LEARNING TO SEE SIMPLICITY WITHIN A COMPLEX PROJECT THROUGH THE LENS OF PULL PLANNING

Cynthia C.Y. Tsao[1] and Glenn J. Hammons[2]

ABSTRACT

Ideally, project teams should get feedback from foremen from key trades to help guide work structuring decisions early in the design process. Doing so enables project teams to reveal the constructability implications intrinsic to different design options. Then, project owners may make product design decisions that would better support the construction process and thus improve the likelihood of meeting their project goals. Unfortunately, if trade foremen missed the opportunity to influence a project's product design at project inception, the project team may later face daunting challenges to construct project components that appear complex at first glance. This paper describes such a scenario in the building out of an atrium for a $220 million new hospital addition in the U.S. It explores how the project team used pull planning to reveal production lines that needed to be created to build out the hospital's five-story atrium. It explains how the project team considered various work structuring scenarios and eventually settled on the final work sequence. Thus, this case study will demonstrate how the project team was able to learn how to see simpler process approaches to constructing what initially appeared to be a complex product design.

KEYWORDS

Work structuring, sequencing, product-process design integration, pull planning, process standardization

INTRODUCTION

Previous case studies have demonstrated the value of using location-based planning (e.g., Seppänen et al. 2010) and modularity to build out identical and similar building units in the housing (e.g., Lennartsson et al. 2008) and healthcare industries (e.g., Olsen and Ralston 2013). However, modularity combined with pull planning (that is, the collaborative planning process in which meeting attendees determine how work must be sequenced and handed off between different trades to achieve an end milestone) can also be used to assist with building out complex product designs that do not initially appear to contain identical or similar building units. This paper will outline such a case study in which the project team leveraged pull planning, work structuring, and a production system design approach to standardize the process for building out a five-story hospital atrium.

[1] Owner, Navilean; Senior Associate, Lean Project Consulting; Adjunct Faculty, Wentworth Inst. of Technology; Brookline, MA, 02445, USA, Phone +1 510/593-4884, research@navilean.com

[2] Project Director, Skanska USA Building Inc., Nemours – AIDHC DE Expansion Project, 1610 Rockland Road, Wilmington, DE, USA, Phone +1 302/298-7663 Glenn.Hammons@skanska.com

PROJECT OVERVIEW

In July 2011, the Nemours Foundation selected Skanska USA Building Inc. to construct an expansion of the Nemours/Alfred I. duPont Hospital for Children (AIDHC) in Wilmington, Delaware (Skanska 2011). FKP Architects of Texas provided master planning, architecture, and interior design services for the project (FKP 2014). The $220 million, 38,460 m^2 (414,000 ft^2) project includes the construction of two new football-shaped towers that provide space for 72 beds each (144 beds total) and 188 parking spaces on the ground level (FKP 2011 and Skanska 2011) (Figures 1 and 2). The project expands the hospital's acute care, critical care, and trauma care capabilities, and the first floor will include a new Emergency Department, five-story "Main Street" atrium, retail stores, and dining facilities (ibid).

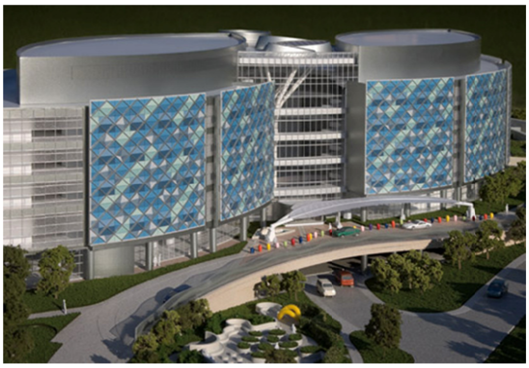

Figure 1: AIDHC Expansion exterior rendering (FKP Architects 2011)

Figure 2: AIDHC Expansion under construction (Photo by C. Tsao)

From its inception, the AIDHC expansion project was made for one-piece flow production management (Howell and Ballard 1998). Six of its eight built-out floors in the two bed towers contain patient room units containing space for a single bed and personal bathroom. Although the 144 patient care rooms encompassed a variety of patient care models, there was a high degree of room-to-room similarity. As a result, the contractor built the original schedule around prefabricating typical assemblies including bathroom pods, headwalls, and footwalls. The contractor also migrated all Mechanical-Electrical-Plumbing support services into prefabricated overhead racks in the bed towers' corridors. The blue-colored patient care rooms in Figure 3 illustrate the repetitive nature of the building space within the football-shaped bed towers.

Figure 3: AIDHC Level 3 Floor Plan (FKP Architects 2012)

On the AIDHC expansion project, the contractor's prefabrication process included: (1) reviewing the project as a whole to determine potential areas for prefabrication, (2) developing a list of the types and quantities of prefabricated units, (3) building mock-ups for each of the various prefabricated units, and (4) conducting time and motion studies to determine accurate durations for building out each prefabricated unit.

Using data from the time and motion studies, the contractor established the number of production lines along with the labor, tooling requirements, and material lists. Then, the contractor conducted a pull plan to finalize how work would be handed off between trades to build out the prefabricated units and calculate the overall lead times for production. Finally, to minimize overhead costs, the contractor converted an offsite warehouse space into the project's prefabrication facility at the last responsible moment (Ballard and Zabelle 2000) and began production of the units.

Once the contractor started delivering prefabricated units to the job site, they conducted another pull plan to streamline the process for installing prefabricated units. Despite a shaky start on implementing the job site pull plan, results soon began to show as the job site's rhythm of installation began to take hold. It was then that the contractor began to wonder, "Could pull planning be applied to something that was not so repetitive? Are there opportunities to try this out on this project?"

The contractor quickly homed in on the project's atrium and set about studying how pull planning could help. Although the atrium seemed to lack the repetitive characteristics that typically enable better production management through pull planning, the contractor experimented with pull planning to plan out the construction of the atypical atrium space. As a result, the contractor started learning how to see the simplicity that exists within a complex product design.

ATRIUM OVERVIEW

AIDHC's five-story "Main Street" atrium is roughly an eight-sided space (Figure 4). The face that is adjacent to the atrium elevators features a curtain wall. Some faces of the atrium feature drywall pop-out sections with meltdown glass, and other faces contain custom-made ferrous metal powder-coated rail posts with laminated glass. The atrium floor is made of terrazzo and the atrium ceiling features three oval skylights surrounded by drywall soffits and acoustical ceiling tile. Trades used two 38 m (125 feet) lifts inside the atrium to complete the atrium ceiling work (Figure 5).

Figure 4: AIDHC Expansion atrium rendering (FKP Architects 2011)

Figure 5: AIDHC Expansion atrium under construction (Photo by C. Tsao)

The ceilings of the walkways along the atrium face contain acoustical ceiling tile, wood wall coverings, and light fixtures. Glass fronted niches are located along the walkways to house artwork from local artists that would be of particular interest to children. The walkways' concrete floors contain plywood pockets that served as placeholders for the ferrous metal rail posts, and they needed to be removed before the posts could be installed. Also, once most atrium work was complete, the concrete subcontractor would add a topping slab on top of the walkway floors.

WORK STRUCTURING ISSUES FOR ATRIUM WORK

In October 2013, the contractor's atrium team consisting of a senior superintendent, assistant superintendent, senior project engineer, and lean coach started evaluating work structuring issues (Ballard 1999, Tsao et al. 2004) for atrium work including: (1) "What path should the trades take to complete atrium work?" (2) "*Who* should be doing *what* work and *when?*" (Tsao and Tommelein 2004) (3) "What counts as atrium work vs. non-atrium work?" which then allowed the project team to determine – (4) "How will atrium work interact with other production lines?" Since these issues were interdependent in many ways, the atrium team considered some of them in concert as opposed to just independently and sequentially.

At the most basic level, work for the eight-sided atrium could proceed either in a corkscrew fashion or one face at a time. Furthermore, it was unclear whether there were any advantages to having atrium work proceed in a clockwise vs. counter-clockwise path. Taking these two factors into account, four permutations for possible work paths emerged for the atrium (Figures 6, 7, 8, and 9). In addition, the atrium team wanted to determine how to establish the best starting point for atrium work.

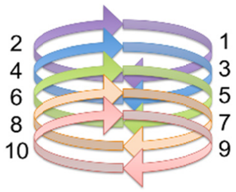

Figure 6: Going clockwise, in a corkscrew, and downwards

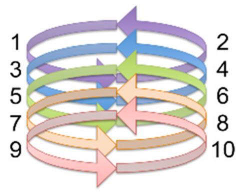

Figure 7: Going counter-clockwise, in a corkscrew, and downwards

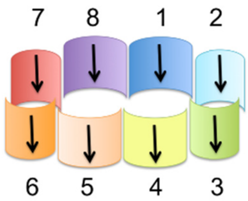

Figure 8: Going clockwise, one face at a time, and downwards

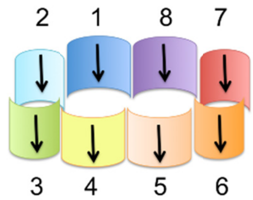

Figure 9: Going counter-clockwise, one face at a time, and downwards

With regards to "*Who* should be doing *what* work and *when?*" the contractor already knew which trades were involved in atrium work – miscellaneous metals, interior glass, acoustical ceiling, curtain wall, drywall, paint, mechanical, and electrical. However, it was still uncertain which trade would be responsible for some portions of atrium work such as meltdown glass installation. While the miscellaneous metals subcontractor was contractually responsible for installing the meltdown glass, they were negotiating with the curtain wall subcontractor to take care of that work as the miscellaneous metals subcontractor's subcontractor (i.e., to be a sub-subcontractor). In addition, the atrium team needed to settle on the atrium work path so that they could then determine how to sequence the trades through the atrium space.

At the same time, the atrium team also examined what should be counted as atrium work vs. non-atrium work (Figure 10). Once the atrium team established which elements counted as atrium work, they needed to account for the remaining elements in other production lines before determining how atrium work would interact with other production lines (e.g., whether the other production lines took priority over atrium work and vice versa).

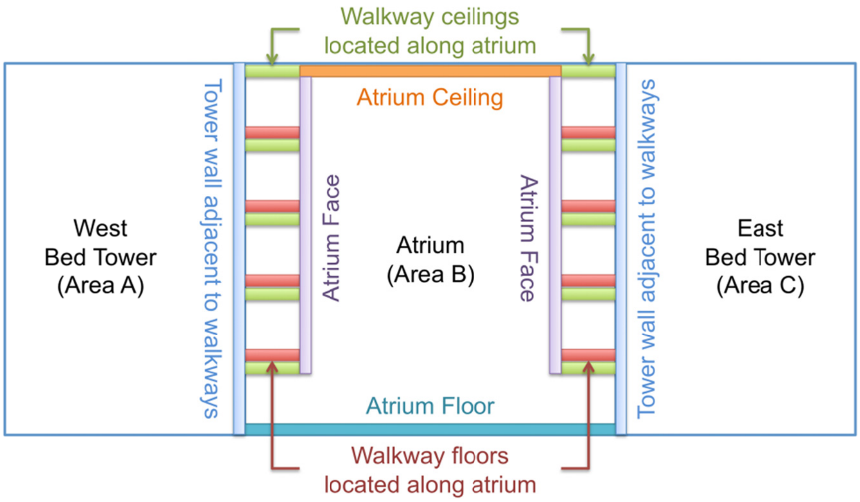

Figure 10: Basic elements of the five-story atrium and its adjacent areas

PLANNING THE ATRIUM WORK

In late November 2013, the contractor provided basic Lean Construction training to trade project managers and foremen involved in atrium work. Then, the atrium team worked with trades to pull plan atrium work from the end milestone of "Ready for Walkway Topping Slabs." At the pull planning start, the contractor handed out a diagram that broke the eight-sided atrium into eight modules to help guide the trades (Figure 11). The handout used the term "work zones" as opposed to "modules" because it was more colloquial and would thus be more accessible as a concept to the trades. Each work zone code started with a "B" because project drawings designated the atrium as area "B" and the bed towers as areas "A" and "C" (Figure 10).

In addition, the handout instructed foremen to identify work descriptions, crew sizes, and durations for each work zone and on each floor to demonstrate their work paths. By the end of this initial pull planning effort, the atrium project managers and foremen posted sticky notes that identified some work in the atrium ceiling as well as work zones B3, B4, and B5. As the pull plan was far from complete, the contractor scheduled a follow-up pull planning session for atrium work two weeks later.

Since they had experience from the first pull planning session, the atrium trades came to the second session in early December 2013 better prepared. The contractor also set up the plotter paper on the walls of the double-wide trailer to mimic the atrium layout. On the job site, visitors typically observed the atrium from work zone B8, so they would see work zones B4 and B5 straight ahead. Thus, the contractor arranged the plotter paper containing work zones B4 and B5 based on a direct sight line from the door that visitors used to enter into the trailer (Figure 12). The plotter paper for the atrium ceiling and work zones B3, B4, and B5 contained sticky notes from the first session, so the trades were able to revise them throughout the meeting.

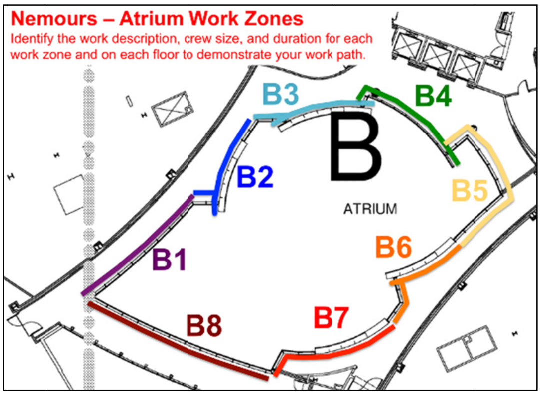

Figure 11: Pull planning handout

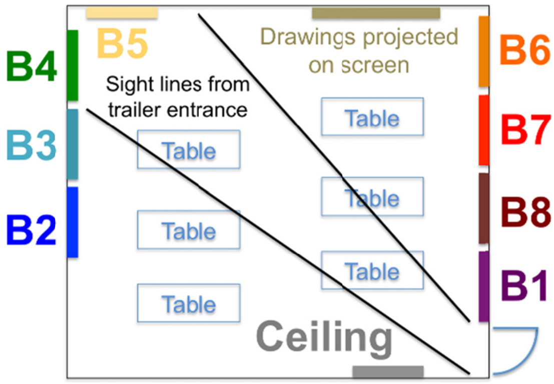

Figure 12: Pull planning room layout

At the start of the session, the atrium team discussed possible work paths (Figures 6, 7, 8, and 9) with the trades. The senior superintendent noted that proceeding in a corkscrew fashion would allow the project to switch from 38 m (125 feet) lifts to 23 m (75 feet) lifts sooner, but he was open to considering other work paths. After some deliberation, the trades all concurred with the senior superintendent's suggestion. However, it was still unclear how to identify the best starting point for atrium work and if there were any advantages to working clockwise vs. counter-clockwise.

With the group's decision to work in a corkscrew fashion in place, the atrium team then asked, "Does the face work on the fourth and fifth floors need to be complete to allow for the lifts to be switched?" After running some calculations, the trades concluded that only the fifth floor's face work would need to be complete to support the lift switch. Then, the atrium team and trades focused on pulling the atrium work from the end milestone of "Ready to Switch Lifts" for each atrium work zone.

The atrium team also decided to define atrium work that would be addressed in the atrium pull planning sessions as all work involving the atrium face, as well as walkway ceilings and floors located along the atrium. Then, the atrium ceiling and atrium floors would be treated as separate production lines, and the tower walls adjacent to atrium walkways would be managed as part of the bed tower production lines. These decisions combined helped establish the boundaries for the pull planning session, so the atrium trades became more focused in their planning.

Although the atrium ceiling and floors were not directly incorporated into the atrium pull plans, they did influence the second pull planning session. Pull planning meeting attendees recognized that it would be better if the atrium ceiling work were completed before atrium face work began. As a result, the drywall foreman prioritized finishing out the atrium ceiling soffits before focusing on building out the atrium face.

Meanwhile, the atrium team started meeting with the terrazzo subcontractor to understand how they wished to proceed. They requested to layout in the middle of the floor so they could begin installation outside of the atrium. However, layout required access to over half of the floor (Figure 13). This was challenging because while two large lifts clearly could not fit within half of the floor, it was unclear if a large and medium lift could fit, let alone two medium lifts. As a result, the atrium team shifted terrazzo layout to a different time frame so it would not impact the atrium pull plan.

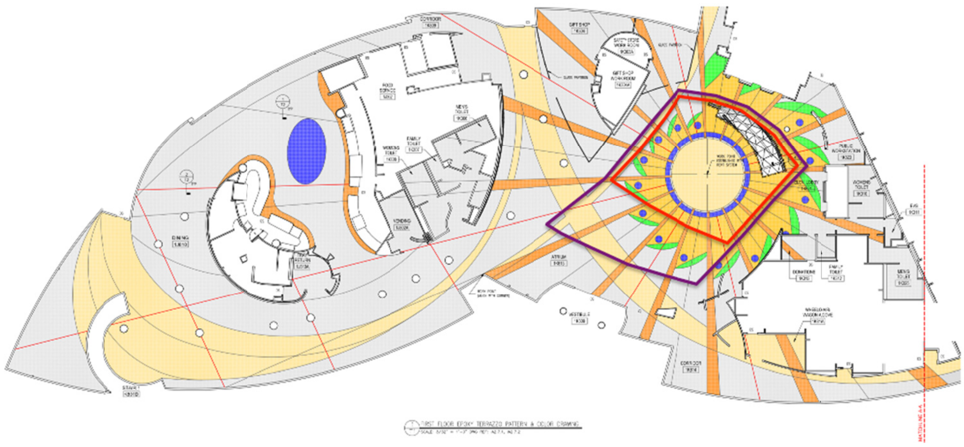

Figure 13: Terrazzo pattern with atrium outlined in purple (Roman 2013). Terrazzo layout area outlined in red, and terrazzo layout starts from the + sign.

LEARNING TO SEE SIMPLICITY IN A COMPLEX DESIGN

FKP Architects' atrium design uses drywall pop-outs to break up the space visually (Figure 4). As a result, each section "pops-out" differently, and this variation is intentional to create a more interesting aesthetic. However, "interesting aesthetics" typically creates building challenges because it is difficult for builders to find enough repetition within the design to gain the benefits of learning curves and fewer setups. Furthermore, the contractor regarded the atrium face as complex to build because: (1) the drywall subcontractor had to identify points in space for layout as opposed to snapping a line on the floor, (2) in some atrium face locations, corners formed at the intersection of two curves, (3) all atrium faces were on a radius, and (4) there was no consistency in design from one atrium face to the next. Thus, on first impression, the atrium team regarded the atrium face design as complex and a challenge to build.

Once the second pull planning meeting began, the atrium team asked the trades to focus on planning atrium face work. As a result, while the trades did not complete the ceiling pull plan, they were able to fully plan out five of the eight pull plans for the atrium face, including B4 which represented the curtain wall. Then, they realized that the three remaining pull plans were similar to the pull plans they had just completed, so they quickly developed them by copying over information from the other pull plans. This led the atrium team to realize that repetition did exist in the atrium, although it was still challenging to see. After the second pull planning session ended, the senior project engineer started trying to identify the source of that repetition and came up with the following areas of repetition within the atrium (Table 1):

Table 1: Areas of repetition in AIDHC's complex atrium design

Floor	E-shaped Drywall Pop-outs	Ferrous Metal Rail Posts	Curtain Wall
2nd	B6	B1, B2, B3, B5, B7	B4
3rd	B1, B6, B7	B2, B3, B5, B8	B4
4th	B1, B2, B3, B6, B7	B5, B8	B4
5th	B2, B3, B6, B7	B1, B5, B8	B4

Combining this insight with studying the color patterns in the pull plans on the trailer walls (Figure 14), the atrium team realized that in addition to the curtain wall work, there were two basic types of atrium face work flows – (1) drywall pop-out sections and (2) ferrous metal rail posts sections. The atrium team called the drywall pop-out sections "E-work" because some drywall pop-out sections resembled the letter "E," and they called the ferrous metal rail posts sections "Rail-work."

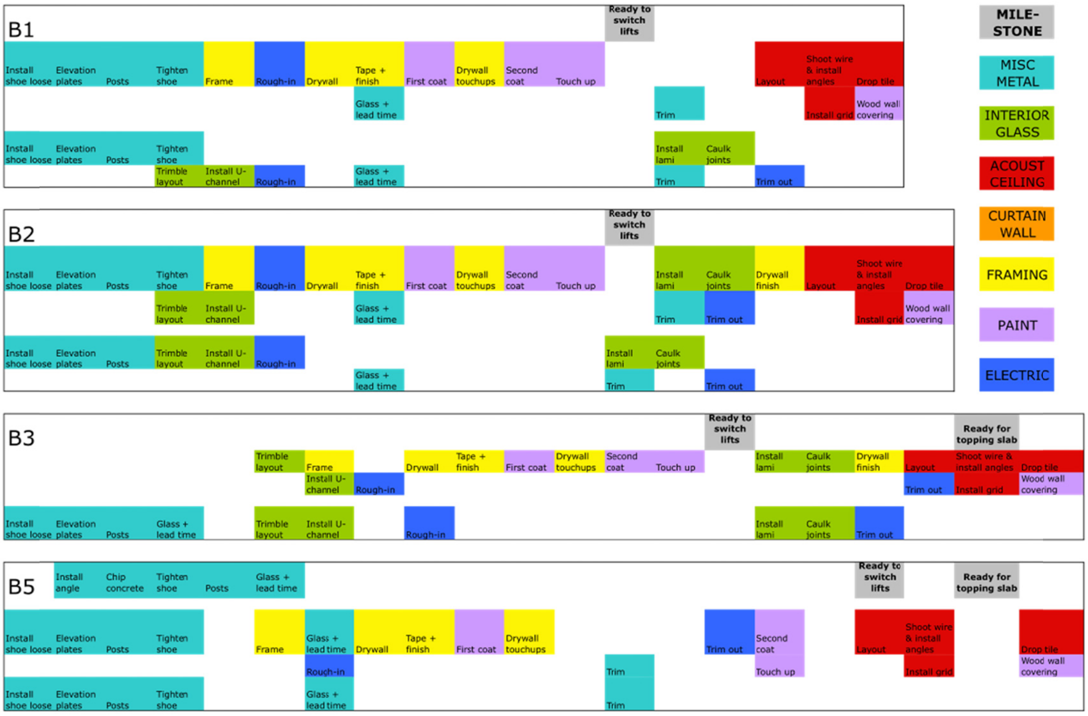

Figure 14: Pull plans for atrium work zones B1, B2, B3, and B5
(B6, B7, and B8 pull plans not shown due to space limitations)

STANDARDIZING THE BUILDING PROCESS FOR ATRIUM FACE WORK

With the new clarity that the atrium face consisted of "E-work" and "Rail-work," the atrium team developed two new pull plans in mid-December 2013 that represented 3 m (10') of standard "E-work" and 3 m (10') of standard "Rail-work" (Figure 15).

Figure 15: Atrium face pull plans that represented 3 m (10') of standard "E-work" and 3 m (10') of standard "Rail-work" (Photo by C. Tsao)

The atrium team was careful to copy over the productivity rates developed by trade project managers and foremen from the earlier pull plans into the new 3 m (10') length standard pull plans. In a few instances, the new pull plans were more conservative in terms of the time estimate for completing work. Figure 15 shows the new pull plans captured on a single sheet of plotter paper with the 3 m (10') of standard "Rail-work" on top and the 3 m (10') of standard "E-work" on the bottom.

After developing the new pull plans, the atrium team met with the trade foremen to get their feedback and develop buy-in into the new pull plans (Miles 1998). At first, some foremen were concerned that these "new plans" deviated from the earlier plans that they developed in early December 2013 with their project managers. To allay their concerns, the atrium team moved the old pull plans into the conference room and walked the foremen slowly through the new pull plans so they could see that the new plans were either equal or more conservative in time estimate. It was only after the step-by-step walk-through between the old and new pull plans that the foremen became comfortable with the new pull plans and were willing to follow them.

DETERMINING WHERE TO START ATRIUM FACE WORK

With standard work processes established for atrium face work, the atrium team now had to resolve: (1) how to determine where to start the work, (2) whether to have work move in a clockwise or counter-clockwise fashion, and (3) how atrium face work would interact with the other production lines. After the mid-December 2013 meeting with the trade foremen, the atrium team decided to hold off on terrazzo work until after the trades completed the bulk of atrium face work. This then de-coupled the atrium floor production line from the atrium face production line (Figure 10).

Next, the atrium team re-examined the atrium ceiling production line. At that time, the drywall foreman was planning on completing the northern half of the drywall soffits before moving on to the southern half. Once the soffits were installed, the other trades still needed to use the high 38 m (125 feet) lifts to complete two more elements of atrium ceiling work – painting and acoustical ceiling tile. The atrium team concluded that in order to switch from 38 m (125 feet) lifts to 23 m (75 feet) lifts sooner, painting and acoustical ceiling tile work should be broken up and managed in two phases – first, to complete the northern half of the atrium ceiling and then, to complete the southern half. This enabled the trades to overlap at least some of the atrium ceiling work. The atrium team would have preferred to break up the atrium ceiling work into three or more phases, but it was impossible to do so because there were only two lifts available in the atrium.

Now that the sequence for the last activities of atrium ceiling work has been established, the atrium team could then determine its impact on atrium face work. The northern half of the atrium face consists of work zones B2, B3, B4, and B5 (Figure 11). The southern half of the atrium face consists of work zones B1, B8, B7, and B6. The atrium team studied how atrium make-ready work had been progressing to that point (e.g., removing the plywood pockets from the concrete floors) and determined that it felt more natural and made more sense for atrium face work to proceed in a clockwise fashion as most workers were right-handed. As a result, the atrium team could finally establish where to start atrium face work – in work zone B2, and work would proceed in a clockwise fashion.

FINALIZING THE SEQUENCE FOR ATRIUM FACE WORK

With a starting point (i.e., work zone B2) and direction (i.e., clockwise) established for atrium face work, the atrium team then examined whether work should proceed in a pure corkscrew path (Figure 6). The atrium team suspected that the drywall crews would be more efficient finishing out an entire E-section at a time before moving on to the next one. They checked-in with the drywall foreman to confirm if this was the case, and he confirmed it was. As a result, the atrium team needed to develop an atrium face work sequence that was a hybrid variation of Figures 6 and 8 – that is, atrium face work started in work zone B2, went clockwise, and allowed the drywall crews to complete an entire E-section before moving on to the next one.

Working from both a push and pull perspective, the atrium team then developed a sequence that considered all of these factors in addition to the fact that E-sections spanned one or two floors. They outlined the subsequent sequence in a handout that they distributed in a meeting with the foremen in early January 2014 (Figure 16). The handout introduced a new coding system for atrium work: "[Floor level]B-[E for drywall or R for rail work][Priority of work completion]."

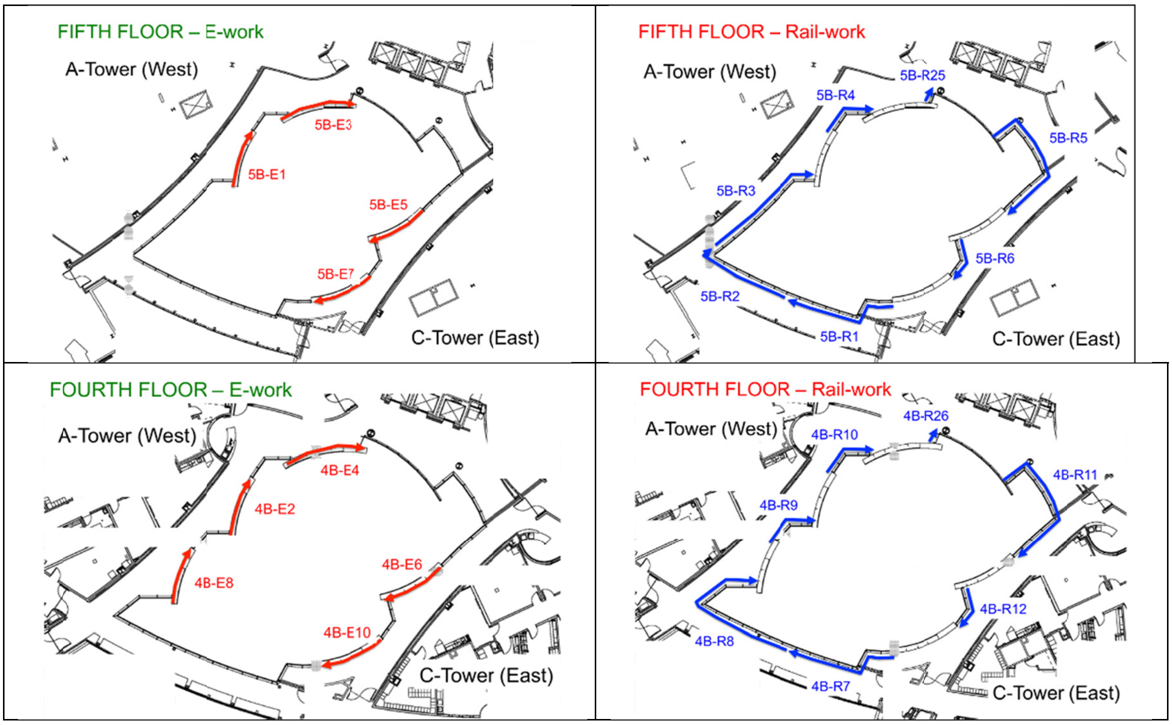

Figure 16: Final Sequence for Atrium Face Work on fifth and fourth floors (Third and second floors not shown due to space limitations)

As noted in the "Planning the Atrium Work" section, the "B" in the code just indicated that it was atrium work as opposed to bed tower work.

Since the foremen had participated in a majority of the production planning steps for atrium work up to this point, they readily agreed with the final sequencing logic developed by the atrium team and proposed in Figure 16. Then, the atrium team began working with the foremen to implement the final sequence for atrium face work starting in mid-January 2014. As of April 2014, the atrium face work has been flowing well, and the trades have only worked out of sequence on occasion as opposed to regularly. Thus, the atrium team found that their investment in planning has paid off since all trades are on the same page with regards to sequencing and the foremen are committed to the plan since they bought into it after participating in the pull planning sessions.

CONCLUSIONS

The contractor's experiment with the use of pull planning to organize build out of the atypical atrium space evolved over a period of four months. During that time, the contractor methodically considered various activity sequences and work flows to uncover hidden production lines. Along the path of this experimentation, the project team reached three primary conclusions:

- At first, the atrium design seemed like a "one of a kind" work of art to the project team, and there would be no ability to implement much of a flow other than the typical work breakdown by level or elevation. The atrium team's pull planning efforts revealed that complex, artistic building spaces can be broken down into distinct production lines that provide better clarity, structure, and discipline to the construction process.
- Implementing pull planning in the later stages of a project can still generate value. Whereas an initial belief was that it was too late to use lean on atrium work, the final process in planning atrium work revealed that benefits can be derived even if implementation occurred in later project phases.
- Significant gains are achievable through the use of pull planning. The project team originally regarded the atrium as a distressed portion of the schedule, and it eventually became one of the most successful parts of the project.

In addition, the project team reached three other conclusions about pull planning:

- Changing the culture is difficult but achievable. During the pull planning sessions, the trade foremen could not resist the temptation to overstate their durations. Everyone wants to under promise and then overachieve. Then, since the attendees only started to unravel the details that would impact how work might be handed off between trades, the first pull planning session was inconclusive. When the trade foremen were faced with a lack of clear direction for atrium work, they became argumentative, obstinate, and defensive, and a few literally walked away from the meeting. It took several follow-up meetings until the trade foremen realized that the planning meetings would result in less supervisory effort, so their quality and production would actually increase if they maintained the required production rates to make work flow.
- In some cases, trade foremen do not really know enough about what they are doing to provide accurate information. When asked to assign times to their work in the pull planning sessions, some really did not seem to know, knew but could not express it, or did not want to divulge the information. "You have to ask the Project Manager" or "Ask my office" was a typical reply. Trade foremen need to be informed and empowered individuals to better support efforts in pull planning.

- The concept of production system design for organizing workflow is actually foreign to many trade foremen. Boiling work down to one repetitive unit that can be monitored, adjusted, and improved upon to create higher efficiency in construction is not a prevalent way of thinking or acting.

By documenting this project team's pull planning journey, we hope this case study will inspire other project teams to learn how to see the simplicity within complex project designs and take pull planning to yet another higher level of use.

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