analyzed, it is also possible to begin to glean other pricing information beyond the simple material costs. Oversize materials are a common issue. Fabricators have limits on what size material can be produced in high volume through their normal tooling. For instance, metal panels and glass are typically limited in maximum size. Glass, in particular, can also be too small or its aspect ratio can be too large for a fabricator to make efficiently – if it can be made at all. Specialty products are often even more restricted. Ballistic Glass, for example, is much more difficult to source in oversize applications. This is also somewhat true of bent or curved glass. In addition, these kinds of material size issues often come with added costs for new testing if the product's typical rating or test results (e.g. UL product certification) cannot be applied to an oversize or deformed piece. The cost of shipping oversize material to a shop where it is assembled into the curtainwall units can also be an issue.

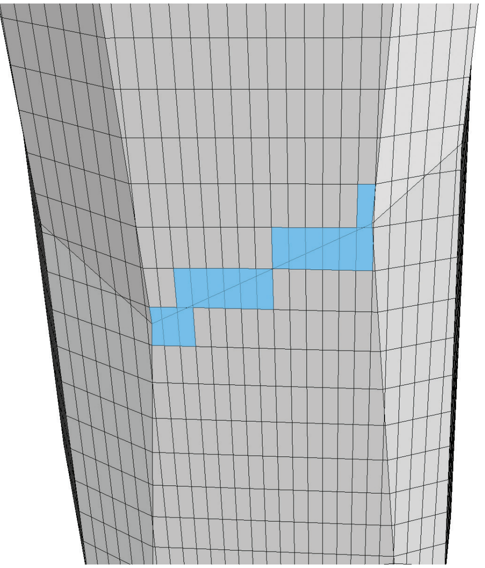
Another shipping related cost which is often overlooked is the unit shipping between the assembly facility and the field. Modular curtainwall construction relies on fabricating and assembling units in a factory and then sending them to the jobsite for final installation on the building structure. That assembly factory could be relatively close to the jobsite or it could be on the other side of the world. Units which do not fit nicely in typical oceangoing shipping containers or cannot be crated efficiently with other units on flatbed trucks, will increase the cost of a project. As an example, an Enclos project in San Diego had a handful of units that were so large, they each required their own semi-truck. Additionally, the truck drivers had to go far out of their way to avoid low underpasses on the typical route from the shop to the jobsite thereby decreasing efficiency and increasing shipping costs.

Oversize units also complicate unit setting and increase labor and equipment costs in the field. A relatively "normal" unit can be taken up to its location on the building via a material hoist or sometimes even a manlift. Once on the proper floor they can be flown into place using a small hoist-rig from a position a floor or two above where the unit setting is occurring. Oversize – or overweight – units often require use of the project's tower crane in order to lift them to the floor and sometimes to lift them for final setting. A tower crane is the most expensive piece of equipment on a jobsite and is always in high demand. A curtainwall setting crew is usually only allowed access to a tower crane during an off hour shift like a swing or night shift.

Other items which increase costs are things which increase the overall depth of the curtainwall unit. Some examples of this are deep horizontal or vertical glass captures or caps, large bullnose panels in the spandrel area, vertical glass or metal fins, sunshades, catwalks and dual-wall. Obviously, these are things which can bring greater architectural interest and greater performance to a facade. However, they also bring added costs beyond the cost of additional materials – largely in the area of shipping inefficiency if they are integrated into the units in the assembly shop, or of increased

FIGURE 3
Cantilevering the stack joint can have a dramatic effect on cost. Here, a cantilever of 4'-0" on a 20'-0" unit allowed Enclos to reduce the system depth from 12.5" to 8" by taking advantage of the cantilever's effect of reducing overall deflection compared with the simple span condition. In general, a cantilever of 20% of the overall unit height will provide the largest reduction.





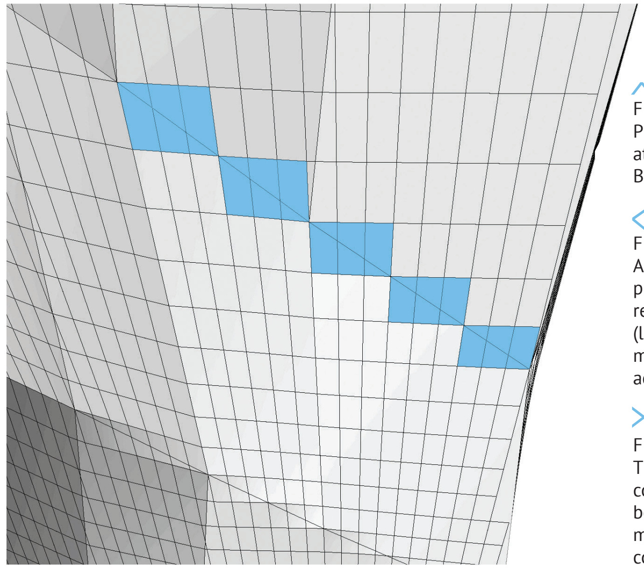


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FIGURE 4
Photo of complex transition units at facade folds on the Dove Federal Building in Miramar, Florida.

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FIGURE 5
A detail of the previous massing model prior to rationalization showing low unit repetition across a fold in the facade (left). A detail of the rationalized massing model showing high unit repetition across a fold in the facade (right).

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FIGURE 6
These narrow glass lites at the outside corner—at an aspect ratio of 1:20—are beyond the typical 1:10 ratio allowed by most manufacturers and incurred extra costs to produce.

FIGURE 7
This wing wall unit from a project requires a complex crate and its own flatbed to get it to the jobsite from the shop.

FIGURE 8
Half of this unit passed by the return wall and projected into space. Thus the adjacent lites had to be part of a single construct in order to include steel backspans hidden in the spandrel zone. This photo was taken during loading. The curtainwall unit was set into place with a tower crane during the night in downtown Los Angeles.

field labor in attaching these kinds of features to the curtainwall frames prior to unit setting.
A note unrelated to the wireframe or the module layout of the building, but it is worth mentioning that material sourcing and logistics also play a role in cost which is frequently overlooked during a project's early design phase. An open specification for products which is performance based, as opposed to a single source specification, gives more leverage in negotiating material costs. It also potentially allows for sourcing products from the most strategic locations relative to the production and shipping demands of a project.

Form is a huge part of any art – in fact, it is half of the word *artform* — and whether it is music, sculpture, ceramics, painting, writing or architecture, the form helps to contain and also make evident the expression. Part of what has happened in the last twenty years as computer-aided design technology has advanced is that what were once considered the boundaries of architectural form due to technological constraints are considered such no longer. Today's architects have used emergent technology to dissolve the boundaries of form, and curtainwall companies have had to work hard to keep up with and meet the demands of these artistic ideals.

Applying just the workpoints of what will eventually be refined curtainwall details over a form and connecting the points with wires to understand the modular geometry of the skin, will go a very long way in highlighting potential problems early on. Rationalizing the form so that transitions in the facade fall precisely on these workpoints has the ability to not only facilitate design and construction but to ultimately reduce the project costs and shorten the construction schedule. Material sizes, logistics, design, engineering, shop labor, shipping costs, field labor, the demands of unit setting, the project schedule – all these things which can ultimately drive up the price of a project can be thought of in the earliest phases of design in careful consideration of a building's wireframe. In the end, of course, a building's facade is greater than the sum of its parts, but an early analysis of the individual unit modules can make the difference between a successful use of form and artistic compromise.

FIGURE 9
Reusable metal racks have decreased the packaging costs for these wing wall units, but the trucking Is still inefficient.