Due to the fragmentation on Architecture-Engineering-Construction projects, many services and products provided by specialty contractors and fabricators have become commodities. As a result of this local optimization, project planners may use contracts primarily as purchasing agreements and subsequently fail to identify opportunities for global optimization. This article explains one such case, and it has been used by the Lean Construction Institute (LCI) in its introductory seminar to explain the concept of work structuring. We are rethinking how contracts should be structured to provide proper incentives that encourage all project participants to work on and improve the integration of product and process design. Thus, we are working on reshaping the role of specialty contractors and fabricators so that they can become involved earlier in project delivery as value generators as opposed to commodity suppliers. LCI is planning on holding a Supplier Forum in the near future to address this issue. We appreciate DHI’s interest in our article, and we welcome your feedback and comments to help us shape the agenda of the upcoming forum. Please direct all correspondence to Cynthia Tsao, Assistant Professor in the Civil and Environmental Engineering Department at the University of Cincinnati (cynthia.tsao@uc.edu or 513-556-3673). Thank you.

Abstract

This paper presents “Work Structuring,” a term used to describe the effort of integrating product and process design throughout the project development process. To illustrate current Work Structuring practice, we describe a case study involving the installation of door frames into walls in a prison. We analyze why various problems existed. To improve the Work Structuring effort, we apply the “Five WHYs” to develop local and global fixes for the system of precast walls and door frames. The “Five WHYs” is a technique to elicit alternative ways of structuring work without being constrained by contractual agreements, traditions, or trade boundaries. We discuss the importance of dimensional tolerances in construction and how these affect the handoff of work from one group of workers to the next. We argue that these constraints and tolerance management practices are so embedded that project participants can miss opportunities to better integrate product and process design. We propose shifting the focus of Work Structuring from maximizing local trade efficiency to improving overall performance in the delivery system of a capital project.

Work Structuring

Various levels in project organizations determine the structure of work, the way boundaries are established between tasks, the design and location of each task’s production process, and the aggregation of the resulting products into completed projects. Designers, fabricators, and contractors each have some input, and work is structured within the traditions and norms of the familiar craft and contractual structures. This current practice typically strives to maximize performance in the preparation of each piece, so project participants often become blinded to important opportunities for improving overall project performance (Paulson 1976).

Work Structuring in Lean Construction is defined as “the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts” with the goal of making “work flow more reliable and quick while delivering value to the customer” (Ballard 2000). Ballard (1999) initially equated the term ‘Work Structuring’ to process design and has since broadened the scope of Work Structuring by equating it with
production system design (Ballard et al. 2001). In the remainder of this paper, we advocate this definition for "Work Structuring" and illustrate how it differs from current practices of structuring work.

Work Structuring answers the following questions (Ballard 1999): (1) In what units will work be assigned to groups of workers? (2) How will work be sequenced? (3) How will work be released from one group of workers to the next? (4) Will consecutive groups of workers execute work in a continuous flow process or will their work be de-coupled? (5) Where will de-coupling buffers be needed and how should they be sized? (Howell et al. 1993) and (6) When will different units of work be done? In particular, Work Structuring is a dynamic process that should be reevaluated in the course of a project. At the project onset, Work Structuring deals with designing the overall system. As the project progresses, Work Structuring becomes more focused to guide the design and execution of interacting pieces of impending work. This concept is certainly not new—practitioners have been "structuring work" for as long as construction projects have been in existence. However, we hope to highlight work structuring as a fundamental skill based on organizing principles that should be examined and refined through research.

We use the term "Work Structuring" to be distinct from the term "work breakdown structure." Contracts, history, and traditional practices of designers, suppliers, and building trades affect how planners conceive of the work required to complete a project. In particular, planners often use a work breakdown structure (WBS) to decompose a project into work packages to create a framework for project planning, scheduling, and controls (DOD-NASA 1962 p. 26, Halpin et al. 1987 p. 3, Neil 1988 p. 3). Work breakdown may proceed according to the 16 divisions outlined by the Construction Specifications Institute’s and Construction Specifications Canada’s 5-digit MasterFormat system of classification and numbering (Means 1997). Consequently, designers and builders view production primarily as a transformation process where: (1) the total transformation can be decomposed into smaller transformations, (2) the cost of production can be minimized by minimizing the cost of each decomposed transformation,
and (3) it is advantageous to buffer production” (Koskela 2000 p. 49). In this regard, production consists of a sequence of transformations of inputs into outputs, and buffering production involves staging resources before transformations so that the transformations execute as planned. In anticipation of this piece-meal decomposition, designers often leave interface resolution, such as dealing with issues of scope gap and scope overlap, to the builders. They leave tolerance management to installers because they assume that the pieces they have designed will be relatively simple to identify and fit together. By viewing a project as an aggregation of parts, designers may not realize that they can—and we think should—design the project as an assembly of interacting pieces all the way from design through construction. While the design of each part may appear to be reasonable and logical upon inspection (MCAA 2003), the design of the overall assembly may actually be far from optimal. Not only may it fail to take advantage of overlapping disciplines, the uncertainties and errors created upstream (e.g., during design) may prove to be detrimental to performance downstream (e.g., during installation) (Tommelein et al. 1999).

A piece-meal, product-oriented contracting mentality prevents the development of a comprehensive work structure that supports design through construction as well as operations and maintenance. An alternative approach is to use UNIFORMAT II (Charette and Marshall 1999) to classify major building components and related site work. UNIFORMAT II provides project planners an “elemental framework instead of...a product-based classification” for evaluating alternatives at the early design stage, developing design specifications, and performing cost estimates and analysis. Designers and general contractors could also involve specialty contractors and fabricators early in the design process to take advantage of their insights into process efficiencies (Tommelein and Ballard 1997, Gil et al. 2000). Specialty contractors and fabricators have insight into recent advances in and availability of materials, equipment, and trade skills. Slaughter (1993) noted that innovations on site are needed because problems at the interfaces between products are less likely to be tackled by any one of the product fabricators. This creates a reliance on craft skills, which is difficult today but unrealistic in the future as fewer people are entering the construction trades.

The phrase, “work structuring”, has been used in manufacturing (e.g., Heizmann 1983). However, that use focused primarily on optimizing productivity on a manufacturing floor, often through automation. The case study described in this paper uses “Work Structuring” with a broader meaning tailored to the Architecture-Engineering-Construction (AEC) industry. We also use the term “Work Structure” to be distinct from the term “work structure process.” The Construction Industry Institute (CII) developed the Work Structure Process to distribute roles and responsibilities between the owner and contractor based on key project competencies (Anderson 1997). While it is important to clearly define these roles and responsibilities, other project participants—most notably suppliers—play a significant role in project delivery as well. More recent CII research recognizes the suppliers’ and other stakeholders’ role and value in project delivery (e.g., Tommelein et al. 2003). In summary, we use the term “Work Structure” to generically describe how work on a project will create a product that meets customer needs.

**Research Design and Methodology**

Case study research is used here to introduce and contribute to the development of a theory of Work Structuring applicable to the AEC industry. Meredith (1998) notes that researchers use either a rationalist or a case study research paradigm. Rationalist research “employs quantitative methodologies to describe or explain phenomena... [It] is concerned with explaining what happens and how.” In contrast, case study research “uses both quantitative and qualitative methodologies to help understand phenomena. It is more processor means-oriented and helps the researcher comprehend why certain characteristics or effects occur, or do not occur.” Developing such an understanding is the aim of our research.

We decided to focus our case study on a Work Structure consisting of walls and door frames in prison construction for many reasons. First, the construction manager’s Vice-President of Production and Process Innovation (formerly a Manager of Project Controls) suggested that this case study...
be an exercise in operations design to warrant a First Run Study (Howell and Ballard 1999) as he wanted to improve the productivity of the labor-intensive door frame installation process. However, once it became apparent that problems were rooted in the structure of work as opposed to operations design, the research focus shifted to re-evaluating the AEC project development process. Second, as we try to formalize the concept of Work Structuring, it makes sense to start with a simple example. The system of walls and frames works well in this regard as it is simple in comparison to other systems that make up AEC projects. Third, door frames in prison walls represent a primary building component within a sizable industry. Between 1990 and 1995, U.S. state and federal officials built 213 new prisons housing more than 280,000 beds to increase their capacity to 976,000 beds (DOJ 1997). What we observed represents accepted and common practice in parts of the U.S., so insight into improving the project development process would be of interest to companies employing similar design and construction practice.

For many building projects, the creation of open spaces is a primary activity that brings value to the owner. As the purpose of a prison is to keep inmates confined, the creation of walls and doors brings value to the owner of this project. Consequently, recommendations to improve door frame installation would also be of interest to the owner.

This research began with a site visit to document current practice (Tsao et al. 2000a). We conducted telephone interviews with the construction manager, the precast wall fabricator, the door frame manufacturer, and a grout pump manufacturer to deepen our understanding of the case. We also contacted other materials-, equipment-, and design service suppliers to help us develop alternative Work Structures. Then, we visited the site again to develop a cost analysis for the alternatives. During the second site visit, we interviewed the workers, met with the precast wall fabricator, and visited another project that would implement selected recommendations.

**Project Background**

This case study focuses on the construction of the Redgranite Correctional Institution in the state of Wisconsin.
Wisconsin. This project consists of 4 housing buildings that cover a total of 15,310 m² (164,800 ft²) (Thompson 2000). Additional facilities cover another 11,140 m² (119,900 ft²). Housing buildings are 2 stories tall and their walls are made from precast concrete panels. The first-level floors are slab-on-grade while the second-level floors are precast concrete slabs. In particular, this case study investigates the installation of 285 detention hollow metal door frames into Housing Buildings E and F.

The owner of the project is Wisconsin's Department of Corrections. The Oscar J. Boldt Construction Company is the construction manager. Venture is the project architect. The State awarded Boldt this design-build project based upon a guaranteed maximum price bid of $48 million. The design-build team started work in late 1997 and spent 1998 designing, budgeting, and scheduling the project (Thompson 2000). Construction lasted from February 1999 to November 2000. Before this project, Boldt had already built 4 prisons in a similar fashion.

The State held a contract with Boldt. Boldt, in turn, held a contract with Venture. Boldt selected Spancrete Industries, Inc. to supply the concrete panels and LaForce to supply the doors and door frames. LaForce is a licensed manufacturer of the Ceco brand doors specified by Venture. While Boldt chose Central City Construction, Inc. to install the concrete panels, they self-performed the installation of the door frames. Boldt hired R.J. Jacques to caulk around the door frames, and then Boldt took care of grouting the door frames.

The project included four primary design packages: footings and foundation, superstructure, electrical and mechanical, and finishes. Venture released design information about these design packages to Boldt in a piece-meal fashion so that suppliers could begin fabricating pieces early.

The concrete panel supply chain was as follows. First, the State determined its enclosure criteria. With that information, Venture developed an initial wall design with rough openings. Using Venture's initial design, Spancrete developed shop drawings for approximately 3,000 precast concrete pieces and submitted them to Boldt. Venture and Boldt reviewed the shop drawings, approved them, and gave Spancrete permission to proceed. Spancrete fabricated the concrete panels and then delivered them to the job site. The lead time from Boldt's receipt of Spancrete shop drawings to site delivery of the panels was about 12 weeks. Venture specified most panel sizes although they did not have all details on the mechanical requirements (e.g., louvers, air intake and exhaust duct) for panel penetration. When early design data changed later, several mechanical openings had to be cut on the job site. This was an expensive, labor-intensive process that Boldt tried to eliminate in subsequent projects.

The door frame supply chain was as follows. With the State's enclosure criteria, Venture developed the door bid package containing door and door frame designs within a door schedule. Venture developed the door bid package 5 months after Spancrete developed the precast wall shop drawings. LaForce submitted a bid to supply the frames. Boldt approved LaForce’s bid and gave them permission to proceed with fabrication. From Boldt’s receipt of LaForce shop drawings to site delivery, door frames took about 6 weeks and door hardware took about 10 to 12 weeks.

Central City installed the walls and Boldt installed the door frames. Then, following Venture’s caulking specifications, Jacques caulked the door frames. Boldt subsequently installed a Plywood Fix (which will be discussed later) and pumped grout into the door frames. Finally, once the grout had set and Boldt removed the Plywood Fix, Jacques returned to fix any damaged caulking. Tsao et al.
(2000a) illustrate this door frame and concrete panel supply chain.

**Door Frame Installation: Current Practice**

**Hollow Metal Door Frames**

*Door Frame Installation*

Boldt installed the hollow metal door frames according to prison plans. Figure 1 illustrates the door frame detail in 3 dimensions. Boldt’s installation procedure is the following. First, the installer moves a frame into the cell. He then uses a level to draw a plumb line to mark where the frame should be installed. Next, he positions the frame into the door space and places the frame against the plumb line. Then, he aligns the frame by using a level and wooden shims. Finally, he installs anchor bolts through the frame and into the precast wall, turns them as tightly as possible, grinds the heads of the bolts down, and applies a Bondo filler over the ground bolt heads.

*Caulking Procedure*

Once a frame is installed, the next step is to caulk the seam that separates it from the precast concrete panel. Jacques’ procedure is the following. First, a worker cuts the shims off with a hand chisel, a procedure called “trim out”, so the shim will not protrude through the caulking surface. Then, he inspects the gap between the frame and the wall to see if the caulking will stay in place. If the gap is too wide, the worker inserts a foam backer rod to bridge the gap and caulks directly over it. Usually, the worker first caulks along the door jambs and then caulks along the header. Finally, he brushes the caulking to finish the job, a procedure called “feathering”.

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Caulking and Grouting Procedure

In prison construction, the door frame installation process differs from standard door frame installation processes due to added security measures. At Redgranite, Venture specified that frames be grouted. In addition, Venture required that security sealant be used along the cell side and hallway side edges of the door frames. In response to a request by Boldt, Venture changed their caulking requirement by allowing latex caulking to be used on the hallway side of the frames. Latex caulking is the type used in bathrooms and kitchens. It is not used inside cells because inmates may attempt to remove or eat it. Latex caulking contains ethylene glycol and eating large amounts of it can result in serious illness or even death. Security sealant is about 55 MPa (8,000 psi) in strength, so it effectively resists inmate tampering. We believe the purpose of caulking is to (1) prevent grout from leaking out during installation and (2) prevent inmates from having access to any gaps that might develop between the grout and the wall.

Venture specified a grout with a strength of at least 14 MPa (2,000 psi) and left it up to Boldt to develop the mix. Boldt was also responsible for grouting the frames. The crew used an air-pressure powered grout pump operating at 30 MPa (4,350 psi) for this application. When the crew developed an initial mix, they found that it did not pump well into the frame due to too much coarse sand. After consulting two other contractors who had performed similar work, they tried 4 other mixes until they found a good ratio of sand, cement, and water. Boldt decided that the final mix was adequate, informed Venture of their mix design, and used it on Redgranite.

Boldt pumped grout through 2 holes in the frame called “grout ports,” located 76 mm (3”) below the header, one on each doorjamb. A grouting crew first fills the doorjams halfway. Once this grout has set, the crew then fills the remaining halves and the header. Unfortunately, this procedure had problems. During placement, grout leaked through the cracks between the frame and the wall, blowing out the foam backer rods and caulking. As frames were already installed when they began grouting, any leak prevention system had to be applied to the outside of the frame. At first, Boldt tried to use the latex caulking and security sealant as a barrier, however both the caulking and sealant kept blowing out. To prevent further blowout, Boldt devised a “Plywood Fix” (according to Boldt, other contractors use similar fixes). They cut two large U-shaped pieces of plywood sized to fit directly against the seam between the door frame and precast wall (Figure 2). They built C-clamps out of plywood and used them to hold the two U-shaped pieces together against the door frame. Workers added wooden shims between the C-clamps and the U-shaped pieces to tighten the fit.

Boldt had selected the grouting process with the plywood Fix as a candidate for a First Run Study. A First Run Study accepts the existing design and develops solutions that can work within the current contractual relationships. However, when we applied the “Five WHYS” to unravel aspects of the Plywood Fix, it became apparent that problems were more deeply rooted in the structure of work. This case study is a means to understand what happened and to determine systematic means to eliminate the need for “Plywood Fixes” on future projects.

Part 2 of this Case Study will be published in the July issue of Doors and Hardware.