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CASE STUDY FOR WORK STRUCTURING: INSTALLATION OF METAL DOOR FRAMES

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ABSTRACT

Work structuring means developing a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts. The goal of work structuring is to make work flow more reliable and quick while delivering value to the customer. Current work structuring practices are driven by contracts, the history of trades, and the traditions of craft. As a result, they rarely consider alternatives for making the construction process more efficient. To illustrate current practice and the opportunities provided by work structuring, this case study discusses the installation of metal door frames at a prison project. Because the project is a correctional facility, the door frame installation process involves a special grouting procedure which makes the installation process less routine. Those involved recognized the difficulty of the situation but better solutions were impeded by normal practice. This case study thus provided the opportunity to illustrate how one may come up with alternative ways to perform the work without being constrained by contractual agreements and trade boundaries. By doing so, we illustrate what work structuring means. Local and global fixes for the system comprising walls and doors are explored. In addition, we discuss the importance of dimensional tolerances in construction and how these affect the handoff of work chunks from one production unit to the next.

KEY WORDS

lean construction, work structuring, process design, operations design, first run study, methods analysis, precast concrete, door installation, planning, coordination

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WORK STRUCTURING

According to the Lean Construction Institute (Howell and Ballard 1999), work structuring means developing a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts. The goal of work structuring is to make work flow more reliable and quick while delivering value to the customer. In particular, work structuring views a project as consisting of production units and work chunks (Ballard 1999). A production unit is an individual or group performing production tasks. Production units are recipients of work assignments. A work chunk is a unit of work that can be handed off from one production unit to the next. In the process of performing a production task, each production unit may or may not make changes to the boundaries of the work chunk before handing it off to the next production unit. Production units continue adding value to a work chunk until it becomes completed work.

Work structuring involves determining:

1. In what chunks will work be assigned to specialists?
2. How will work chunks be sequenced?
3. How will work be released from one production unit to the next?
4. Will consecutive production units 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)
6. When will different chunks of work be done?

Current work structuring decisions are governed by contracts, the history of trades, and the traditions of craft, that is, decision makers rarely consider how to optimize the entire production process. Projects that use design-bid-build contracting separate design and construction into two distinct non-overlapping processes. In an attempt to fast track a project, designers and general contractors often view a project as an assembly of pieces. They release each piece and then assign contracts to fabricate and install it separately.

This view is reinforced by work breakdown practices such as those used in estimating according to the 16 divisions outlined by the Construction Specifications Institute's (CSI) and Construction Specifications Canada's (CSC) 5-digit MasterFormat system of classification and numbering (Means 1997). In anticipation of this piece-meal decomposition, designers focus primarily on optimizing the design of parts rather than the overall system. They leave interface resolution, including dealing with issues of scope gap and scope overlap, to the contractor 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 each part design may appear to be reasonable and logical upon inspection, the design of the overall assembly may actually be inefficient. 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). This piece-meal contracting mentality prevents the development of a comprehensive design for the project that supports the entire process. An alternative approach is to involve specialty contractors early on in the design process to take advantage of the insight they have into process efficiencies and improvements in product quality (Gil et al. 2000). Work structuring supports this approach to setting up the construction production process.

This case study will illustrate how current work structures are driven by contracts, trades, and craft. It will describe problems the construction crews faced, examine what solutions they came up with, and then explore system design decisions that shaped operations. The aim of this paper is to illustrate the kind of reasoning that underlies the work structuring process. We apply the quality management technique known as the “5 WHYs” to get to the root causes of the problems. Unfortunately, page length and time limitations have prevented us from including a more detailed benefit/cost analysis of alternative work structures in this paper, but further research will include such a quantitative analysis. However, we anticipate that the alternative work structures outlined in this paper can lower the cost and duration of door installation from 5% to 30%.

PROJECT BACKGROUND

This case study focuses on the construction of the Redgranite Correctional Institution, located in Wisconsin. This project consists of 2 housing buildings that cover a total of 140,000 square feet (13,500 m^2). Additional facilities cover another 140,000 square feet. These 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 510 hollow metal door frames into the housing buildings. For many building projects, the creation of open spaces is the primary activity that brings value to the owner. As the purpose of a prison is to keep inmates confined, on this project, it is the creation of walls and doors that brings value to the owner. Recommendations to improve door frame installation would thus be of interest to both the contractor and the owner.

The owner of the project is the Department of Corrections of the State of Wisconsin. 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. Construction of the Redgranite Prison began in February 1999 and is to complete by October 2000. Prior to this project, Boldt already built 4 similar prisons.

Figure 1 illustrates the key supply and contractual relationships on this project using Rother and Shook’s (1998) technique for mapping value streams. The State holds a contract with Boldt. Boldt, in turn, holds a contract with Venture. Boldt also holds a contract with Spancrete Industries Inc. to supply the concrete panels as well as with Laforce to supply the doors and door frames. Laforce is a licensed manufacturer of the Ceco brand doors specified by Venture. While Boldt hired Central City Construction Inc. to install the concrete panels, they self-performed the installation of the door frames. Later, Boldt hired R.J. Jacques to caulk around the door frames, and then they decided to self-perform the injection of grout into the door frames.

On this project, there were four primary design packages: footings and foundation, superstructure, electrical and mechanical, and finishes. Venture released design information to Boldt in a piecemeal fashion. This allowed contractors to begin fabricating pieces early.

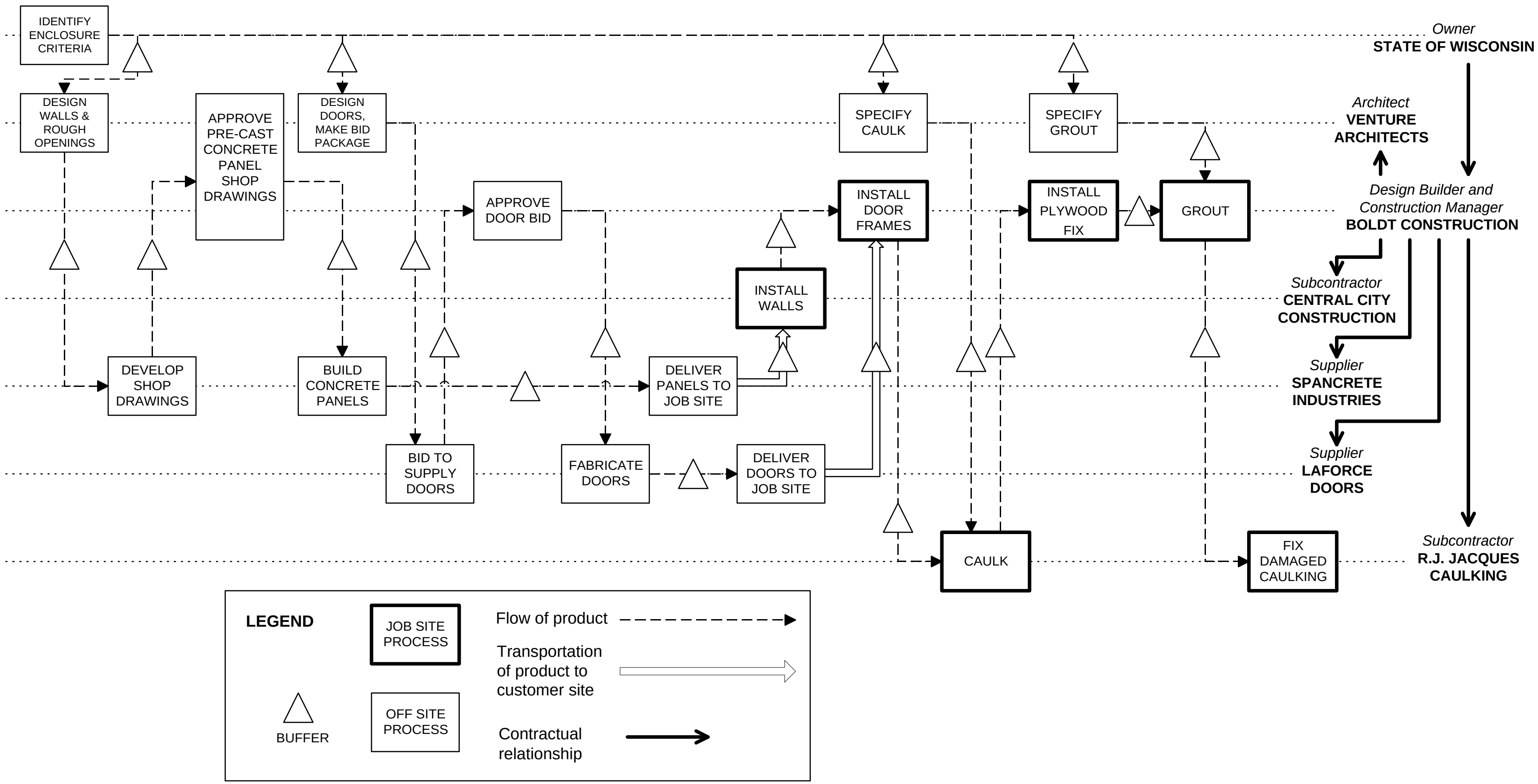

Figure 1: Supply and Contractual Relationships on Redgranite Correctional Institution

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 permission to Spancrete to proceed with manufacturing. After Spancrete built the concrete panels, they delivered them to the job site. The lead time from receipt of the shop drawings from Spancrete to site delivery of the panels was 12 weeks. In many situations Venture specified the panel size although they did not have details on the mechanical requirements (e.g., louvers, air intake and exhaust duct) for the panel. As some early design data was changed later, several mechanical openings had to be cut on the job site.

The door frame supply chain was as follows. With the State's enclosure criteria, Venture developed the door bid package that contained the door and door frame designs. The door bid package was developed 5 months after the concrete panel shop drawings were developed. Then, Laforce submitted a bid to supply the frames. Boldt approved Laforce's bid and gave permission to Laforce to proceed with manufacturing. From shop drawings to site delivery, door frames take about 6 weeks and door hardware takes about 10 to 12 weeks.

Central City installed the concrete panels and Boldt installed the door frames. 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 the Plywood Fix was removed, Jacques returned to fix any damaged caulking.

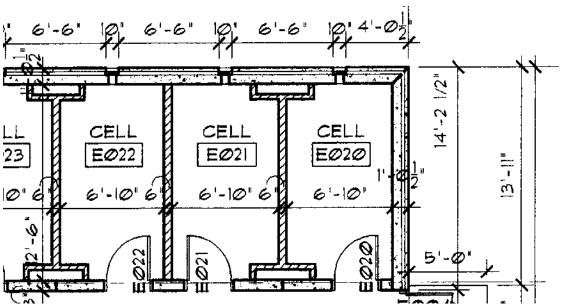

Figure 2: Plan View of Prison Cells
(From Housing Building E, Sheet A-1)

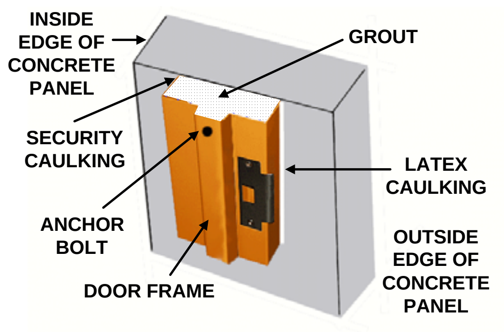

Figure 3: 3-D Diagram of Frame Design
(Adapted from detail from Ceco 2000)

DOOR FRAME INSTALLATION: CURRENT PRACTICE

HOLLOW METAL DOOR FRAMES

Door Frame Installation

As mentioned, Boldt was responsible for installing the hollow metal door frames according to prison plans (Figure 2). Figure 3 is a 3-dimensional rendering using a detail from Ceco doors (Ceco 2000). Boldt's installation procedure is the following. First, a worker moves a frame into the cell and leans it against a wall beside the opening. He then uses a level to draw a plumb line along the wall opening to mark where the frame should be installed (Figure 4). Then, he positions the frame into the door space and lines it up against that plumb line. He aligns and squares the frame by using a level and wooden shims (Figure 5). While holding the frame in position, he drills holes into the frame, installs anchor bolts (Figure 6), and tightens them. The worker then adds wooden shims to ensure that the frame is square and plumb, and he turns the bolts as tightly as possible. Finally, he grinds the heads of the bolts down, and applies Bondo over the ground bolt heads to create a smooth finish.

Figure 4: Drawing a Plumb Line

Figure 5: Inserting Wooden Shims

Figure 6: Drilling for Anchor Bolts

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 can stay in place. If the gap is too wide, the worker inserts a foam backer rod (Figure 7). He jams it into the crevice and caulks directly over it. On occasion, the backer rod may fall into the frame channel. When that happens, the worker does not try to remove it and installs another backer rod in its place. The worker usually caulks along the sides of the door and then runs the caulking along the top (Figure 8). Finally, he brushes the caulking, a procedure called "feathering" (Figure 9).

Figure 7: Installing a Foam Backer Rod

Figure 8: Caulking along the Top

Figure 9: Feathering

PRISON CELL DOOR FRAMES

Caulking and Grouting Procedure

On prisons, the door frame installation process differs from usual door frame installation processes due to added security measures. For Redgranite Prison, Venture specified that the frames were to be filled with grout. In addition, Venture required that security caulking be used along the frames. In response to a request for information submitted by Boldt, Venture allowed for two kinds of caulking: security caulking on the inside and latex caulking on the outside. Latex caulking is the type used in bathrooms and kitchens. It is not used inside prison cells because inmates may attempt to eat it. Latex caulking contains ethylene glycol and eating large amounts of it can result in serious illness or even death (USDHHS 2000). Moreover, inmates may try to store items in a void they create after scraping latex caulking away. Security caulking is about 8,000 psi (55 MPa) in strength, so it can resist inmate tampering better than latex caulking.

Venture specified a grout with a strength of at least 2,000 psi (14 MPa) and left it up to Boldt to develop the grout mix. Boldt was also responsible for inserting the grout into the frames. Boldt developed the mix by means of trial and error. The grouting crew developed an initial mix, tested it, and found that it did not pump well into the frame because it contained too much aggregate. 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 this mix was adequate and proceeded to use it. Boldt informed Venture of their mix design and Venture has not objected to its use.

Boldt's procedure for inserting grout makes use of 2 to 4 holes in the frame called "grout ports". A worker first fills the sides of the frame halfway with grout. Once this grout has set, the worker then fills the other half of the sides of the frame. After the second grout pass has set, the worker finally grouts the top of the frame. Unfortunately, this situation still had problems. During placement, grout leaked through the cracks between the frame and the wall, blowing out the backer rods and caulking.

Plywood Fix: As the frames were already installed at the time of the grouting, any leak prevention system had to be applied to the outside of the frame. At first, Jacques' crew tried to use the caulking as a barrier, but there was nothing to prevent it from blowing out. To alleviate this blowout problem, they devised a Plywood Fix. They cut two large U-shaped pieces of plywood (sized slightly larger than the frames) and fit each piece directly against the caulked frame. They built C-clamps out of plywood and used them to hold the two U-shaped pieces in. The workers added wooden shims between the C-clamps and the U-shaped pieces to tighten the fit (Figure 10). After pouring the grout and allowing it to set, they removed this fix. Sometimes, the plywood damaged the caulking, so the workers had to re-caulk the frames. Figure 1 includes this rework procedure. However, after becoming experienced in applying the Plywood Fix, the workers learned to remove it without damaging the caulking. As a result, Jacques did not have to come back and re-caulk everywhere.

This Plywood Fix was unwieldy and time-consuming. Boldt's workers take about 20 minutes to install it and 5 minutes to remove it. As a result, Boldt identified the Plywood Fix as a good candidate for a First Run Study (Howell and Ballard 1999). A First Run Study accepts the existing design and develops solutions that can work within the existing contractual relationships. However, as aspects of the Plywood Fix got unraveled, it became apparent that the problems were rooted in work structuring. Work structuring challenges the existing product and process design and comes up with solutions that may shift contractual obligations. This case study is a means to understand what happened and determine how to eliminate the need for "Plywood Fixes" on future projects.

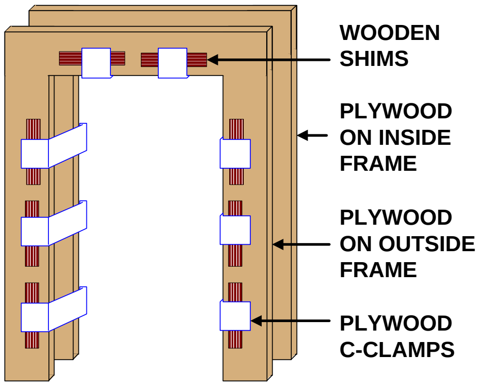

Figure 10: Diagram of Plywood Fix

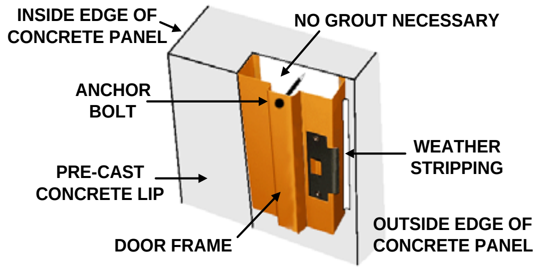

Figure 11: Concrete Lip Fix
(Adapted from detail from Ceco 2000)

5 WHYs

In order to get to the root cause of this problem, we apply a common quality management method of problem solving called the "5 WHYs". When a problem occurs, a worker should ask "Why did this problem develop?" After coming up with an explanation, the worker should ask again "Why is that the case?" The worker should continue with this repetitive inquiry until at least five "Why?"s have been asked and answered. The answer to the last "Why?" will give insight into the original cause of the problem. The strategy for fixing the system is to then eliminate that original cause (Koskela 1992). The "5 WHYs" are an integral part of the Toyota Production System (e.g., Shimbum 1995). On this project, the "5 WHYs" is appropriate to use to understand why the door frame installation process was structured as it was and why it ran into the problems it had.

LOCAL AND GLOBAL FIXES

The following local and global fixes were developed by the authors. Typically, the local fixes are feasible within the existing contractual arrangements whereas the global fixes are not. Many local fixes fall under the category of "productivity improvement" efforts as explored by Oglesby et al. (1989). Each section begins with a discussion of the "Why?". Then, individual fixes that address the question are explained in detail.

Why did caulking and foam backer rods blow out? Caulking and backer rods blew out because of the hydrostatic pressure developed by wet grout during the grouting process.

Grout Pump Fix: Boldt used a variable air-pressure powered grout pump that operates at about 4,350 psi (30 MPa). Hand-operated grout pumps on the market operate up to a pressure of 725 psi (5 MPa). These low pressure pumps are capable of up to 20' (6.1 m) of horizontal push and 10' (3.1 m) of vertical lift. Use of a low pressure grout pump may have reduced the number of blowouts.

Caulking Fix: We are assuming that caulking and backer rod blowout is independent of the type of caulking used. It is conceivable that security caulking is more resilient to blowout because it is stronger and adheres to surfaces better. If this is indeed the case, and blowout only occurs on the side with latex caulking, then the solution is simple: use security caulking everywhere. Venture's favorable reply to Boldt's request for information then had undesirable consequences and may not save Boldt any money in the long run. However, if neither one of the two types of caulking resists blowout, then Boldt might inquire if any other type of caulking would meet all requirements.

Why did grout leak through the cracks? Grout leaked through the cracks because of the pump pressure and thin grout mixture. With those two factors, the cracks were not tight enough to hold back the grout. This lack of tightness is the reason why backer rods were used to provide support when caulking over wide cracks. Because backer rods and caulking could not hold back the grout, the caulking crew introduced the Plywood Fix.

On-site Weather Stripping Fix: Boldt can attempt to tighten the seal between the frame and the wall. If access to the inside of the frame had been easy, then some sealant could have been applied at the inside without compromising the appearance of the door on the outside. For example, some kind of weather stripping material might be glued to run along the outside edges of the frame prior to frame installation so that it would be compressed when tightening the anchor bolts, thereby providing a tight seal. Security caulking would still have to be applied to the inside edge of the frame to prevent tampering by inmates, however the need for aesthetic caulking along the outside edge may be eliminated. This fix appears to be easy and cheap and could be applied on site.

Why was grouting of the hollow metal door frame needed? We do not know the origin of the grouting requirement but speculate that grout adds to prison security by (1) protecting the anchor bolts that connect the frame to the wall, (2) providing a bond between the frame and the wall while also making the frame heavier should an inmate try to push the frame out, (3) preventing inmates from hiding objects in the hollow frame, and (4) making it more difficult to disable the electrical lock mechanism inside the frame of some security doors.

Concrete Lip Fix: An alternative to eliminate the need for grouting is to prefabricate the walls with a concrete lip that protrudes on the inside of the cell wall (Figure 11). The inmates would then see only a recessed door and concrete walls, and the lip would block their access to the frame completely. This fix would not remove the need for caulking. By anchoring the frame against the lip, the contractor would still have to apply aesthetic caulking on the outside. The inside seam between the concrete lip and the frame should still be caulked with security caulking to prevent inmates from hiding weapons in it.

When asked if such an alternative is possible to manufacture, Spancrete replied that concrete panels of at least 8" (20.3 cm) thick could accommodate a 3" (7.6 cm) lip, assuming a frame was at most 5" (12.7 cm) thick. A wider frame resulting in a more narrow (e.g., 2" or 5.1 cm) lip would not work well because the lip might get damaged during shipping and handling. The addition of a lip would not violate any building codes because that area of the precast concrete panels is not designed to meet load-bearing requirements. The manufacture of such a lip involves adding an extra block to the wooden forms before pouring the concrete panels, slightly increasing the amount of concrete used, and adding a piece of reinforcing bar and meshing to strengthen the lip.

Why were there cracks between the door frames and precast panels? First, door frame installers need to have a 1/8" (3.2 mm) or so opening between the frame and the wall to make it possible to slide the frame into the panel opening and plumb it properly. Second, this opening will vary in size along the frame as a result of dimensional tolerances (stochastic variation relative to the design dimensions of a product) during manufacturing and placement of the concrete walls and metal frames. Openings are to be expected when surfaces touch each other in any assembly of parts. It may be difficult to manufacture each part with a smooth surface as smoothness is a relative concept. Materials change in dimensions over time (e.g., shrinkage cracks, deflection and settlement cracks, and cracks resulting from items that wear out). They also may expand or shrink with temperature changes throughout the day and vary with the season.

The construction industry has developed many kinds of materials and techniques to fill cracks, to cover them up, to make them water- or air tight, to provide structural integrity to the assembly, or to meet other functional requirements.

Tolerance Fix: Tolerances are specified by contract. They represent acceptable variation. Nevertheless, if not managed properly, they may compound problems as design and construction progress. As mentioned earlier, variation has the greatest detrimental impact on those downstream in the supply chain.

For this project, Venture developed design drawings that showed the rough openings in the walls. Then, using those rough openings, Spancrete developed shop drawings for the walls. The American Concrete Institute recommends a tolerance of 1/4” (0.64 cm) for openings in precast wall panels (ACI 1994). Because Spancrete builds walls within a tolerance of 1/8” (0.32 cm) and because of the previously mentioned field installation requirements, its rule of thumb is to increase the given dimensions by 1/4” (0.64 cm) on each side of the door opening so that the door opening is 1/4” (0.64 cm) taller and 1/2” (1.27 cm) wider than Venture’s design. After Boldt and Venture approved Spancrete’s shop drawings, Spancrete proceeded with manufacturing (Spancrete 2000).

A few months after Spancrete’s shop drawings were approved, Venture developed a bid package that specified the required door frames. Laforce submitted a bid to supply the frames using the door openings shown in Venture’s initial design drawings and the bid package. Laforce builds frames within a tolerance of 1/32” (0.08 cm). A door specified as 3’ (92 cm) to be used in a door frame that is 2” (5.1 cm) thick on each side, is built with a matching frame width of 3’-4” (101.6 cm). Spancrete’s corresponding opening would then be 3’-4-1/2” (102.9 cm) wide, leaving a gap of 1/2” (1.3 cm) (Figure 12).

We have not yet investigated the quality of these manufacturers’ products to determine what percentage of their products indeed falls within the tolerance range as specified and if all dimensions match those on the door schedule. Poor quality would lead to frames not fitting in the panel opening or leaving an excessively wide gap. Both situations occurred on this project. Sometimes, door openings had to be widened by grinding down the concrete in order for the frame to fit. Other times, masonry in-fill had to be used to narrow an opening that was too large. This uncertainty made it difficult for Boldt to anticipate which cracks would require the Plywood Fix. As a result, they installed this fix to all frames because doing so was easier than judging which caulking jobs would hold up against the grout and then dealing with occasional blowouts later.

Similarly, we have not yet investigated the quality of the design, that is, the extent to which the door schedule’s dimensions are correct. Poor quality would lead to drawings that do not show door openings, or the door schedule listing extra doors.

Considering these tolerances, the computed range in dimensions for the opening between the wall and the frame are:

$$\text{lower bound} = (\text{mean value}_{\text{panel}} - \text{tolerance}_{\text{panel}}) - (\text{mean value}_{\text{frame}} + \text{tolerance}_{\text{frame}})$$

$$= 3/32\text{” } (2.4 \text{ mm})$$

upper bound = (mean value$_{panel}$ + tolerance$_{panel}$) - (mean value$_{frame}$ - tolerance$_{frame}$)

= 13/32” (10.3 mm)

These numbers assume that the frame is perfectly centered in the door opening. If not, the lower bound may be 0 and the upper bound up to twice as large. Note also that the tolerance range may be exceeded on occasion, which is why Figure 12 shows bell curves (normal distributions) to depict the range of variation. Consequently, some frames and panels may not fit together at all, but swapping them out may result in a fit.

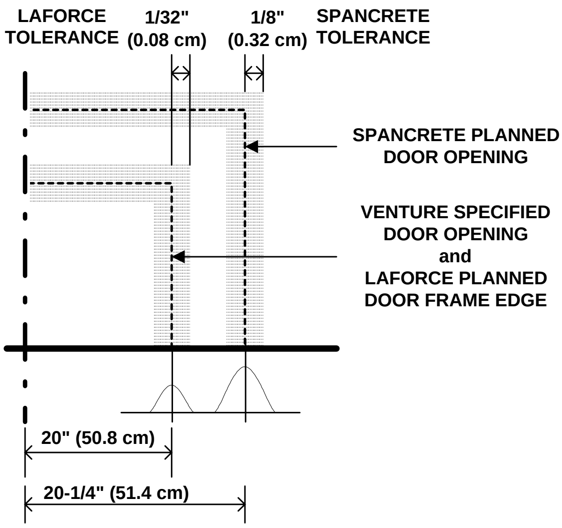

Figure 12: Tolerances on Door Frame and on Precast Concrete Panel

Why are door frames and panels manufactured separately? These two parts are manufactured separately because they require different materials, knowledge, skills, and fabrication tools. Industry specialization has further led to this division of labor. Much of the way work is done is governed by this fragmentation. It will come as no surprise that through such fragmentation, valuable opportunities for integration are lost.

Precast Fix: Taking the Concrete Lip Fix one step further, why not cast the frame into the walls, i.e., use the frame as part of the formwork? Again, the feasibility of this fix will depend on field quality issues.

WORK STRUCTURING REVISITED

To improve the process of installing frames, different perspectives are to be considered. Each of the parties involved have key roles to play. The owner, the architect, and the fabricator negotiate their needs and resources to develop the design. The construction manager, the panel erector, the frame installer, and caulker negotiate their standard work procedures to develop the operation design. However, since all parties rarely have the opportunity to consider work structuring together and early enough in the process to decide what would work best for the system, the engineering design is usually developed without any consideration for the operation design. As a result, the system is inefficient.

The system studied at Redgranite Prison, comprising precast concrete wall panels, door frames, caulking, and grout, is about as simple a system can get. Nevertheless, this system was plagued with problems as revealed by the introduction of the Plywood Fix.

Table 1 lists the fixes that were discussed in this paper and the parties involved. Additional fixes listed in Table 1 that were not discussed in this paper are discussed in Tsao et al. (2000). Very few fixes are local, that is, very few are under the control of a single party. All parties are involved in at least one fix. A more detailed investigation for each fix and additional ones should assess their feasibility and the benefits relative to costs and timing in terms of system design and operation execution. This is the very task of work structuring.

The likelihood of recognizing and then implementing one fix or another is highly dependent on the contractual organization of the project. For instance, had Spancrete also been responsible for mounting the frames, they would have had an incentive to work towards a more global fix. The issue thus is: Who owns/controls the supply chain? In the existing situation, as Boldt is the construction manager who self-performs a considerable portion of the work, Boldt owns and controls a significant part of the supply chain.

Fixes require change but not necessarily an increase in cost or time. In fact, the opposite should be true: fixes should yield cost and time savings.

The “5 WHYs” is a practical technique to determine root causes. However, the “5 WHYs” is rarely applied in practice in the architecture-engineering-construction industry. People seldom get the opportunity to take the time and question why things are the way they are. Trades do not necessarily complain about site problems because (1) contractually speaking, site problems may be considered theirs to resolve, (2) they may have more important problems to address such as developing bargaining tactics and determining which battles to fight, and (3) complaining might reflect poorly on their trade skill and pride (“tricks of the trade”) so they believe workarounds are what they are supposed to do.

Different planning techniques are used in construction. The contractual planning method asks, for example, “You have 30 doors to install. Finish this task.” The next level of planning asks, “You have 30 doors to install. What are your constraints?” The final level of planning asks, “You have 30 doors to install. How are you going to do it?” The latter question is rarely asked by high level planners and left to the installers. However, if the system design is bad, the installer works around the design with ingenious solutions. Such workarounds are costly and time consuming. However, they are an accepted way to perform work. If there is a problem due to missing details or interference with other pieces, a worker complains about the design and works around it. Workers do not question the design because their contracts have already been signed and work must proceed according to the original design. Therefore, it would be interesting to investigate how to determine when it is appropriate to release less complete designs earlier versus more complete designs later.

While the “5 WHYs” is a good approach to begin developing a better work structure, it is hardly enough to cover all aspects of work structuring. The “5 WHYs” addresses the following questions of work structuring: (1) In what chunks will work be assigned to specialists? (2) How will work chunks be sequenced? and (6) When will different chunks of work be done? Future research efforts will explore how to deal with the previously listed questions as well as the other work structuring questions: (3) How will work be released from one production unit to the next? (4) Will consecutive production units 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?

Table 1: Fixes and Responsibilities (* indicates fixes discussed in Tsao et al. 2000)

perform fix | work affected by fix | approve fix

	FIXES	Venture Architects	Boldt Constr.	Spancrete Industries	Laforce Doors	Central City Panel Erection	Jacques Caulking
Prevent Caulking Blowout	Grout Pump Fix		perform fix				
	Caulking Fix	approve fix	approve fix				perform fix
	Grout Fix *	approve fix	perform fix				
	Foam Fix *	approve fix	perform fix				
	Hydrostatic Pressure Fix *		perform fix				
Prevent Grout Leakage	Plywood Fix (Actual Fix)		perform fix				work affected by fix
	Bungee Cord Fix *		perform fix				
	On-site Weather Stripping Fix		perform fix				
	Off-site Weather Stripping Fix *		approve fix		perform fix		
Eliminate Grouting	Solid Frame Fix *	approve fix	work affected by fix		perform fix		
	Concrete Lip Fix	approve fix	work affected by fix	perform fix			
Manage Cracks	Field Sequencing Fix *	approve fix	perform fix		work affected by fix	work affected by fix	work affected by fix
	Tolerance Fix		work affected by fix	perform fix	perform fix		
Combine Components	Precast Fix	approve fix	work affected by fix	perform fix	work affected by fix	work affected by fix	

SUMMARY

This case study illustrates typical problems encountered in the architecture-engineering-construction industry today, where a contracting mentality hampers thinking about system-wide solutions. The case illustrates the consequences of poorly made work structuring decisions. Work structuring decisions regarding the system of walls and doors were made by Venture. Spancrete and Laforce together might have come up with a better system design. The involvement of specialists/suppliers in design is advocated by lean practices (Tommelein and Ballard 1997, Gil et al. 2000). Perhaps it would have been worthwhile for all parties to participate in a "Schematic Design In A Day" (SDIAD) exercise (Miles 1998). However, this type of collaboration is unlikely to happen due to contractual restraints. Spancrete and Laforce hold contracts with Boldt. If they developed a system design together or with other parties, the issue of assigning liability for the design would likely be disputed.

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