APPLICATION OF PULL AND CONWIP IN CONSTRUCTION PRODUCTION SYSTEMS

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ABSTRACT

One of the main characteristics of construction is that work flows through temporary production systems from the start to the end of a project. The way the production system is designed has a major influence in the outcome of the project. This paper presents a case study on rebar that illustrates how the application of PULL and CONWIP techniques can drastically improve value delivered. Benefits include reduction in physical inventories, an increase on transparency across the production system, reduction in variability levels for both demand and supply, lead time reduction, and better collaboration amongst stakeholders.

KEY WORDS

CONWIP, demand, lean, production control, PULL, production system, reliability, supply, WIP.

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INTRODUCTION

One of the main characteristics of construction is that work flows through temporary production systems from the start to the end of a project. The way the production system is designed has a major influence in the outcome of the project. However, production system design has been neglected (Ballard et al. 2001). Ballard (2005) states that ‘once we learned that production systems could be designed, and conceived projects as temporary production systems, we began to understand the need to design systems adequate to dynamic projects: projects that are quick, uncertain and complex’.

The majority of the construction industry (around the world) continues being very traditional. In the context of this paper, few organizations are looking at projects as a combination of multiple production systems that require a design to guarantee a positive project outcome. The typical thinking is to execute projects as they have always been done before, with schedules controlling production, looking at projects only as sources of profit instead of as opportunities to develop new capabilities such as how to use CONWIP (constant work in process) to enhance the organization’s competitive advantage.

Experience tells us that some organizations view project delivery as gambling. Sometimes you got lucky and win, sometimes you lose. This paper proposes a way of increasing the likelihood of always winning through a view on production systems. As part of the design of these production systems, the paper explains how the application of PULL and CONWIP techniques can drastically improve value delivered (quality, safety, time and cost). A case study on the definition, design, and implementation of a rebar production system is presented to illustrate an application.

UNDERSTANDING THE PROBLEM

Problems in the construction industry abound. One of these problems is how to synchronize demand and supply at the operations level so waste is minimized and value is maximized. This section analyzes how this synchronization is hypothetically performed in construction.

Think about the following analogy: construction projects should be like airports. An airport has a control tower that authorizes when airplanes should land and/or depart, and which runway they should use. The control tower uses a series of systems, processes and procedures for daily control of operations, and has several teams working behind these operations. If the control tower does not manage real-time flight information, it will be very difficult to properly perform the control function (e.g., accidents will be likely to occur at any time).

Some airports are small with minimum air traffic, others are like mini cities handling an important amount of air traffic every day - airplanes constantly landing and departing. For either small or large airports, changes in daily routines are a given so their ability to react to these changes draw a line between success and failure, between accidents and an incident-free airport. The systems that control towers use for air traffic control have been designed to enable the control tower team to quickly react to unexpected ‘changes’.

Following this analogy, construction job sites would then be like the airport site, the project production systems are the equivalent to runways where work orders (the airplanes) constantly land, the control tower is like the site office or trailer where typically control occurs, and the system/tool used for control (the control tower system) is called schedule.

The reality is that control tower systems are far more sophisticated than schedules (actually schedules are not systems). The reality in construction is that schedules are used for tracking the past rather than controlling the present and forecast the future due to project dynamics and speed. The question is: can schedules be used to control production across production systems? The answer is simple: No. One of the consequences of doing this is the generation of large amounts of waste across the production systems.

But, why is waste generated when using schedules for production control, and in what form waste presents itself? To help answer this question, Figure 1 shows a schematic representation of a construction production system in different stages. This example includes three steps: (1) Fabrication, (2) Assembly, and (3) Installation. Figure 1a) shows the schedule playing the role of the 'control tower system' determining when components should be fabricated, assembled, and installed. The project team (or control tower team in our analogy) then gives instructions to all project stakeholders (the pilots flying the airplanes) to make to schedule (Figure 1b). Everybody gets a copy of the schedule and starts making. Once making is underway, work in process (WIP) becomes evident (you can 'see' it) across the project production systems (WIP 1 and 2 in Figure 1c). Suddenly, the final customer (e.g., project owner) realizes that needs are changing and requests a series of changes to the project (while it's under construction). Changes may imply modifications to the original design which may impact site production. Does this sound familiar?

Meanwhile, everyone keeps making to schedule (Figure 1d) and WIP levels across production systems increase rapidly. Following the analogy, this is like having an accident in the runway, but airplanes keep landing. The current belief in construction is that production is/can be controlled using schedules, however, schedules have not been designed for this purpose, therefore, are unable to keep up with project complexity and dynamics, uncertainty (e.g., changes), and speed.

Schedules are the best example of push. This is similar to what happens in manufacturing with Manufacturing Resource Planning (MRP) systems that constantly feed machines in the production line just to keep them busy in order to maximize capacity utilization, independently of what may be happening upstream or downstream. Schedules are not tools to synchronize demand and supply. This means that there are questions to be answered: how can demand and supply be synchronized at the operations level? How to control the process across the production system? This paper presents PULL and CONWIP as techniques that provide answers to these questions.

UNDERSTANDING THE SOLUTION

Schedules are not tools to effectively synchronize demand and supply; however, schedules are required for project management. Synchronizing demand and supply across production systems is key for project success. Some of the challenges for this synchronization in construction are: (1) the fact that the final product is not repetitive, therefore the need to design production systems every time a project starts, (2) the fact that there is a high degree of engineered-to-order (ETO) components with long lead times, therefore the need to better understand engineering processes and find ways to reduce lead times, and (3) the fact that the product is assembled in a fixed-position environment (versus line flow like in manufacturing), therefore the need to avoid having excessive amounts of materials inventories laying around the 'fixed positions' to minimize a negative impact in performance and safety.

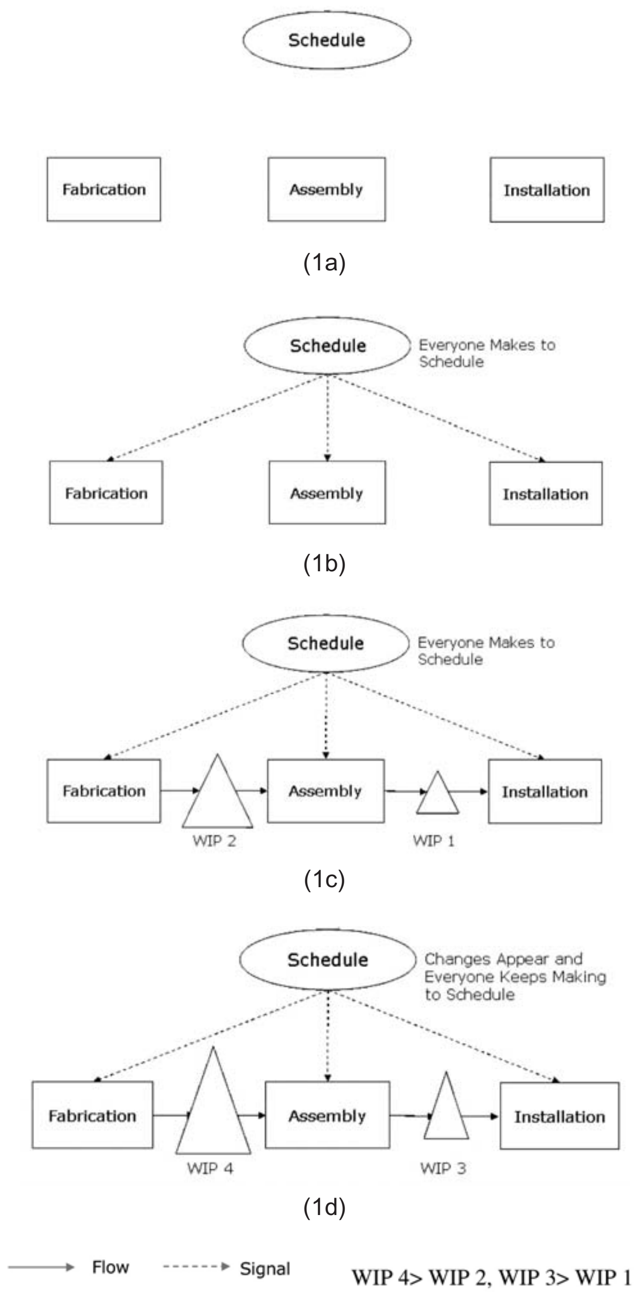

Figure 1: Schematic Representation of PUSH through Scheduling

The objective of this section is to present PULL and CONWIP as techniques that better support the synchronization of demand and supply across production systems in construction instead of using schedules. Due to project complexity nowadays and considering the fact that construction has a large amount of engineered-to-order products, PULL and CONWIP can not be implemented in isolation. PULL and CONWIP techniques need to be implemented in a platform that allows stakeholders to manage real-time information (like control tower systems). The case study presented later on this paper supports this statement.

Pull

Previous IGLC papers have discussed the concept of 'pulling' (e.g., Ballard, 1998). The objective of this section is to present pulling in the context of project production systems. The aim of a 'pull' system is to produce only what is needed, when it is needed, and in the right quantities. The way a pull production system works is explained next using the same steps as the example presented above: (1) Fabrication, (2) Assembly, and (3) Installation (Figure 2a).

In this example, the first signal pulls from a buffer between Installation and Assembly (Figure 2b). This signal triggers the start of the Assembly operation for specific quantity and type of components. The assemblies requested then become WIP in the production system until they are installed (WIP 1 in Figure 2c). This WIP typically sits anywhere between the job site and the assembly facilities (e.g., if different to site). The Assembly operation then sends a different signal to pull from a buffer located between Fabrication and Assembly (WIP 2) in order to replenish components required for assembly. As a result of this pull signal, Fabrication is initiated generating WIP 4 (Figure 2d). The process is repetitive until Installation stops releasing pull signals. This is how a pull production system behaves. Some of the benefits include:

- Demand triggers supply step by step on a just-in-time basis,
- WIP levels can be monitored and then reduced,
- If WIP levels are reduced while maintaining or increasing throughput, projects can have shorter duration (Little's Law: Cycle time = WIP/Throughput)
- Working capital can be reduced. Capital tied up in: (1) inventories of materials requested too early and materials that are not being used, (2) less labor time spent handling materials, (3) less loss, damage or misplacement of materials, etc.

Conwip – Constant Work in Process

Hopp and Spearman (2000) developed the concept of CONWIP as a mechanism to cap WIP in a production line. A CONWIP production system is really a pull production system with specific limits on WIP levels. A CONWIP production system differs from a pure pull production system (Figure 2) on how pull signals are utilized. The following example (Figure 3) illustrates the behavior of a CONWIP production system in construction considering the same example as in Figures 1 and 2.

One of the first steps is to determine the start and end of the production system. In this particular example, the start is Fabrication and the end is Installation. Installation pulls Fabrication (Figure 3b). Note that there is only one pull signal because the production system is linear. Having more than one pull signal is possible in the case of non-linear production systems (meaning one or more ramifications). Once the pull signal has been released, the same amount of work flows through the production system, meaning the WIP levels are the same for each signal (Figures 3c and 3d). The challenge in construction is the definition of the production unit. In construction, the product going through the production system changes constantly. In the case of a rebar production system, for example, one day the product may be rebar columns, the next day rebar beams. One way to deal with this challenge is to establish a rule across the production system that defines CONWIP as days of work instead of a number of units. This requires the design of the production system to be flexible enough to handle different types of product configurations.

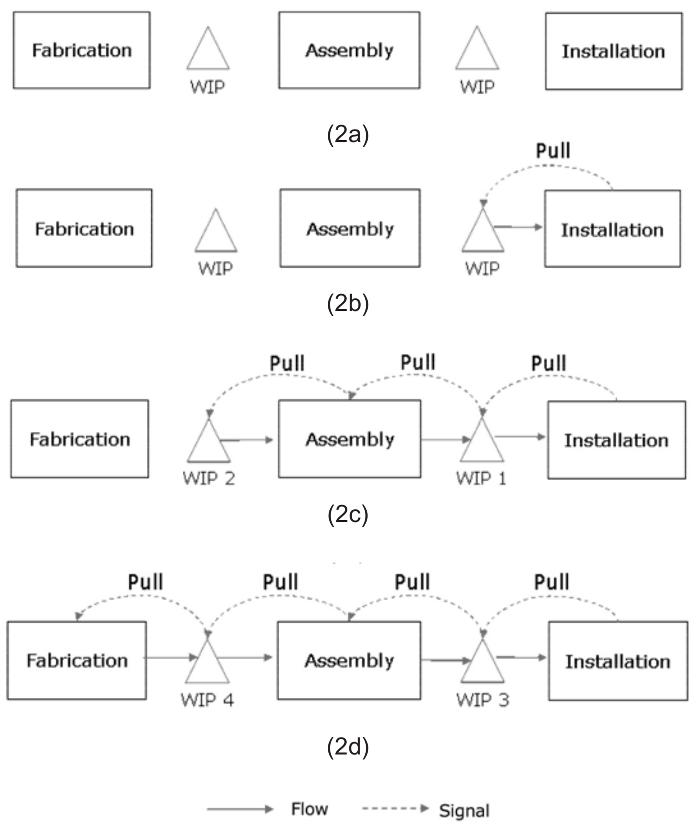

Figure 2: Schematic Representation of Pure PULL

A CONWIP system can be also seen as a push system except for the first step. Basically, once the first step gets the pull signal, work is pushed through the production system.

Hopp and Spearman (2002) propose that a CONWIP production system has the following main advantages:

- WIP levels are directly observable, while the release rate in a push system (schedule driven) must be set with respect to capacity, which is difficult to observe
- It requires less WIP on average to attain the same throughput
- It is more robust to errors in control parameters
- It requires setting one pull signal only. A reduction in the number of pull signals introduces less stress in the stakeholders across the production system.
- It is more flexible in terms of handling different product types for each signal (e.g., CONWIP = 1 day of work, independently of the type of products in the production order)

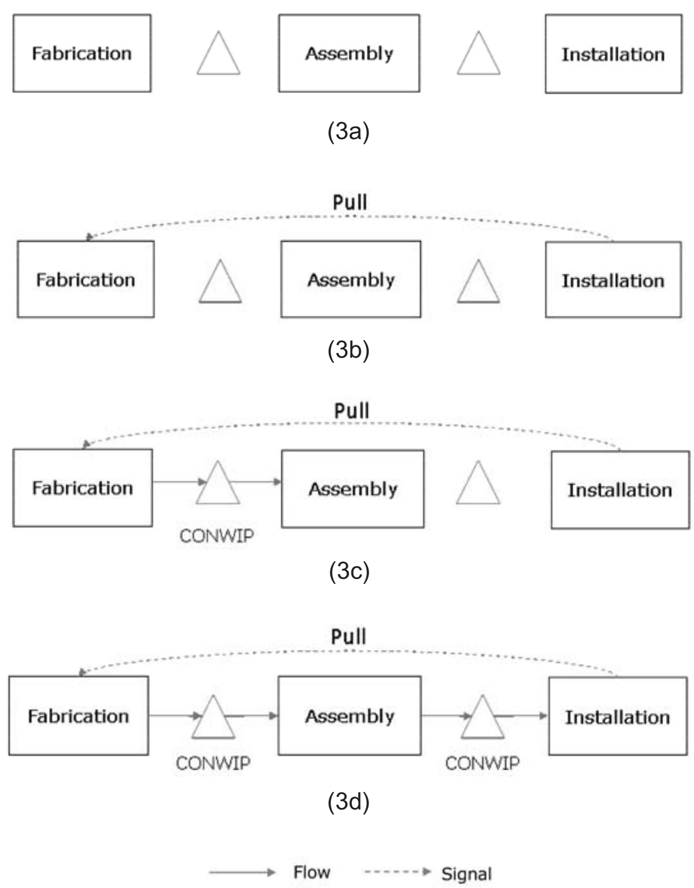

Figure 3: Schematic Representation of CONWIP

CASE STUDY: CONWIP PRODUCTION SYSTEM FOR REBAR

Due to space constraints, this paper does not present a case study on a pull production system. For a detailed example of the application of pull, please refer to Arbulu et al. 2003, where pull is introduced in the way of kanban to control the supply of made-to-stock products. The following is a case study focused on CONWIP for the control of rebar, an engineered-to-order product.

Background

This section presents a case study on the implementation of a CONWIP production system for rebar supply. This implementation took place during the Civils Phase of the construction of a major transportation hub in the U.K. This project involves multiple teams, each in charge of different sub-projects. This case study builds on the challenges of one of these teams.

The Challenges

The team identified the following challenges:

- The start of the project was delayed in 12 weeks
- The directive from the project leadership was that the team needed to meet the original milestone date – there was no other option.

Once the challenges were exposed and understood, the team worked with Strategic Project Solutions to analyze all critical elements that needed to be in place to finish the project 12 weeks ahead of the initial plan. The conclusion was that the availability of rebar was critical and the development of a strategy to face these challenges was needed.

The Strategy

The strategy was developed following the overall process of definition, design, implementation, and operation.

As part of definition, the strategy considered the voice of the customer: 'the availability of rebar is critical for the success of the project'. In order to develop the strategy, the voice of the customer needed to be translated into something more concrete. In this case, it was translated as 'maintaining a high reliability of rebar supply throughout the delivery of the project is a must'. The challenge then switched to how to ensure rebar supply is reliable all the time and what are the conditions for this to occur (the voice of the engineer).

As part of the design of the strategy, it was important to understand the nature of rebar as a product so the right solution is implemented. In this case, the product was not a piece of rebar but a rebar assembly. As engineered-to-order products, rebar assemblies require that someone engineers, makes and assembles rebar components based on site orders. The overall delivery process throughout the rebar production system then included steps such as detailing, fabrication, pre-assembly, delivery, and site installation. Therefore, to ensure a reliable supply of rebar, the final solution needed to include actions in all these areas. Taking this into consideration, the final design of the strategy included the following:

1. Re-engineer the process throughout the entire rebar production system
2. Implement a CONWIP Production System to control WIP

3. Form cross-functional teams instead of working in silos
4. Use SPS|Production Manager[2] (aka ProjectFlow) as a tool to synchronize demand and supply
5. Design standard rebar products using immersed Virtual Reality
6. Assemble rebar elements and limit site to final install
7. Use a single data set from detailing through installation

The strategy did not rely only in the application of CONWIP; however, the decision to use CONWIP defined how the production system behaved.

The Results

This section not only presents details about the results obtained, but also provides insights about the implementation of the strategy.

As part of the results, the team was able to complete the project on schedule with more than 12 weeks recovered ensuring customer satisfaction. Other project teams recognized the effectiveness of the CONWIP production system and it became standard practice for the Civils Phase.

The first step in implementation was to understand the current process of how rebar was detailed, fabricated, assembled, and delivered to site. This allowed a detailed calculation of the lead time across the rebar production system as well as the identification of steps that could be eliminated from the current process. Considering that rebar assemblies are engineered-to-order products, long lead times were expected. In this case, a long lead time was defined as one that exceeds the windows of site reliability. Ballard (1998) proposed that '…we need to get delivery time within our window of predictability and reliability. We need to close the gap by increasing work flow predictability beyond 1 day and by reducing delivery times'. Zabelle et al. (1999) stated that in order to use pull-based systems on AEC projects, a window of reliability greater than supplier lead-time must be obtained.

In this case, the lead time from detailing, fabrication, assembly, delivery, and installation was identified as 6 weeks. After re-engineering the process, the lead time was reduced to 7 days (see Figure 5), a reduction of 84%. In addition, the number of process steps was reduced in 50%.

The new rebar production system design incorporated the use of (1) digital prototypes and immersed Virtual Reality to enable the design of standard rebar assemblies, and (2) SPS|Production Manager as the 'control tower system' to enable the synchronization of rebar demand and supply across the production system. The use of SPS|Production Manager enabled an improvement of daily production reliability (or reliability of daily demand) to levels over 90% as shown in Figure 4.

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2 SPS|Production Manager is an integrated suite of web-based modules designed to enable better control of cost, time and associated use of capital, enhanced quality and reduced health and safety risk for the delivery of capital projects.

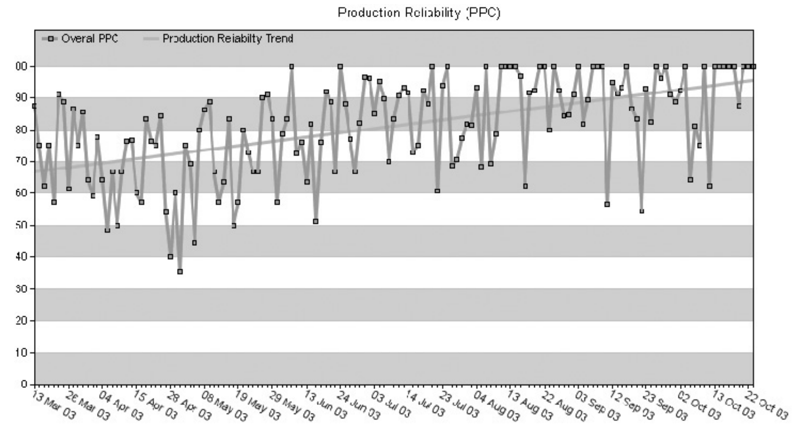

Figure 4: Improvements in Demand Reliability.

The site team (in charge of installation) released a PULL signal through SPS|Production Manager that triggered the start of rebar detailing for a specific area of the project. CONWIP was defined as 7 days of work, which means that 7 days of work flowed through the production system from detailing through final installation at any point in time. The production system processed an order in a total of 5 days as shown in Figure 4. Installation took 2 days, one of which was pure installation and the other day was a time buffer to control site variation (rebar components arrived to site the day before installation).

To ensure successful implementation of the new process design, collaboration amongst stakeholders was critical. To incentive collaboration, a cross-functional team was formed. The cross-functional team included the structural engineers, the fabrication and assembly teams, the transportation team, and the site team doing final installation. All of them used a single data set from detailing through production.

Due to the speed required to finish the project on time, the strategy included the fabrication of modular units. These units were fabricated in factory conditions helping to speed up site operations and keep on-site labor to a minimum. Modularization worked as an incentive to remove complexity from the workface. It was absolutely critical to eliminate the "contractor-can-sort-out-on-site" mentality up front. One way to eliminate this mentality was to use immersed virtual reality (VR) to develop product and process standards that provide the basis for detailed engineering. In immersive VR, the user becomes fully immersed in an artificial, three-dimensional world that is completely generated by a computer. Figure 6 shows examples of this work.

Regarding scheduling, the project team did not use schedules for control across the production system, but rather to plan the overall job at a macro level. In terms of commercial conditions, stakeholders worked under a cost-plus commercial framework where the owner focused on the creation of the right environment towards project success.

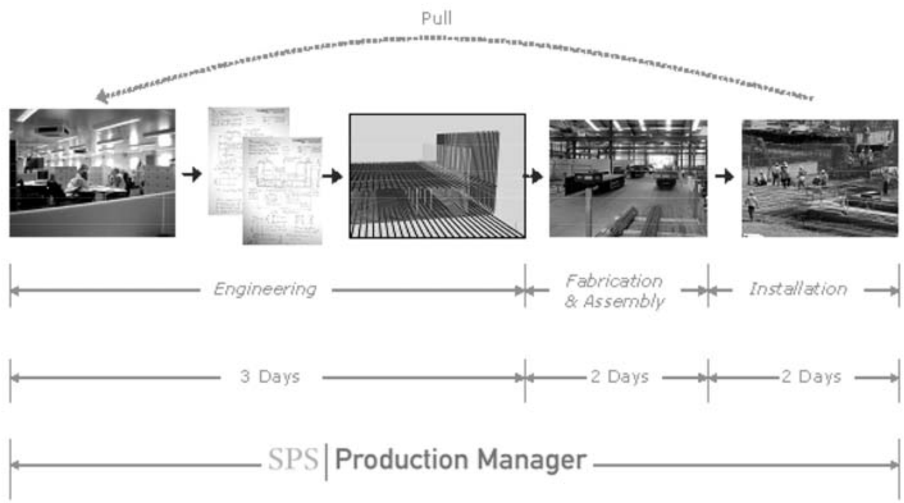

Figure 5: CONWIP Production System for Rebar (CONWIP=7 days).

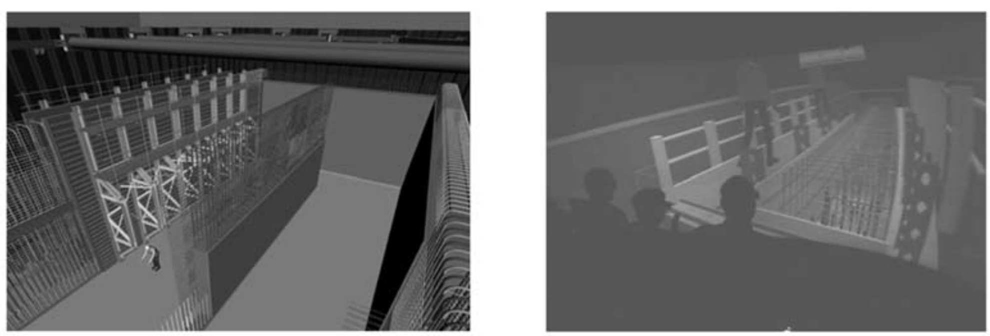

Figure 6: Creating Standard Product & Process – Immersed VR.

CONCLUSIONS

This paper has introduced the concepts of PULL and CONWIP as control techniques to be applied across construction production systems. The paper has made a distinction between the role of these techniques and the role of schedules in project delivery. The case study has presented results that demonstrate that lead time reductions of more than 80% are possible in construction. It has highlighted process improvement results where 50% of original steps are removed thanks to the understanding of customer value.

Finally, the use of technology has been presented as key to (1) support the implementation of these techniques towards value maximization, (2) to enable synchronization of demand and supply, and (3) to identify and eliminate sources of variation coming from product and process.

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