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# TOWARDS ON-SITE FABRICATION: A CASE STUDY ON MULTI-TRADE PREFABRICATION

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## INTRODUCTION

Off-site fabrication in the construction industry is dated back to the twelfth century introduced by the use of off-site timber buildings (Gibb 1999). It was diffused internationally through British colonization efforts during the 18<sup>th</sup> and 19<sup>th</sup> century (Smith 2010). Internationally, the adoption of prefabrication varies depending on the market structure, customer acceptance, industrialization, etc., in Japan, the UK, the Netherlands, and the US, etc. (Gibb 1999; Smith 2010).

The benefits of using offsite fabrication techniques have been well researched (Gann 1996; Venables et al. 2004; Lu 2009):

- 1) The reduction of overall project schedule
- 2) The improvement of product quality
- 3) Increased onsite safety performance
- 4) A reduction in the need for onsite skilled workers
- 5) A decrease in the negative environmental impact caused by construction

Thus off-site fabrication in the construction industry has become synonymous with efficiency, economy and quality. Nevertheless a recent survey (McGrawHill 2011) illustrates that while the majority of contractors, engineers, and architects have been using prefabrication processes, only third of the respondents has been using it on more than 50% of their projects. The study highlights that the highest level of usage is driven by fabricators, mechanical contractors, and design-builders. The primary reason for not using prefabrication is attributed to architects not including prefabrication in the design and owner's resistance. Hence, there is a need to better define the parameters of prefabrication strategies to assist designers and owners to adopt appropriate prefabrication strategies.

With the recent advancements in material and digital fabrication processes (e.g., composites and pultrusion processes, contour crafting, full scale 3D printing, etc.), BIM technologies, and growing awareness of lean construction processes, anecdotal evidence (McGrawHill

2011) shows that a number of projects have employed novel strategies that bring fabrication on-site or closer to the site. As a result, the projects achieve (a) reduced transportation costs; (b) larger units which are desirable to reduce installation time by avoiding shipping limitations on the unit size of building assemblies; (c) cost reduction in packing and shipping; (d) tighter construction tolerances of site assembled joints; (e) improvement of joint sealing errors; and (f) improvement of safety and ergonomics during site erection.

The authors question if the benefits of centralized 'prefabrication' can be brought closer to the site and mitigate the economic and energy impacts of packaging and transportation. Figure 1 proposes a paradigm shift from centralized manufacturing to distributed manufacturing that may change how products are made and delivered to the site.

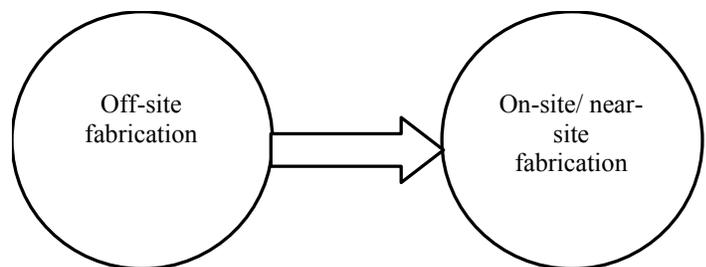


Figure 1. Paradigm shift in prefabrication approaches towards onsite distributed manufacturing

In this paper, the authors discuss *multi-trade prefabrication* (which utilizes near-site fabrication) through a detailed case study on *the Miami Valley Hospital* – an innovative approach improving the construction of buildings by assembling subcontractors in a local warehouse to construct MEP ceiling racks, patient room bathroom pods, and patient room headwall assemblies.

## CASE STUDY: THE MIAMI VALLEY HOSPITAL

The primary research sources of the case study were structured interviews and project documentation to collect data.

## TOWARDS ON-SITE FABRICATION

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Miami Valley Hospital (MVH) is part of the Premier Health Partners (PHP) health care system based in Southwest Ohio. In December 2010, MVH opened their new 484,000 square-foot, \$155 Million addition, consisting of a 12-story tower with a new patient/visitor entry lobby, two levels of underground parking, overhead pedestrian walkways, 178 new patient rooms and room for 72 additional patient rooms in the future. The MVH addition was awarded as a design-bid-build project, designed by NBBJ and constructed by the joint venture of Skanska USA and Shook Construction. The project has been awarded LEED Silver certification. The MVH Southeast Addition is one of the first major hospital projects in the US to incorporate all of the following areas of prefabrication: Bathroom Pods, MEP Ceiling Racks, Patient Room Headwalls, Modular Nurses Stations and Exterior Panels.

### MVH PREFABRICATION STRATEGY

Both NBBJ and Skanska sought ways to improve hospital construction. NBBJ began to identify systems that would be good candidates for prefabrication with an emphasis on areas that were complex and repetitive. Skanska was also searching for ways to improve hospital construction by researching the prefabrication methods that Skanska UK had been using for years in London. The Skanska team visited the St. Bartholomew's and the Royal London Hospitals and observed how they were using multi-trade prefabrication to create Mechanical, Electrical and Plumbing (MEP) ceiling racks. MEP ceiling racks have been used for years in Europe, and Skanska UK has a special division with dedicated facilities and personnel to support prefabrication in London. According to the Skanska team, this prefabrication facility has allowed Skanska UK to vertically integrate the prefabrication and perfect it over the last eight to ten years.

As a result of the research being done by NBBJ and Skanska, the project team decided to proceed with five prefabrication initiatives on the MVH project. The first three initiatives were accomplished by procuring prefabricated components through third-party vendors.

1. Unitized Curtain Wall: the curtain wall is comprised of modular units that can be manufactured to higher standards and installed on site in a faster and safer manner.
2. Modular, demountable caregiver workstations: these are flexible workstations found in each of the three patient wings, on the seven patient room floors that allow the hospital to easily adapt the furniture and workstations to their needs.
3. Temporary Bridge: to construct the new tower, three existing buildings were demolished but the hospital needed to maintain access to the surrounding buildings with a temporary elevated walkway. The solution was to use a jet way manufacturer that was able to prefabricate the walkway, install it in three days, and caused no disruptions to hospital activities.

The last two initiatives were accomplished by establishing a multi-trade, off-site prefabrication warehouse, arranged and managed by Skanska Shook, within miles of the project site to manufacture components that could be easily transported to the site.

4. Patient Rooms (Bathroom Pods, Head Walls, and Case Work): to establish standardization but maintain flexibility. NBBJ designed the patient bed tower rooms with prefabrication in mind.
5. Integrated MEP Racks due to the complexity and congestion of the MEP systems that could be routed in the corridor ceiling of the patient room floors were an excellent candidate for the prefabrication techniques that the Skanska team had researched in London with Skanska UK. These units were designed and detailed by Korda Nemeth Engineering, the building systems consultant.

### MULTI-TRADE PREFABRICATION

#### Project Planning

The original project duration, without multi-trade prefabrication, was 30 months but a sandy seam that was missed during soil test bores, forced the removal of ten newly placed footings and the redesign of some of the foundations. This rework delayed the project by 15 weeks and further encouraged the project team to implement their prefabrication ideas to save time. Premier Health says that at an early stage Skanska Shook and NBBJ were able to collaborate on the prefabrication ideas and recover 7-8 weeks of construction time.

Off-site Multi-trade prefabrication allowed the subcontractors to construct complex components of the building project in a nearby warehouse. This initiative allowed the subcontractors to work concurrently on construction tasks such as site work, foundations, structural steel and/or concrete. The vicinity of the warehouse eliminated the transportation costs typically associated with shipping large prefabricated components.

Skanska led the ceiling rack initiative to get everyone on board while NBBJ pushed for the prefabricated patient room. The owner project representative, and mechanical, electrical subcontractor visited London to see Skanska UK's prefabrication operation. After this visit the PHP management was convinced to allow the team to move forward with prefabrication. The owner representative mentioned that they had gone through two other jobs with Skanska Shook and they had a lot of faith in their abilities.

#### Design Considerations

Prefabrication was a major goal when designing this project but the designer of NBBJ notes that they did not want the prefabrication to dictate how the building would be designed. They considered

the functionality and aesthetics first before making a decision to go forward with prefabrication. It was important to Premier Health, NBBJ and Skanska Shook that nobody would be able to tell which items were prefabricated on the project.

**Same-handed room design:** The design adopted the same-handed room design (Figure 2) instead of the typical mirror-image patient room in which the headwall of one patient room backs up to the headwall of the room next to it. The same handed design has been recently advocated to promote patient safety and standardization but also proved to be conducive for prefabrication because each patient room could be defined by a single ‘blade’ that consisted of the bathroom pod and headwall assembly.

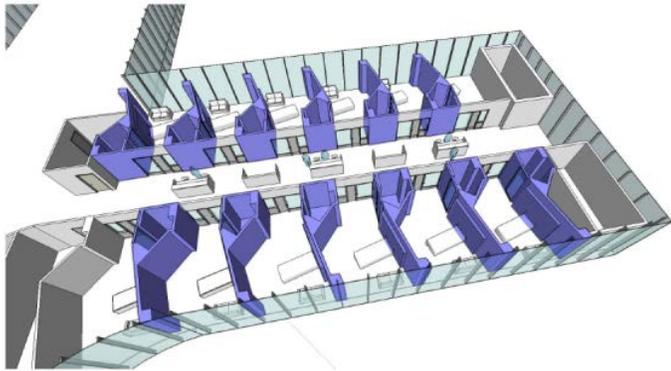


Figure 2. Typical patient room wing (Source: [http://www.nbbj.com/presentations/MVH\\_Prefab/](http://www.nbbj.com/presentations/MVH_Prefab/))

**Subcontractor design-assist:** Chapel Electric and TP Mechanical were brought on as design-assist subcontractors before the decision was made to go ahead with the off-site multi-trade prefabrication. With the assistance of the subcontractors, the project team was able to route utilities such as electrical, plumbing and medical gas through the corridor rather than along the perimeter of the building. Routing the systems down increased the materials required to complete the installation but allowed the project team to maximize the utility of the MEP ceiling racks. The more systems the team was able to install in the racks in the warehouse, the more they were able to take advantage of the improved working conditions that provided a safer and more comfortable working environment resulting in increased productivity and cost savings.

**Use of BIM:** In order to coordinate the available spaces in the ceiling racks, the subcontractors used Building Information Modeling (BIM) for spatial coordination and clash detection. NBBJ and Korda Nemeth Engineering provided a structural, architectural and MEP model to be used by the subcontractors to model their systems. Both members of NBBJ and Skanska agree that despite prefabrication has been done for a long time, given the complexity of the systems that are in a hospital and a patient room, it is difficult to resolve the three dimensional systems without the use of a very robust building information model.

NBBJ used Bentley MicroStation Triforma to create their model, while the structural engineer was using Autodesk’s Revit Structure. NBBJ has since switched to the Revit platform for their models. Many of the subcontractors used different software packages which required them to re-create the models provided by NBBJ. The different software packages and different subcontractors contributing to the models required more collaboration than typically found amongst the trades. Subcontractors worked together to establish the level of detail required for each system, the space each subcontractor would be allowed to use, and rules to resolve any clashes. Larger pieces of equipment and equipment requiring tighter tolerances were modeled in detail but smaller components such as an electrical conduit was designated with a ‘box-out’. For example, Chapel Electric was not required to draw each conduit but rather draw a box that represented the space in which they needed to place their conduit. This technique saved them a lot of time when modeling, but also provided flexibility if another subcontractor required additional space in particular places. The sheetrock contractor, Dayton Walls & Ceilings (DWC), was also involved to provide the proper cut-outs for beam pockets.

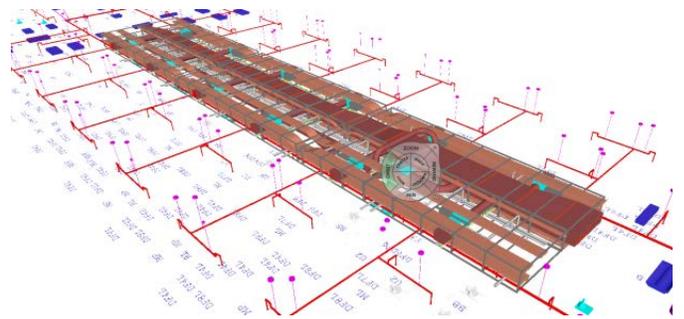


Figure 3. Typical patient wing MEP services in Navisworks (Source: Skanska USA Building)



Figure 4. Bathroom pod mockup for the MVH South project (Photo taken by author)

## TOWARDS ON-SITE FABRICATION

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Autodesk NavisWorks (Figure 3) was used to integrate all of the models by Skanska Shook in regular coordination meetings. The subcontractors also used NavisWorks to solve coordination issues within their own models and between other trades in between the formal coordination meetings.

**Mock-ups:** Once the decision was made to proceed with the off-site multi-trade prefabrication, Skanska and NBBJ constructed full-scale mock-ups of the MEP Ceiling Racks and a patient bath room to get buy-in (Figure 4).

Skanska and Korda Engineering members explained that this allowed the prospective bidders to physically walk around the mock-ups and get an idea of how it would be constructed so that they could estimate what would be involved in constructing 178 bathroom pods and 120 ceiling racks.

### Construction Considerations

**Procurement Strategy:** The MVH Southeast Tower Addition was procured as a traditional design-bid-build project but the implementation of off-site multi-trade prefabrication required that each party worked together in a more collaborative manner. The NBBJ project leader explains that this project was not formally an Integrated Project Delivery (IPD) type of a project but that the IPD process lends itself very well to prefabrication, emphasizing the need for a true partnership between the design team and the construction manager.

Project leaders were concerned from the beginning about having the trades work alongside each other in the warehouse in a production line setting, especially with a union electrician (Chapel), a union fire protection subcontractor (Dalmation), an open-shop drywall subcontractor (DWC) and an open-shop mechanical subcontractor (TP), but they had confidence in the subcontractors and worked with the subcontractors to make sure that only employees who were open-minded and excited about prefabrication were involved. A Skanska team leader explained, “a lot of it had to do with the right people...not only did we have the right contractors, we had the right people within the contractors too.” The union workers and non-union workers realized they were performing the same tasks in the warehouse that they normally would do in the field and that neither was taking work from the other. The teamwork of the subcontractors working in the warehouse was so successful that they tried to keep as many of the same employees on a subsequent MVH project.

**Near-site Warehouse:** The selection of a warehouse to use for prefabrication dictates the largest expense in using multi-trade prefabrication. Skanska Shook was able to secure a 35,000 sq. ft. warehouse less than three miles away from the site for prefabrication. However, the delay from the soil conditions and higher than expected production rates forced Skanska to lease an additional 70,000 sq. ft. warehouse three miles in the opposite direction (Post 2010). According to the contract arrangements, TP Mechanical was responsible for the cost of the warehouse but was reimbursed by Skanska. The only ma-

jor expense for setting up the warehouse was the leasing of the space and general utilities. No special equipment was required for the subcontractors to complete their tasks and Skanska purposely requested that they did not want to have anything in the warehouse that they did not have on site. The components could be maneuvered throughout the warehouse with small dollies and loaded on to the truck with a standard loading dock.

**Building Codes and Seismic Considerations:** To prevent any delays or concerns with the local inspectors the prefabrication team decided to involve the different inspection departments in the entire process. During the design phases of the project, NBBJ and Korda Nemeth Engineering communicated the process to the local authorities. The inspectors were invited to the warehouse for initial inspections and pressure testing, and the standard inspection after installation. After the installation on site, they conducted an additional pressure test.

The International Building Code requires the use of seismic restraint for hospital and healthcare even in areas of the country without significant seismic activity. PHP knew about the requirement and was satisfied when it turned out the ceiling racks could be used as seismic bracing.

### Construction and Installation

Installation of the prefabricated components began once the concrete deck, corridor walls had been laid out, hanging clips for the racks had been installed and fireproofing had been sprayed. It was necessary to haul and hoist the components on Saturdays in order to use the site's tower crane without interrupting the ongoing steel erection. The 8'x20' size of the racks allowed the team to transport the racks on flatbed trucks without having to obtain any additional permitting. Tower cranes were the only option for hoisting due to the extremely limited lay-down area around the site and the 'land-locked' orientation of the building (Post 2010). The racks were easily managed by the site's tower crane, with the heaviest rack weighing approximately 2000 pounds.

The ceiling racks were hauled to the site and lifted to the correct level, and TP Mechanical took a week to a week-and-a-half to move and lift each rack into its final location. As illustrated in Figure 5 the ceiling racks were hoisted into the building using straps to a landing platform that extended out from the building. Once inside the building, TP could move each rack into position using the same dollies from the warehouse and then lifting the racks with lifts. A lift was positioned at each corner of rack in order to prevent damaging the rack.

During the installation of the first set of racks, the team discovered that they did not take in to account the thickness of the fireproofing on the face of the columns and it was causing the racks to hang out of square. With the help of the BIM model the team was able to alter the remaining 72 racks to avoid future problems, by simply altering the sheetrock and metal studs that were attached to racks. As a result of the BIM coordination every beam pocket, located every 8 feet, was exactly where it needed and did not require any modifications in the field.



Figure 5. MEP ceiling rack being hoisted to the landing platform with lifting straps (Source: Skanska USA Building)

To ensure that the racks were going to work, Skanska asked TP Mechanical to practice jacking up and connecting the racks together in the warehouse. The copper piping uses the same hard piping and soldered connections that would be found in the field, and requires soldering after the racks are hung. The electrical conduit is connected from rack to rack with a flexible conduit. Chapel Electric, found that the flexible conduit serves its purpose but that change in material causes some trouble when trying to pull wires through the rack system compared to a traditional, hard-piped connection. The UK electricians do not use conduit to house their wiring so there is no need for a slip connection. Slip connections are currently available and allowed for other MEP systems but Bridgeport, the vendor, has to write the UL specifications and seek approval in order for the product to receive a UL listing.

The bathroom pods and head wall units were transported to the site and hoisted into the building. The crew was able to haul and lift 33 bathroom pods in one 8-hour day and 3-4 more days to level and secure each pod. Once inside the building, the pods could be maneuvered using the same metal dollies as the ceiling racks as seen.

## BENEFITS OF MULTI-TRADE PREFABRICATION

### Schedule Reduction

Multi-trade prefabrication saved seven to eight weeks in this project and Skanska key team members estimate that they could have saved up to four to six months from the schedule delivering higher quality more safely if the team decided to prefab from day one.

### Cost Savings and Quality Improvements

Total Cost savings were reported across the three multi-trade prefabricated elements – pods, headwalls, and racks. The 360 degree access of the units on a shop floor allowed easier access and inspection of the work allowing better quality control. The three subcontractors – mechanical, electrical, and drywall – vary in terms of their labor sav-

ings. While overall material savings were reported across all trades, the cost of leasing the warehouse, transportation, unistrut and additional fireproofing added to the expenses.

**Ceiling racks:** The production of the racks exceeded initial estimates of 5-8 racks per week by completing 12-15 racks per week after three weeks of production in the warehouse. This equates completing the ceiling racks for an entire wing of the hospital in a week. The MEP ceiling racks resulted in a slight increase in labor hours per rack but still achieved an overall cost savings. The mechanical contractor explained that the ceiling racks in comparison to the bathroom pods resulted in labor increase from not including all the necessary unistrut bracing material in the estimate.

**Bathroom pods:** The bathroom pod provides utilities for the adjoining patient, rough-ins for the caregiver wash station and media and data connections. While a number of third party companies manufacture bathroom pods for hospitals, the project team decided to construct the pods in the warehouse to ensure accountability, and achieve a level of standardization and customization that third-party vendors could not provide. Overall labor savings and cost savings were reported by all three trades involved.

**Head walls:** this wall section extends from the bathroom pod to the exterior wall of the patient room and provides medical gases, electrical and data outlets. The drywall was applied on site. Overall labor hour savings and cost savings were reported.

### Safety and Productivity

There were zero injuries in the prefabrication warehouse throughout the duration of the project and only a small number of recordable injuries on the site during construction. This is significantly lower than those reported on similar projects. Anecdotal evidence provided by the electrical contractor shows a 300 percent increase in productivity.

### Environmental Impact

As a result of the efficiencies achieved in the warehouse, only one dumpster was used throughout the entire fabrication stage of the project. According to data provided by Skanska, a typical hospital project of this size would accrue a total dumpster cost of approximately 0.14 percent of the total \$155M project cost. Actual dumpster costs for the MVH Southeast addition were only 0.09 percent. The environmental impact as a result of energy savings from reduced labor hours and fewer workers travelling to the construction site are not available.

## CHALLENGES OF MULTI-TRADE PREFABRICATION

### Procurement

In this project the subcontractors were allowed to keep any savings that were realized as a result of prefabrication. Skanska Shook felt

that it was the best way to allocate potential risks and rewards. In an effort to pass and share some of the expected savings from the subcontractors, the mock-ups were constructed with the hopes that the subcontractor's bids would be lower. Unfortunately, most of the bids did not reflect savings over a traditional installation. From a CM-at-Risk perspective, a number of the Skanska team members believe that one of the biggest areas for improvement is to improve Skanska's in-house preconstruction estimates and budgets for prefabricated elements to compare against subcontractor bids. Having more accurate preconstruction budgets would allow Skanska to pass any savings on to the owner.

The owner representative shared that going forward he believes that projects could be bid in two different ways. The first does not require the use of prefabrication but allows using the time savings and any other benefits as a competitive advantage. If construction managers choose this path, he fully expects them to be able to show the expected cost savings in their bid. The other pricing strategy would involve building prefabrication in to the specifications and allowing every potential construction manager bid the project with a prefabrication plan.

### Design/Engineering/Interfaces

Project requirements present different challenges for prefabrication. For example, in another hospital project by Skanska, the plans were based on 8 foot corridors as opposed to the 16 foot corridors seen in the MVH project and the patient room adopted the common mirror image layout. This resulted in less favorable conditions to apply bathroom pods and headwall units. The issues of tolerance and product connectors also need to be addressed during design.

### Manufacturing vs. Construction

The experiences from the first MVH project highlighted the need for more informed scheduling decisions. With more realistic production rates, construction can achieve just-in-time delivery for the prefabricated elements and eliminate the leasing of additional warehouse space. To achieve a leaner process, the CM may need to take on more control of the entire process including the manufacturing logistics in the warehouse.

### Performance Measurement

Prefabrication requires reexamining the productivity in multi-trade environments. More accurate performance metrics that reflect the productivity gains achieved through eliminating idle time and non-value adding activities from the site need to be measured. Transportation activities need to be carefully studied as near-site fabrication not only impacts the coordination within the factory but also the packaging, storing, and unloading, and staging on the construction site.

### CONCLUSION

One of the keys to using multi-trade prefabrication is that the end result is visually identical to a traditional stick-built installation but often constructed faster to a higher level of quality. As observed in the MVH case study the biggest advantage to using prefabrication was the ability to open the hospital sooner. While the owner's revenue gains were not quantified it was noted it would be a significant driver during the design and construction team selection.

The case study provides researchers and practitioners with valuable lessons to better understand the implications of novel fabrication approaches (i.e., multi-trade prefabrication) that attempt to bring the benefits of off-site fabrication closer to the site. The challenges presented in this paper, highlight research areas of importance such as new business models, engineering capacities, performance metrics, and needs for further investigation.

### ACKNOWLEDGEMENTS

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