Prefabricated Exterior Wall Panels for Commercial Building Enclosures

Kenneth C. Loush, P.E.
Member NIBS, ASCE, NSPE, CFSEI

ABSTRACT

Offsite fabrication in construction is growing in popularity and scope. Prefabrication of exterior wall panels expedites schedule and improves quality of the final product. This paper discusses the benefits as well as the process of prefabrication that differs from traditional field built construction. Many wall panel fabricators provide only framing and sheathing. The case studies examined here include complete wall sections including framing, exterior sheathing, air barrier, outboard insulation and finish. A wide array of cladding systems are available insuring architects their design intent will be satisfied. In addition, prefabricated wall panels have performed well under developing energy codes, including passive house requirements. Exterior wall panels easily contribute to LEED status if necessary. Besides finish and aesthetic options, the design team has flexibility in choosing a wall system or type. Prefabricated exterior wall panels can be rain screens or barrier walls. Sealing between panel-to-panel joints can be accomplished using pre-cured silicone gaskets (dry seal system) or double caulk joints (wet seal system).

INTRODUCTION

Research shows that off-site construction generally improves project schedules, improves final product quality, minimizes risk and liability and lowers overall construction costs. When considering prefabricated construction components, whether complete living modules, bathroom pods or wall panels, it is important to understand that these components are all manufactured from the same materials as traditional construction. And, labor is required to assemble/fabricate, handle, deliver and install the components. So the material and labor costs may or may not be less than a traditional field built building. The benefits are realized in other aspects of the construction process. Prefabrication encourages a manufacturing approach to building components in lieu of a construction approach. It has been estimated that 57% of construction activities are wasteful and non-value adding. While, on the other hand, 62% of manufacturing activities add value. [1] By reducing waste and adding value, prefabrication improves building efficiency. Traditional contracts reinforce risk aversion at the expense of collaboration between subcontractors resulting in higher cost, reduced quality and elevated risk. Early engagement of offsite contractors encourages collaboration and controls the workflow process. Typically, prefabricators are able to maintain a steady workforce with few labor transitions contributing to a high quality finished product.

BENEFITS OF OFFSITE EXTERIOR WALL PANEL FABRICATION:

At face value, prefabricated exterior wall panels may or may not present a monetary savings as compared to field built construction. However, upon investigation by astute general contractors, cost savings can be applied to the offsite construction option by analyzing its benefits.

Offsite construction of exterior wall panels is done in a **climate controlled environment**. There is no time lost to bad weather. Furthermore, these ideal working conditions result in high quality wall construction. For the most part, panels are built while "laying on their back". The various trades are essentially working on a table, with their eye on the finished product as fabrication proceeds from frame to exterior finish. For example, it is easier to layout a sheet air barrier on a horizontal surface than try to adhere it to a vertical wall. Consider two workers on a scaffold trying to neatly adhere this same barrier at 50', 100' or 200' above grade; it is obvious how much more difficult this task becomes in the field.

Third party **inspection is a much simpler task** in the shop as well. There still may be field inspection required during panel installation but the critical wall construction can be closely monitored in the shop.

The high quality of the finished wall panels **insures high performing energy efficient** building enclosures. Wall panels have been successfully used on passive house designed commercial buildings. These building enclosures exhibited extremely air tight barriers with critical attention given to outboard (of the stud cavity) insulation and thermal breaks throughout.

The **jobsite is safer** when field work is minimized through the use of prefabricated exterior wall panels. Fewer workers are required onsite to close in the building. A typical panel crew includes 6 workers (2 on the truck rigging/unloading panels and 4 on the building floors attaching panels to the structure) and a crane operator. Stored material onsite and jobsite congestion are minimized by using prefabricated wall panels. Depending on installation production and number of panels per truckload, only one or two flatbed trailers with panels for installation are required onsite every day.

The panel fabricator's scope can be optimized to the project's benefit. More work performed in the shop means less work required in the field. **This increases the building's speed to market, reduces cost and provides the client with a single source of responsibility for the building enclosure**. So, items like punched windows, louvers, PTAC sleeves, penetrations, electric boxes, etc. can be designed into the wall panels and installed in the shop. A potential drawback to this approach is the need for the architect and owner to have details and locations for all of these items worked out early enough so that they can be included in the wall panel shop and fabrication drawings.

Working with experienced prefabricators adds a layer of knowledge, engineering and management to your project. This insures the success of a prefabricated building enclosure solution.

TYPES OF PREFABRICATED WALL PANELS

There are several types of prefabricated wall panels used for commercial construction. Availability is dependent on project location and proximity to prefabricators. Prefabrication tends to be a regional business since transporting wall panels over long distances may adversely affect the competitiveness of the prefabricator.

Precast concrete wall panels are available with a variety of finishes. Insulation can be sandwiched between an inner and outer layer of concrete to offer an improved R-value over a totally concrete wall. The typical manufacturing method for precast concrete is "down-casting." In other words, the finished face of the wall panel is the bottom of the form. This allows the design or finish in the form to be captured on the face of the wall panel. Unfortunately, the end result is not known until the panel is pulled from the form. Any miscues during the manufacturing process will show up in the final product. Due to size and weight of precast concrete panels, a limited number, frequently only one panel, can be shipped on a single truck. Concrete panel's higher weight (than typical cold formed steel framed panels) may require a bigger crane for installation and a heavier building frame to carry the concrete panels compared with other panel systems.

Frame only wall panels are manufactured from cold formed steel studs and track with bridging as required. These frames can be welded, screwed or riveted together. Field labor required to assemble the frames in place. The frames are shipped to the site and attached to the structure using powder actuated fasteners, concrete screw anchors or expansion anchors. In many applications, frame only panels will be manufactured with sheathing and air/weather or air/vapor barriers. Obviously, any work not performed in the fabrication facility will need to be completed in the field and be subject to all the drawbacks of field construction. Even if air/weather barrier or air/vapor barrier are shop installed, joint treatment will be required in the field to seal the panel-to-panel joints.

Frame-to-Finish wall panels start as if frame only wall panels. In this case, a complete finish including outboard insulation is done in the fabrication facility. Panel-to-panel joints can be effectively sealed one of two ways. A double bead of sealant is placed and tooled in a two-step process using open cell backer rod on the inner bead and closed cell backer rod for the outer bead. Caulk is installed, typically from a swing scaffold, after all panels are hung. An option to caulk is pre-cured silicone (dry) gasket joints. Gasket joints require the addition of aluminum extrusions at the panel perimeter. Gasket joints have the benefit of providing a weather tight enclosure as soon as the panels are installed and the swing scaffold step (and expense) is eliminated.

This paper will focus on Frame-to-Finish wall panels.

THE PREFABRICATION PROCESS - EXTERIOR WALLS

Design Assist has become a popular project delivery method for building enclosures. By introducing building enclosure subcontractors into the design process early, the project will *"…benefit… (from) improvements in design efficiency, better managed cost, speed to market and constructability*." [2] The exterior wall subcontractor is uniquely positioned to contribute knowledge and experience to the good of the overall project with positive effects on quality, schedule and cost.

If required by contract, shop drawings for visual and/or performance mock-ups are prepared and submitted for approval. Once approved, visual mock-ups are fabricated and erected onsite or at the fabricators shop to verify the end product matches the owner's vision and architect's design intent for the building enclosure. Likewise, performance mock-ups are fabricated and erected in the fabricator's shop or at an independent laboratory in preparation for third party air, static water, dynamic water, structural, movement, thermal and seismic testing as required.

In a traditional Design-Bid-Build contract approach, following scope definition, bidding/negotiation and final contract, panel design and detailing begins. The initial step is to **layout the building structure** using 3D BIM software, such as Revit, that will support the exterior wall panels. Critical information includes:

1. Type of structure (frame, slabs, etc.)
2. Structural Engineer of Record's preferred load path,
3. Column and beam locations,
4. Slab edge locations,
5. Adjacent conditions (foundations, storefronts, window walls, curtain walls, roofing, etc.).

Panel layout can proceed with specific attention to panel connections to building structure and adjacent panels. **Panel joint size and location** are dictated by several factors and have both aesthetic and technical implications. In order to satisfy the design intent, panel joints must located so that they add to rather than detract from the appearance. For example, joints can be hidden at inside corners of façade projections or can be boldly located so that they are clearly visible and a part of the aesthetic. Another critical element of joint design is the anticipated amount of movement the structure will experience in its life. Amount of relative movement between adjacent floors is provided by the Structural Engineer of Record. This is incorporated into the panel fabricator's design criteria. Typically, panel-to-panel joints are ¾" or 1" wide.

Other considerations for panel layout include:

1. Window locations,
2. PTAC locations,
3. Miscellaneous penetrations,
4. Balcony locations,
5. Canopy locations,

6. Other adjacent conditions

Panel size and configuration is determined to large extent on the building structure. Connection locations and framing span lengths are major factors in the framing member design (size, thickness, spacing, flange size). The most common configurations are horizontal panels that span floor to floor and are up to 40' 0" long, vertical panels that may span two or three floors and are 8'0" to 12'0" wide or a combination of vertical column panels with horizontal spandrel panels. These panels are dead loaded on the upper floor slab with lateral panel-to-panel connections at the panel bottom. If floor slabs are unable to handle the panel dead load, an option is to design the panel as a truss that spans column to column and provide dead load connections at the columns. Another version of column/spandrel panel combination is the spandrel with infill panels between strip windows. In this case, horizontal spandrel panels provide the main focus with a horizontal, wrapping style. Strip windows are above and below the spandrel panels and may be interrupted by narrow infill panels set between upper and lower spandrel panels. Yet another type of panel is the knee wall. This occurs where a short panel only has one point of connection at the bottom of the panel. This connection must be a moment connection resisting shear and rotation at the panel base. Other panel configurations include "letter" panels, such as 'C', 'E', 'M', or 'U' shapes, and corner panels with returns from 8" to several feet long.

Shipping and handling panels must be considered when determining panel size and configuration. After a panel is fabricated, it must be able to be loaded on a flatbed, single or double drop trailer that must then, be able to leave the shop and travel over the road without damaging the load. Upon arrival at the site, each panel must be able to be unloaded, craned into place and attached to the building structure. If any of these steps are prohibited by the size and/or configuration of the panel, then that panel must be re-designed.

At this time, building elevations with the panel layout are submitted to the architect for approval of the layout. Then **shop drawings**, including plans, elevations, sections, details and connections and **engineering** proceed in earnest. Using finite element analysis, engineers analyze the panel structure and develop reactions for connection design. Panel frames consist of cold formed steel studs and track with bridging and HSS, or tube steel, as required. Structurally, panels exhibit a curtain wall design, a truss design or load bearing design. Engineers evaluate load combinations using the appropriate edition **of ASCE 7 code**, including:

1. Dead Load,
2. Live Load,
3. Wind Load,
4. Earthquake Load,
5. Snow Load,
6. Ice Load.

Building movements are also considered including vertical deflection, lateral deflection, inter-story drift, creep (concrete columns) and thermal movements. Values assigned by the Structural Engineer of Record are incorporated into the panel and connection design of the Delegated Design Engineer working for the panel fabricator. Movements are important considerations when determining the panel-to-panel joints and connection design.

Concurrent with shop drawing and engineering development, the subcontractor/fabricator will submit material and product information, product test results including color samples for approval by the design team.

WORK FLOW PROCESS

Regardless of contracting method, the wall panel fabricator should have milestone check points throughout their workflow process at which internal coordination takes place. Typical stage gates include:

Turnover Meeting – When a contract is signed between general contractor and wall panel fabricator, all pertinent information must be disseminated throughout the fabricator's company. This information turnover is presented by the sales and estimating group to all facets of the company so that work can begin on the project. Team members are assigned including project manager, lead designer, drafters, engineer, plant location, and the administrative staff. The project manager begins work on the project plan which includes budget, schedule and quality control program.

Preliminary Design Review - Early in the process, all business functions (sales, estimating, project management, design, drafting, engineering and manufacturing) convene to review the panel layout and special conditions and challenging details throughout the project, such as, adjacent to dissimilar materials (curtain wall, window wall, storefront, field applied work, etc). At the conclusion of this review, everyone in the organization should be in agreement and the design effort, shop drawing and engineering may proceed with clear direction.

Weekly Team Meetings – Organized and conducted by the project manager, these internal meetings keep the entire team appraised of project status and track the project budget and schedule. This forum is used to bring issues to the forefront so that expedient methods for solving problems can be laid out and responsibilities assigned to team members. Design questions may be briefly discussed in this venue but if a satisfactory solution is not readily forthcoming, a separate design meeting should be scheduled for all pertinent personnel.

Critical Design Review – Just prior to submission of shop drawings and engineering for approval, the same players who participated in the PDR should meet to review shop drawings. There should be confirmation that the direction provided during the PDR has been followed in design, drafting and engineering and the fabrication and installation of wall panels will result in a high quality end product on schedule and within budget.

Manufacturing Readiness Review – As the manufacturing group readies for production, a meeting including design, engineering, manufacturing and project management should be held to confirm manufacturing has what it needs to efficiently begin fabrication. Materials, labor and information (drawings, sequencing, etc.) must be complete and correct so that fabrication will run smoothly.

Preconstruction Meeting (onsite) – Preconstruction meetings are typically held onsite by the general contractor or construction manager. This coordination kick-off meeting reviews the general contractor's expectations for subcontractor performance, logistic plans of subcontractors and coordinates efforts of various subcontractors working simultaneously at the site. This is the time for the exterior wall subcontractor to note any deviations in work that has been completed already that may adversely affect wall panel installation (such as missing or misplaced embeds in concrete, etc.).

Once shop drawings including panel layout are approved, planning and coordination turns to **panel sequencing**. Where will installation begin and how will it proceed? These questions are critical because all activities from this point onward will follow the established sequence. Fabrication drawings are created and checked in sequence. Panels are fabricated and loaded on trucks in sequence. On each truck, the last panel loaded will be the first unloaded at the site and installed on the building. So, it is of utmost importance that panel sequence be followed.

A major benefit of offsite construction is simultaneous construction activities. In other words, while foundations and structure are being built in the field, panels are being fabricated in the shop. Ideally, the panel fabricator will have 50% of the project fabricated and on trucks, shrink wrapped and ready for delivery to the site for installation. Fabricators work to stay in front of the installation crew to prevent interruption of panel installation. Ideally, panel fabrication will be complete one to two weeks ahead of the installation crew onsite requiring the last panel to install.

Prior to the first panel delivery, the wall panel installation crew begins layout work at the site. The general contractor provides axis lines from which the panel crew can measure offsets to the back of panel frame, typically 1" off the edge of slab. With this plane established, the panel crew installs connections on top of slab or face of slab as required. With connections in place, panels are hoisted from the truck to their final location on the building.

CASE STUDIES:

Brooklyn Academy of Music (BAM) Tower and Podium (aka 300 Ashland Place) is located on a triangular lot at the intersection of Flatbush Avenue and Lafayette Street in the Fort Greene section of Brooklyn. The podium enclosure employed frame through z-furring panels. A man-made crystalline glass with a glossy, milky white appearance was the field applied finish for the podium. The podium is home to an Apple Store, Whole Foods Market, a branch of the Brooklyn Public Library and the residential entrance and lobby for the tower. The 35 story residential tower includes market value and low income housing units along with theater and rehearsal space for BAM. The tower's enclosure is a composite metal (4mm fire core) rain screen with extruded silicone dry gasket panel-to-panel joints. The complex exterior wall geometry added a degree of difficulty to this building but by following the process illuminated above and maintaining a high level of coordination between members of the design team, the result is a high quality building enclosure that fit together flawlessly and is quite attractive.

This building is a long, narrow structure. The long elevations, east and west, are faceted. Each elevation has an apex point at the 12th level at the approximate horizontal mid-point. Below the apex, panels are forward tilted, i.e, the top of the panel is farther from the building centerline than the bottom of the panel. Above the apex, the panels are back tilted, just the opposite of those below the apex. Facets at the north and south ends of the long elevations were plumb but angled in plan so that they would intersect the forward and back tilted panels. Facet intersections, or fold lines emanate from the apex points in a star burst pattern. The geometry challenged the prefabrication team but it is difficult to image that this enclosure would or even could have been built unless it was prefabricated.

The short elevations, north and south, have balconies for the end apartments. Due to the configuration of the balcony walls, significant field work was required. Panel walls were exposed on both front and back sides. Only one side was finished in the shop so the second side required installation of ACM pans or panels in the field.

Besides the complex geometry and the field applied work, other factors added to the challenges faced by the prefabrication team. Since the panels sloped and the windows were required to remain plumb, there were instances when window frames landed outside of the framing rough opening. To provide adequate support for the windows, liner plates were installed in the rough opening providing a solid attachment point for the window tanks. Windows were designed in two units. The first, a "tank", was installed in the panel rough openings while the panel was horizontal in the fabrication process. Once the furring clips, insulation and ACM finish were installed on the panel frame, panels were stood upright and the glass and surrounding frame were set into the window tank on butyl tape and screwed fast. Windows were then caulked in place, both inside and out.

PTAC unit sleeves were shop installed adding to the coordination exercise since the sleeves were sloped to match the facets of the exterior wall. Perforated aluminum plate was installed in front of the PTAC units for functional reasons to allow air to the PTAC unit. In some instances, the perforated aluminum plate served no function except for aesthetic appeal.

Shipping and handling of completed panels required more attention than usual due to individual panel geometry. Panels with fold lines demanded close attention to prevent damage as they were loaded in the shop and unloaded at the job site.

The gasket panel-to-panel joints eliminated the need for dropping swing scaffolding and caulking the joints. Panel to structure connections were bolted using embeds supplied by the panel fabricator and installed by the concrete subcontractor. By avoiding welded connections, the need for fire watch personnel was eliminated. Both these choices required spending more money upfront for gaskets, extrusions and connections but resulted in installation cost savings in the long run.

The **Cornell House on Roosevelt Island** is currently the tallest passive house certified building in the world. A complicated structure, not so much for the geometry, but for the passive house requirement which intensely scrutinizes the MEP systems (energy recovery systems), fenestration (triple pane windows) and building envelope. The enclosure must be air tight, properly insulated and contain no thermal bridges. The stringent passive house requirements make prefabrication a logical alternative given the inherent high quality of offsite constructed exterior wall panels.

The 24 story Cornell House provides housing for Cornell graduate students and professors working out of the

Roosevelt Island campus. The barrier system enclosure is finished with 6mm fire core composite metal with up to 5" of mineral wool insulation outboard of the stud cavity and 6" of mineral wool insulation in the stud cavity. A vapor permeable air weather barrier is applied over the exterior sheathing and a vapor barrier was installed on the back of panel frame, prior to interior drywall installation. All vapor barrier joints were taped and the vapor barrier was taped to the inside window frame at rough openings to insure an air tight interface between panel and window.

The stud cavity insulation landed in the prefabricator's scope and an attempt was made early on the install as much stud cavity insulation as possible in the shop. This became problematic because the insulation didn't always stay where it was supposed to during shipping and handling. Therefore, it was determined the proper approach is to install only that amount of stud cavity insulation that could be controlled and remain in place until to panel reached its final resting spot on the building.

Bolted connections were used on the Cornell project eliminating the need for fire watch personnel.

Both BAM and Cornell included performance mock ups in the fabricators scope. These were fabricated according to approved shop drawings, shipped to the third party laboratory, Intertek in York, PA and tested. As usual, during testing, improvements in fabrication and installation became apparent and were incorporated into the manufacturing and construction processes.

Both BAM and Cornell employed a design assist component early in the design process so that contributions from all subcontractors could be incorporated into the projects resulting in high quality, buildable enclosures with minimal questions and confusion in the shop drawing and manufacturing stages.

CONCLUSIONS

Commitment to offsite construction is a commitment to design, engineering and coordination. This differs from field built construction where conditions, expected or not, are handled as they come up in the field. By addressing these conditions early in the process, the prefabricator and general contractor develop a strong understand for the project, become proactive instead of reactive to field issues and generally construct a higher quality project overall. Other factors contributing to higher quality in offsite construction relative to field built construction are working in a controlled environment and simplification of activities for labor. Delivering offsite construction components to a construction site for installation can save 40% to 50% of field construction time. Less time on the job with fewer personnel adds up to reduced risk and liability along with quicker to market timing for the owner.

Not every project is a good candidate for prefabrication. However, the benefits are significant enough to require a due diligence evaluation. And, if prefabrication makes sense, then the design team should engage a reputable subcontractor and begin the design assist process to maximize the benefits.

ACKNOWLEDGEMENTS

The author acknowledges the dedication and hard work of co-workers and management at Eastern Exterior Wall Systems, Inc. to each other and to providing high quality building enclosures on time and within budget.

BAM Tower and Podium:

1. Architects: Ten Arquitectos Architects and Ismael Leyva Architects
2. General Contractor: Two Trees Management Corp.
3. Wall Consultant: Vidaris, Inc.
4. Structural Engineer: Rosenwasser
5. Special Consultant: Front, Inc.

Cornell House:

1. Architect: Handel Architects

2. General Contractor: Monadnock Construction
3. Wall Consultant: Vidari, Inc.
4. Structural Engineer:
5. Passive House Consultant: Steven Winters Associates

REFERENCES

1. **WBDG – Offsite and Modular Construction Explained** by Tyan E. Smith, University of Utah, Chair, Offsite Construction Council, NIBS, 8-9-2016.
2. **Design Assist** by Garske, T., Keener, E., Ortman, J., Horvath, J., Wangler, M., Sleeper, R., Metz, S., Ohio Construction Transformation Consortium.