Case Study: Off-site manufacturing of EIFS Panelized Wall Assemblies to Gain Efficiency in Construction Sequencing

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ABSTRACT
This paper examines the process of constructing modular EIFS (exterior insulation and finish system) panelized wall assemblies in a manufacturing environment. The research observed the preparation required, manufacturing procedures applied, measured task times at dedicated work stations and identified bottlenecks that factor into the comprehensive approach to planning and building the exterior envelope off-site. The paper summarizes the results of 70,000 SF of EIFS panels manufactured over 70 days in a 110,000 SF facility located in Tempe, AZ. The benefits (quality control, safety, labour efficiency) and challenges (transportation, hoisting, and cost) in relationship to the traditional construction requirements for in-place EIFS systems is also analysed in this paper.

KEYWORDS
Panelized; Manufacturing; Prefabrication; Off-site Construction; Building Information Modeling (BIM)

INTRODUCTION
The construction industry is seeing a shift from the traditional building process to one that begins to view the building as component parts that are prefabricated offsite and systematically assembled in place. The reasons for this shift in construction practice can vary depending on the region but some common factors that are driving the movement are (Lu et al, 2014): Lack of skilled workers, schedule stress, constrained sites (no laydown area), safety (in and outside of the fence) and limited site access.

This "trend" in the industry is becoming much more accepted and according to the BIM Forum 77% of contractors surveyed noted that as of 2016 the use of offsite prefabricated components has grown over a 3 year period and 35% of those surveyed have seen the amount of prefabricated components triple on their jobs (Cowles 2017). This has led to efficiency gains for labor, schedule, constructability and safety on projects. One of the leaders in offsite construction is M.A. Mortensen Company. In 2014 they released a study based on their successful use of offsite prefabrication on Saint Joseph's Hospital in Denver, Co. The study showed a 1.13 benefit-to-cost ratio in which every dollar spent on prefabrication approximately 13% of the investment was returned as a quantifiable benefit to the project (Benefits of prefabrication…, 2014). The project studied contained 376 headwalls, 440 bathroom pods, 166 multi-trade racks and 346 exterior panels which were built in an off-site warehouse.

Mortensen brought similar offsite strategies to Arizona in 2017 and applied the concepts to The Hampton Inn and Suites built in downtown Phoenix. The constrained site limited the amount of laydown and staging available and lent itself to a prefabrication solution. Chase Gibbs, Mortensen project manager, indicated that speed was a major driver to utilizing prefabrication. "Most of our owners always want things quicker and cheaper and in order to do that you have to find better ways of building it," Gibbs said. The approach shaved 2-6 weeks off the project. "The quicker you open to the public, the quicker you're going to gain revenue and the less overhead you're going to have to build it of course." (Jenkins 2017) Mortensen identified the exterior construction as a major driver in accelerating the project. Along with the exterior framing trade contractor MKB and manufacturer Kapture Prefab, they were able to preplan so the Exterior Insulated Finishing Systems (EIFS) could be panelized and built offsite in a controlled environment (Figure 1).

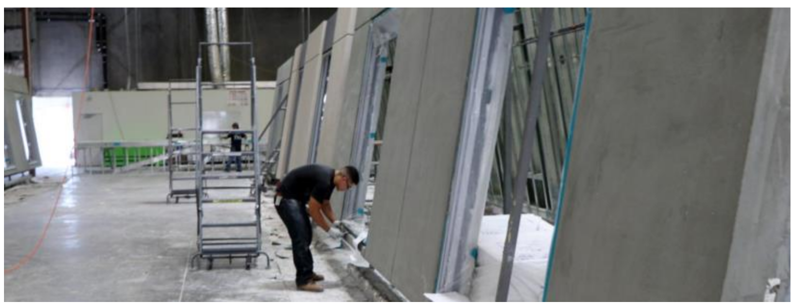

Figure 1. Panel plaster application for the EIFS system applied in off-site manufacturing factory.

By incorporating the trade partner and manufacturer in the design and preconstruction phase, the team eliminated the potential safety hazard of scaffolding and was still able to achieve the high quality EIFS finish that was specified. The project required an extensive BIM effort to properly plan connection details and installation of the exterior. (Jenkins 2017)

The focus of this paper is not to validate the success of projects identified in the introduction, but rather to give context to the research. The off-site manufacturing facility used as part of this study was engaged in the design and fabrication process for another Mortensen project, The Great Wolfe Lodge, which is a 350 room and 95,000 SF hotel and water park resort, in Scottsdale, Arizona. The repetitive nature of the exterior enclosure lent itself to prefabrication and utilized a similar EIFS exterior panelized system that was used on the Hampton Inn. The objective of this research is to examine the various manufacturing techniques utilized to produce the panel and the factors that help influence overall design and construction requirements to gain a better understanding of the effort to build the EIFS panels off-site.

METHODS

This research utilized a case study method that encompassed Participant Observation, Internal Documents Review & Analysis and Unstructured Interviews & Informal Discussions similar to what was used in *"Workflow Management Using Building Information Modeling (BIM) for Prefabrication in a Construction Retrofit Environment,"* in the dissertation by Dr John Cribbs. This research is an initial step in gaining an understanding of the complexity required to build prefabricated EIFS panel and to answer the question if the efficiency gain can offset the lack of skilled labor to perform a similar field task by planning using BIM and manufacturing offsite in a factory controlled environment. Although this paper is not as comprehensive as Dr Cribbs in his in-depth analysis of the mechanical, electrical and plumbing (MEP) trades, future research will be applied to the planning and fabrication of framing and finish plaster.

RESULTS AND DISCUSSION

This research is examining one component of a single project: prefabricated offsite – EIFS panel (Figure 2). The panels were designed in conjunction with the architect, the framing trade contractor and the manufacturing team. Once the design was agreed upon, the approved exterior envelope was then sent to a structural engineer who specializes in light gauge metal stud design. The structural engineer is responsible for sizing the light gauge steel, tube steel and pick points to allow the panels to be installed with a crane. The size of the panel can vary with the largest panel being 42'-4" in length, but the typical size for this project was 29'-6" x 9'-10" wide.

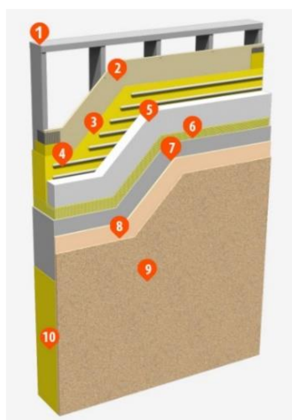

Figure 2. Exterior EIFS Panel Materials – 1. Metal framing 2. Substrate 3. Water proofing 4. Adhesive, 5. Foam insulation 6. Mesh 7. Base coat 8. Primer 9. Finished texture 10. Water proofing

BIM Process

The manufacturing team is responsible for creating fabrication sheets. The process to develop the detailed drawings is through the use of Building Information Modeling (BIM) which is common in prefabrication applications (Nawari, 2012). Although the sheet metal industry has been at the forefront of using BIM to efficiently produce drawings that can be fed into computer-aided manufacturing (CAM) machines (FMI 2012) to produce the final product, this is not the case in the workflow for the EIFS panels. The modeling to manufacturing process of the EIFS Panels is still highly reliant on digital drawings being read by shop fabricators rather than machine to machine data which is not uncommon in the construction industry. (Cribbs, 2016).

The modeling workflow consists of using a parametric model authoring software, Autodesk Revit, as well as a third party plug-in from Structsoft called MWF (Metal Wood Framing) to create the shop drawings. The architects Revit model was provided to the fabrication team and was used to create panel shop drawings. The MWF software was instrumental in populating the architectural model with standard framing sizes, spacing and connection details. The automated functionality was a great starter for the BIM team to gain a sense of the initial global parameters for panel layout but the actual fabrication sheets required extensive manual coordination between the detailer and structural engineer to achieve the desired result.

The BIM produced two (2) dimensional, two (2) sided 11” x 17” shop drawings that included an elevation and cross section of the panel. Side one is labelled “Panel Elevation” and specifies the exact dimensions down to the 1/8”. Keynotes are also added to each sheet identifying any unique feature of the panel such as architectural embellishments. The upper right of the sheet has a color coded legend with corresponding colors that matches the metal stud gauge used in the factory (Figure 3a). Side two is labelled “EIFS Elevation” and contains the finish dimensions as well as the architectural color scheme (Figure 3b). Each drawing has a unique sheet number that determines the sequence of fabrication, shipping and ultimately installation of the panel. A quality assurance (QA) checklist is at the bottom of each side and includes various specialty trades that may interact with the assembly of the panel. A total of 253 shop drawings were produced for the Great Wolfe Lodge and the shop drawings were often modified to respond to field conditions measured by the on-site framing contractor. This real time process added significant complexity and time to the BIM team because the constraints would compound through all the panels that were associated with the modification. The concrete and edge of slab were the most critical as-built elements that at times required the panels to be modified months after the shop drawings were submitted and approved. The workflow demonstrated during this research was ripe for errors to occur because of the lack of time to properly coordinate the actual field conditions with the exactness of the rigid dimensions of the prefabricated panels formed from the basis of a digital environment.

Figure 3a and 3b. Shop drawing side one BS6.2 - metal stud gauge, rough opening dimensions and notes. Shop drawing side 2 BS6.2A – Finished dimensions, EIFS color scheme and notes.

Manufacturing process

The manufacturing plant is located in Tempe, Arizona 13 miles from the Great Wolfe Lodge construction site. The plant has a 105,000 SF production floor and 5,000 SF of dedicated office space. The shop floor is separated into six (6) distinct sections: a sub assembly area, three (3) main production lines, a material storage space and a panel storage/truck loading zone (Figure 4). The

Great Wolfe Lodge panels were constructed in Production Line 2. The production line consisted of 24 stations. Thirty (30) full time equivalent (FTE) employees were assigned to the stations, eight (8) of which had more than two (2) years of construction experience. Eighteen of the workers were hired specifically for this manufacturing line. One bottleneck in the process that was anticipated by the manufacturing team, even before building the first panel, was the learning curve for new construction/manufacturing industry employees.

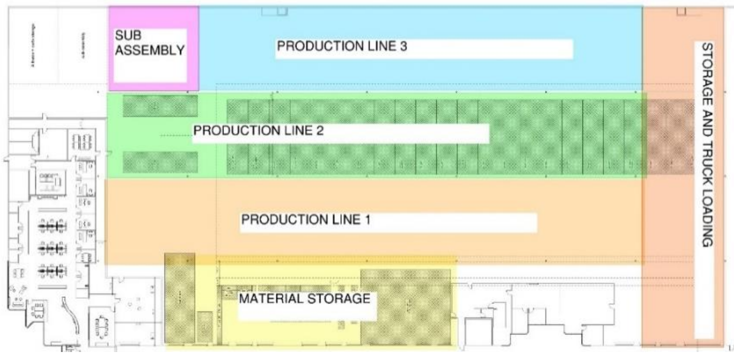

Figure 4. Manufacturing shop layout. Production line 2 was used for the Great Wolfe Lodge.

Station 1 (Figure 5): Two (2) framing tables that are customizable to any panel size are located at the first station. The shop foreman begins the production with a daily huddle where he provides the framers with the shop drawings that they will be working on that day. Four (4) Framers and one (1) welder are located at the station and are scheduled to assemble the framing and sheath a panel every 108 minutes which was based off the time that was required to construct the mock-up. The total task time between the two (2) tables is 216 minutes staggered so that all ensuing stations has a 108 minute task time. The second table was added early in the process because the single table could not keep up. The materials at station 1 include: 14 Gauge metal track, framing screws, tube steel for structural stability of each panel, engineered angles for lifting of panel, flat steel plate for lateral load connection (panel to panel), 4 ft x 11 ft exterior gypsum, and sheathing screws.

Figure 5. Station 1 – Framing of the panel starts the lines production

Station 2: Two (2) workers located at the station pour five (5) gallon buckets of waterproofing onto the panel and spread with a paint roller or brush. Fabric mesh in 4”, 6” and 9” width is then adhered to the panel. The mesh is applied over the seams created when the gypsum board is laid out and installed in station 1.

Stations 3 – 6: The fluid applied waterproofing requires a 24 hour dry time so stations 3 - 6 are drying stations. The stations are also used to screw the flanged windows into the panels. The window installation is done in batches and typically completed by one (1) worker from the window trade contractor and is not part of the plant operation. There were no windows onsite during this observation.

Station 7: 4'x 8' sheets of EPS Foam are then applied over the waterproofing using a sticky adhesive. The foam is cut with a utility knife or hot wire. Two (2) of the lesser skilled workers are assigned to this station. The two (2) who were working at the station had limited construction experience.

Station 8: This station has the most intricate work and requires personnel that are more experienced. Two workers were at this station. The project manager mentioned that the two (2) workers had to be the "smartest on line" because they are responsible for laying out the architectural reveals, pop outs and utilizing foam to square up the panel.

Station 9: One (1) worker was used to "rasp" the foam which is a process that breaks or roughens the face of the foam so the base coat can adhere properly. The other responsibility is to level the joints of abutting foam pieces.

Station 10: Two (2) workers trowel on a cementitious basecoat and embed a fibre mesh.

Stations 11-13: Drying stations with no workers assigned. The station is required for the cementitious basecoat to meet the 24hr specification for drying. No other material can be applied therefore Three (3) panels are queued up until they meet the 24hr rule and once they hit the mark they are then able to move to the next station.

Station 14: One (1) plasterer sands any inconsistencies that are found once the cementitious basecoat is dry and then applies a thin skim coat to give a smooth level surface. An experienced plasterer is assigned to this station as this was described as "art" to achieve the level of flatness required in the specification.

Stations 15 – 17: Drying stations with no workers assigned. The skim coat also requires a 24hr dry time similar to Stations 11-13.

Stations 18-20: The three (3) most experienced plasterers are responsible to apply the finish material to the panel. Different colors on the panels cannot be applied simultaneously because they will potentially blend together so the plasterer's apply one (1) finish color and then move onto the next panel at the station. They can apply a second color roughly 30 minutes after the first color has hardened. 30 minutes was programmed between the stations.

Stations 21-22: Drying stations with no workers assigned. The finished coat requires a 24hr drying period before the panel can be moved.

Station 23: Four (4) workers float between Stations 23 and 24. A Forklift is used to stack the panels and dunnage is placed between the panels to help prevent damage during shipping. The dunnage is typically ¾" plywood with foam (done during project prep but not observed in study). The panels are stacked three (3) high on average which is self-imposed by the prefabricator to limit the potential for damage due to the weight of the panels. The loads are considered "oversized" because the panels are 9'-10" wide. The State of Arizona, Authority Having Jurisdiction (AHJ), requires any shipment 8'-6" to 14'-0" wide to be classified as oversized and anything over 14'-0" would require pilot cars.

Station 24: The final station is used to load the panels onto a flatbed with a forklift. Three (3) to six (6) panels are typical for a load and are secured with ratchet tie-downs. The panels are stacked so the first panel being installed will be the last one on the truck. The number of panels per truck was determined by the shop foreman who took into account the weight and layout to maximize the load. The delivery is Freight on Board (FOB) destination which means that the manufacturer of the panels is responsible for delivering the panels to the site but once on site the ownership of the panels is taken by the framing contractor. The offloading and installation of the panels is typically done by a five (5) to six (6) person crew. Fifty-two panels remained to be fabricated at the time of the observation.

DISCUSSION

The manufacturing process requires extensive planning and even with the strictest process, traditional construction (cast in place concrete) tolerance can have a major impact on the overall workflow. To effectively apply manufacturing techniques to construction of the EFIS panel, all participants must acquire knowledge of the constraints that impact their production. In this research, instances occurred where the design of the panels were approved and ready for assembly but the site conditions dictated a change to the shop drawings. The reworking of the shop drawings left little time for coordination and understanding of all resultant impacts. Several instances of rework would not have occurred if the originally detailed shop drawings had been used for assembly. Due to the tremendous amount of back and forth between the traditional on-site construction and the manufacturing teams, clear communication is required. It was noted several times during the site visit that it is imperative that the architect, general contractor, trade contractors and manufacturer work together and allow flexibility to successfully marry the prefabrication with the onsite construction. This cooperation is necessary for prefabrication to be applied in a manner that can help resolve the challenges listed in the introduction: Lack of skilled workers, schedule stress, constrained sites (no laydown area), safety (in and outside of the fence) and limited site access. The manufacturing process used in the plant was extremely effective at isolating work so it could be completed with a blend of skilled and unskilled labor.

The product specifications had as much impact to the line as any other element. The waterproofing and finish material require a twenty-four (24) hour cure time. Consequently, work would be complete and then the panels would sit at drying stations creating a bottleneck on the line. The shop foreman was adamant that the material was dry and ready for the next station but was required to adhere to the specifications so the warranty would not be voided. The specifications are written for onsite installation, but the controlled shop environment could potentially have a different set of specifications to take advantage of the streamlined manufacturing process. The 108 minute task time was impressive when the line was moving but a bit deceiving. The overall cycle time to produce a panel is 2,592 minutes and spans five (5) work days. Stacking and loading the panels with a forklift was cumbersome and time consuming. An overhead gantry crane to be installed will, according to the shop foreman, reduce the time in half to what is currently being spent on loading. Loading the panels with a forklift created a few instances where the weight of the panel was too great and buckled the metal framing which crumbled the EIFS finish requiring the panel to be put back into the manufacturing line to be repaired. The installation sequence dictated how the trucks would be loaded and required ingenious stacking solutions to maximize the delivery of the panels to the jobsite in order to take advantage of Just-In-Time (JIT) delivery methods.

CONCLUSION

Even in the manufacturing environment, creative thinking is required from the design, construction, and shipping teams to add benefit to the building process. No "one size fits" all panel can be produced by the manufacturing team. It appears there is a huge opportunity to educate the industry on prefabrication constraints if it is going to be successfully implemented. Technology will be a huge driver in moving prefabrication forward from BIM use to full automation, but the project examined makes it clear that craft workers are necessary to maintain the artistic aspect of a finished EIFS panel. This research is just beginning to understand the effectiveness of prefabrication in the current construction climate and provides a snapshot of one (1) component in the overall construction of a building. Follow up research could focus on any of the items touched upon in this case study observation: BIM, shop labor, constraints, quality control, loading/shipping, materials, specifications and cost.

ACKNOWLEDGEMENTS

The authors wish to thank the Kapture Prefab for interviews, access to the plant and drawings.

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