SUSTAINABLE APPROACH TO UNITIZED CURTAINWALL PACKAGING DESIGN

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Packaging design of unitized curtainwall plays a pivotal role in the time frame between production of the unit and it being installed on the building. A good design should allow for the units to be secured easily, protect the unit from damage during shipping and lifting, and be easy to handle with a forklift or crane. Typically, unitized curtainwall is packaged in wooden bunks fastened together with nail or screw fasteners. In addition to not being reusable, wooden bunks have a tendency to fail if not designed and built properly. Steel bunks have greater structural integrity with the bonus of being highly recyclable. Most importantly, steel bunks designed with bolted connection allow for the bunks to be reused over and over again, even for different projects. Here, we will describe our efforts to promote sustainability through the use of reusable steel bunks that also offer additional advantages such as cost reduction and product safety. Work on reusable bunk design and their implementation was carried out by the Applications Engineering group consisting of Brian Koons, Jim Casper, and Carlos Deternoz, under the advisement of Darryl Senne.

In a curtainwall manufacturing facility, parts and components are delivered from vendors in order to be assembled. The majority of the parts come prefabricated and ready to be installed, such as the glass, gaskets, fasteners, and thermal isolators, while some require some degree of cutting and drilling, such as the aluminum extrusions, using a computer numerical control (CNC) programed EMAG. Smaller parts that can be pre-assembled prior to being installed in the unit are grouped together to form sub-assembled parts. Starting with the aluminum framing, the parts, materials, and sub-assemblies are strategically installed in the unit followed by the addition of the glass, or architectural spandrel panel, and subsequent caulking, which are the last steps in the production line. However, a very important step in producing unitized curtainwall comes after each unit is successfully built: packaging. Proper packaging protects the units during shipping and lifting which ensures the units are delivered to the job site in good condition.

In the past, curtainwall units have been packaged in wood bunks consisting of two to four units. The units are placed on a wood base, glass facing up, and then stacked on top of each other with padded wood in-between units. When complete, the bunk is flipped on its side such that the male or female vertical mullion is at the base. The structural basis of the wood bunks is that of a moment frame. The wood and connections maintain stability of the truss to prevent any distortion due to lateral unit loads that are primarily induced during shipping. Currently, we have moved towards using steel re-usable bunks which have proved to reduce costs, improve product safety, reduce labor and time, as well as promote sustainability.

FIGURE 1
Wood bunks are not reusable and a high quantity of wood, screws, and banding is required to create a structurally stable bunk.

FIGURE 2
Bunks from the San Francisco Museum of Modern Art FRP wall.

COST REDUCTION

Unit weights can range from 500 pounds to over 2500 pounds, depending on unit dimensions, glass composition, and presence of steel reinforcement. Due to the large weights, wood bunks require high strength wood to be used. Normally, visually graded No. 3 (minimum) treated Southern Pine is used, or an equivalent wood species. Due to the quality of lumber and the fact that it is unable to be re-used, material costs are very high. To achieve structural adequacy, wood screws must also be used in lieu of nails. Although nails are inexpensive and can easily be inserted with a nail gun, they are relatively weak and tend to pry-out over time. Wood screws provide a much higher tensile capacity at the expense of a higher cost.

Steel bunks may have a higher upfront cost due to the material and fabrication, however, steel parts can be reused over the duration of a construction project and even for multiple jobs in succession if painted to prevent rust. Additionally, the price of steel parts vary drastically by section type which influences bunk design greatly. Channels and angles can be procured for a fraction of the price of W-sections and HSS. In order for the bunks to be reusable, they must also be able to be assembled and disassembled to a certain degree. Consequently, the majority of part connections must be bolted assemblies. Wood bunks are not able to be taken apart without destroying the integrity of the wooden members and fasteners. Although stainless steel fasteners will last longer since they provide better corrosion resistance than tempered steel, they have reduced strength and would require a higher quantity to be used. Also, once bunks reach the construction site, bolts can easily be misplaced. Therefore, it is better to use zinc-coated steel fasteners due to their increased capacity and moderate corrosion resistance. Additionally, steel or zinc-coated steel fasteners are generally less expensive than stainless steel.

Reducing the time it takes to bunk units is another advantage of using steel reusable bunks that saves money. Wood bunks require constructing the bunk around the units as they are stacked by cutting down the wood to size and nailing in place. This requires a lot of time. Steel bunks, on the other hand, are pre-engineered to fit the unit exactly and only require fastening together with the specified bolts. The reduction of time spent bunking units helps with costs since it enables units to be bunked and moved to storage faster, freeing up space and personnel to perform other tasks.

SUSTAINABILITY

A big focus for buildings and architecture is achieving a high level of sustainability. This is accomplished through energy efficient designs and the selection of reusable materials. The U.S. Green Building Council evaluates buildings and awards Leadership in Energy and Environmental Design (LEED) ratings, which is a big incentive for building developers to pursue sustainable buildings. A building with a high LEED certification does not only reduce energy costs, but also serves as a marketing tool to promote a company's brand, recruit and retain employees, and promote sustainability. In this day and age, people are more environmentally aware and aim to take the necessary measures to preserve the environment.

Although a LEED certification only pertains to the building and its components, it is important to promote sustainable designs and measures in all aspects of business operations. A typical Manhattan skyscraper is cladded with thousands of curtainwall units. Each unit was shipped to the construction site in a certain type of package, normally a wooden bunk. Replacing the wood bunks with a better, environmentally friendly alternative is a great opportunity to strive towards sustainability.

Sustainability is a major reason we pursued designing reusable bunks. Steel is one of the most recycled materials in the world. Its properties allow it to be reclaimed with nearly zero reduction in quality after each iteration. Due to its recyclability, structural capacity, and its availability in standard shapes and sizes, it is an obvious choice of material to use. Furthermore, having a reusable design allows for fewer bunks needing to be produced per project since the bunks are sent back from the job site to the manufacturing facility to package new units. Due to the durability and corrosion resistant paint, the bunks can also be used for several jobs consecutively before being retired and recycled yet again.

SAFETY

Another major advantage of using steel bunks is that units are less prone to being damaged in transport in comparison to wood bunks. The wood members and screws are relatively weak and may fail during transport. Additionally, wood may come into contact with the unit which causes scratches or other visible marks. Steel bunks provide unit safety in addition to having units be suspended, in which no part of the unit is in contact with the bunk frame.

Using steel reusable bunks is also safer for workers since they improve ergonomics and allow the bunking process to be less labor intensive. Wood bunks require the use of hazardous tools, such as table saws and nail guns, and manually placing and fastening members to the bunk frame. Steel bunks, on the contrary, are preassembled and placed in position using a bridge crane. Since each steel bunk type is designed to accommodate specific units, the only manual task required is fastening the parts together with an impact driver. OSHA specifies that such changes can greatly reduce physical demands on workers which can lower injury rates. This also leads to an increase in work productivity.

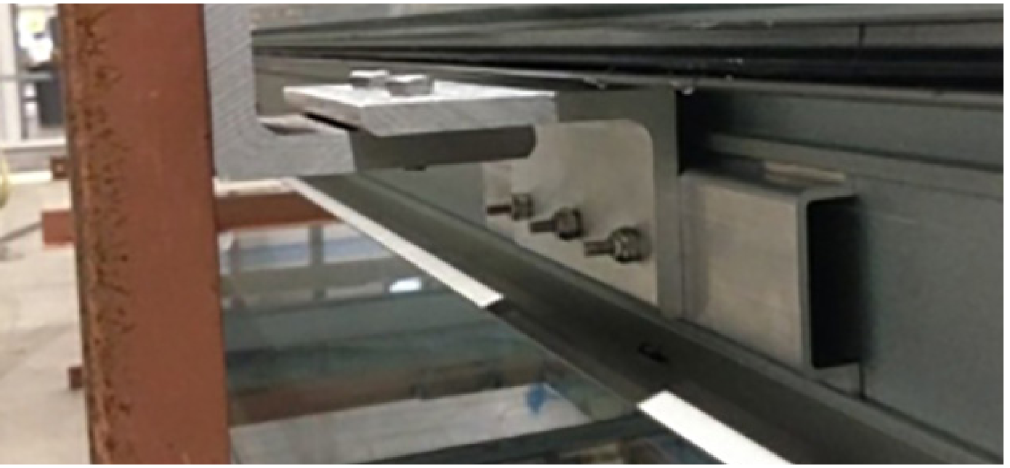

FIGURE 3
Reusable steel bunk frame for Capital One Block B that allows for the unit to be suspended between vertical channels.

FIGURE 4
A custom extruded hat channel slides within a notch in the vertical mullion allowing the connection to the bunk frame by a double angle support.

FIGURE 5
The final state of the bunk consists of three units stacked on top of each other. The entire bunk is lifted using an eight point spreader bar.

FIGURE 6
Three-dimensional CAD drawing.

FIGURE 7
Stone on truss units in steel bunks in shop preparing for delivery to New York.

CAPITAL ONE BLOCK B

Capital One Block B was one of the first projects to utilize the reusable bunking concept. The bunk design revolves around the concept of suspending the unit within the bunk frame. For this project, the vertical mullions had notches specifically designed into the extrusion profile solely for bunking. The notches allowed a foot long aluminum hat channel to slide along the mullion length. The hat channel acts as a connection point for a double angle assembly back to the steel bunk frame. The first angle, connected directly to the hat channel, is aluminum while the back angle, connected directly to the bunk frame, is steel (Fig. 4).

The bunk frame design is modular in that each bunk is composed of three tiers of frames that are bolted together (Fig. 3). Each bunk frame consists of four columns composed of C4x5.4 ASTM A36 channels. A L3x2x3/16 ASTM A36 angle runs along the side of the unit between adjacent channel columns and bolts to the channel webs. Another L3x2x3/16 ASTM A36 angle runs across the unit width and is welded to each channel flange. The length of the welded angle changes with respect to the unit width while the bolted angle length remains constant for all unit types. At the top of the channel, a 1/2" ASTM A36 plate picking eye is welded to the interior of the channel web. When the frames are stacked on top of each other, the hole in the picking eye allows each frame to be bolted together.

Typically, each bunk contains three frames stacked on top of each other, each supporting one unit, equaling three units per bunk. Portions of the unit extend past the bunk frame. The max allowable cantilever of the unit is generally three feet to prevent damage to the unit induced from self-weight deflections. Therefore, for longer units, there must be two bunk frames positioned

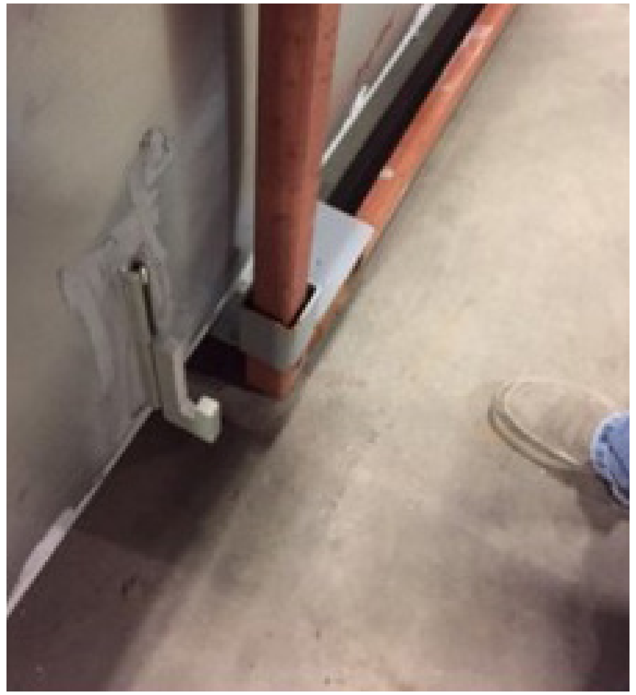

FIGURE 8
A photograph showing a complete bunk used for 220 Central Park South.

FIGURE 9 + 10
An aluminum sleeve at the top of the bunk is secured around the chicken head on the head mullion. Another aluminum sleeve at the base of the bunk has a leg that locates within the chicken head slot on the sill mullion.

FIGURE 11 + 12
Photo of progress of 220 CPS in June 2017 (left) and reusable bunks with project units stored at assembly shop (right).

on either end of the unit such that the unit is supported at eight locations along the vertical mullions as opposed to four. The bunk is lifted using an eight point steel spreader bar designed according to the dimensions of the bunks. Each pick plate is connected to the picking eyes at the top bunk or at pick locations at the bunk base by wire rope slings. The crane lifts the spreader bar from each corner using a four-leg wire rope bridle.

220 CENTRAL PARK SOUTH

Unlike the suspended bunks, the reusable steel bunks for 220 Central Park South require units to rest on their side within the steel frame. The base of the bunk was designed to be lifted via forklift, since that was the primary intended lifting method. The base of the bunk is composed of two HSS7x4x5/16 ASTM A500 Gr B tubes connected together by two C5x3 ASTM A36 channels (Fig. 7). The tube shape, size, and spacing were selected to accept the two forks of a forklift. To keep the units upright, vertical HSS2x2x3/16 ASTM A500 Gr B tubes are inserted and bolted into tube sleeves that are welded on the exterior webs of the fork lift tubes. There are also plate braces spanning between vertical tubes at the top to maintain stability of the frame.

For long and narrow units, the units rest on their side with either one of the vertical mullions at the base. The steel tubes on either side of the unit keep them upright so that three units fit within a bunk. For short and wide units, the units rest upright with the sill at the bunk base. In this case, there are two aluminum sleeves located on each vertical tube. The lower sleeve is dead loaded to the bottom of the frame. It contains a vertical leg that fits within the chicken head slot

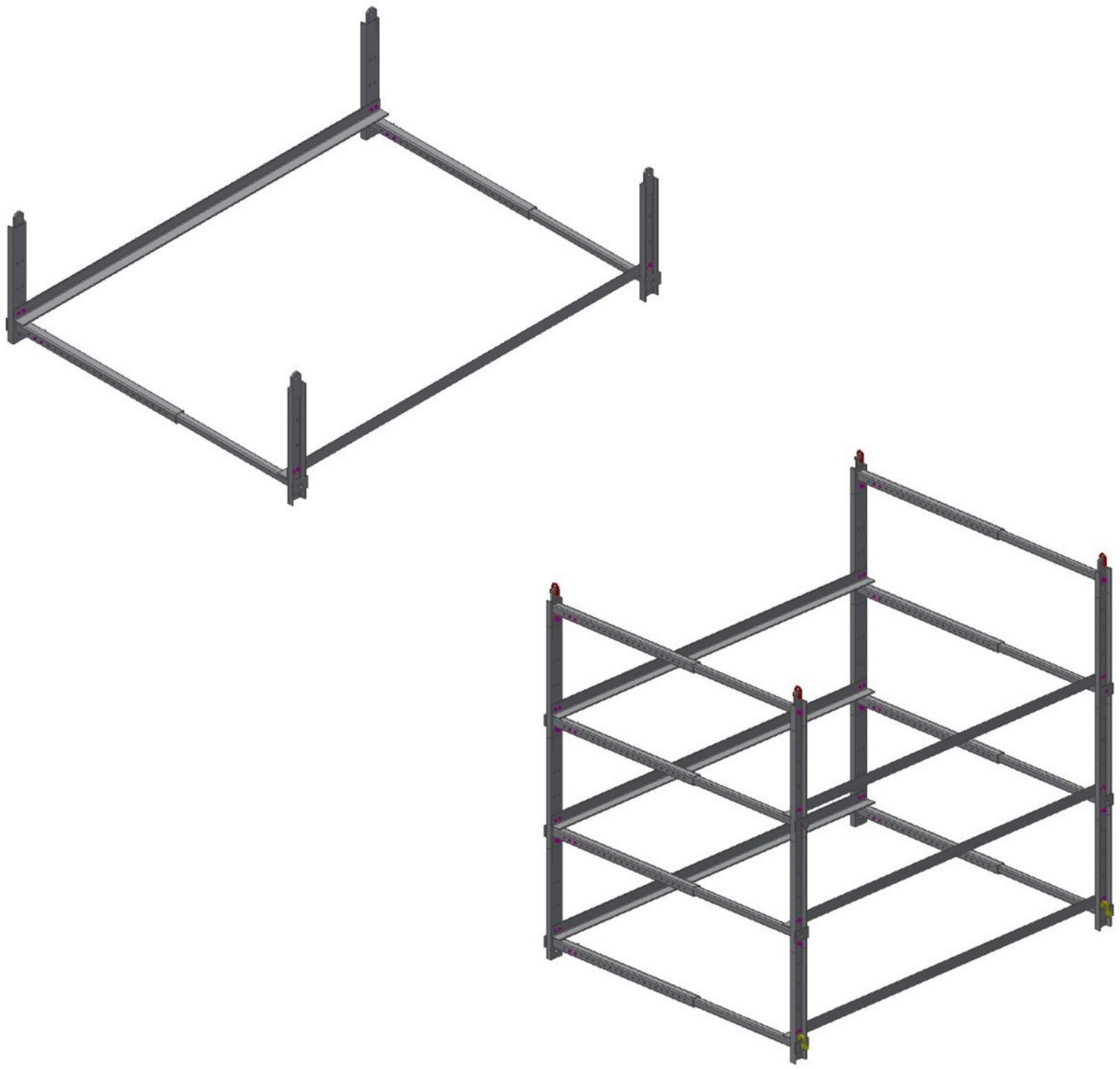

FIGURE 13
The suspended unit steel bunk design is being altered for the Penn First visual mock-up and performance mock-up. Each frame consists of telescoping tubes along the unit width dimension allowing the width to be adjusted for varying unit dimensions (left). The overall bunk is composed of three frames stacked on top of each other so that three units can be shipped per bunk (right).

in the sill. The other sleeve, located at the top, has a notch that securely fits around the chicken head. Together, these sleeves help prevent any lateral movement of the unit during shipping (Figs. 8 - 10).

Due to the unit sizes, another bunk design was used for Pilaster units. In this design, the units stand on their side while resting on a custom steel pallet. Diagonal angle braces are added in the long dimension to maintain stability and prevent distortion. In the short dimension, the units are sandwiched between two channels that span the length of the bunk. The channels are connected to a bunk via a T-bolt connection to a flex-strut anchor channel that is welded to the bunk frame. The anchor channel allows for the unit supporting locations to be adjusted acoordingly. These channels also serve as an anchor point to prevent the units from moving during transport. In order to anchor to the channel, a hook shaped plate is bolted to the unit mullion which grabs onto the flange of the channels. Additionally, the design of the bunk allows for unit accessibility which helps with offloading the units. For this job, a custom hydraulic-powered fork-lift boom, coined the Batwing, was used to remove the units from the bunks.

PENN FIRST

Due to increased variance in unit dimensions, the suspended steel bunk design is being altered for the forthcoming Penn First project so that the frame can be adjusted to accommodate varying unit widths without any cutting and welding. Although the job is not currently in production, the bunk design shown here is being used for the visual mock-up and performance mock-up units. Therefore, a single bunk frame size can accommodate all unit skews since it can expand and contract in the unit width direction. Instead of a welded angle, telescoping tubes traverse the unit width connecting the channel columns on either side of the unit together. One of the tubes has holes drilled every two inches along the length so that the bunk width can be adjusted at two inch increments. A clevis pin secures the tubes from sliding once the desired width is set.

The dimension along the length of the unit was also increased so that a single frame can hold a wider range of unit lengths, further reducing the amount of materials required. Previously, two frames, one at each end of the unit, were necessary for a typical unit length seen on projects. As before, the units are suspended by double angle supports connected to a hat channel that fits within a custom notched vertical mullion.

CONCLUSION

The use of reusable bunks to package unitized curtainwall has proven to be an effective measure to ensure product quality and successful production operations. The ability to reuse bunks through a project's life, in addition to multiple projects in succession, reduces long-term material costs relative to bunking every unit in an unpredictable wood frame. Additionally, the inherent strength of steel and its ability to be used in various designs and connection types increases the structural integrity and stability of the bunks, which in turn promote product safety during shipping and handling. Decreases in the physical demands and assembly time of workers is also an apparent result of using pre-fabricated steel. Lastly, the use of reusable bunks emphasizes Enclos' advocacy towards sustainability since the steel can be easily recycled. Steel bunks are just one example of successful innovations to our standard operations and practices and we hope to proactively seek sustainable solutions in other areas of our company in the future.

COMPLEXITY

BUILDING COMPLEXITY: DESIGN APPROACH BEHIND A PREFABRICATED DOUBLE-CURVED FACADE

NOVEL USES OF METROLOGY ON GEOMETRICALLY COMPLEX FACADES

PARAMETRIC WORKFLOWS FOR COMPLEX ENCLOSURE STRUCTURES

[0] *This article is a reproduction of the research that comprised a paper — under the same title — delivered at the Advanced Building Skins 2015 conference at Graz University of Technology.*

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