

# CREATING WORK STRUCTURING TRANSPARENCY IN CURTAIN WALL DESIGN

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## ABSTRACT

Work Structuring is a means to align supply chain, product, process, and operations designs in the course of project delivery. A challenge is to be able to recognize Work Structuring issues as they emerge, especially during design development. Participants in design coordination meetings typically use meeting tools such as agendas, CPM schedules, electronic whiteboards, 2-, 3-, or 4-dimensional drawings, and large-scale physical mock-ups to identify and resolve problems. We introduce a methodology to capture Work Structuring issues that surface during design development. This methodology is to be used in conjunction with existing meeting tools to help all participants understand the Work Structuring direction, i.e., the project's organizing principle. To demonstrate our methodology, we describe a case study involving the design development of a stone-on-truss curtain wall for a six-story research facility. Since we developed the methodology based on data collected from this case study's design coordination meetings, the generality of our methodology remains to be tested on future projects.

## KEY WORDS

Work Structuring, collaboration, process mapping, stone-on-truss curtain wall, stone panels, aluminum extrusions, insulating glass.

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## INTRODUCTION

Interactive design coordination meetings between project participants uncover an array of options for each parameter under consideration. However, without a methodology to manage the process of uncovering information and tracking the information that surfaces during these meetings, owners and architects may have difficulty: (1) discerning the cause for urgency behind certain design decisions, (2) understanding when lower-level product design decisions might be resolved more effectively at a higher systems level, and (3) clarifying the trade-offs between safety, quality, schedule, and budget. Recognizing this need, we developed a methodology to organize and manage Work Structuring information. Our aim is to increase the likelihood that practitioners will use Work Structuring to improve their collaboration during design coordination meetings.

## WORK STRUCTURING

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 2000b). It spans across all triads in the Lean Project Delivery System (LPDS) (Ballard 2000b), as does Production Control, which is supported by the Last Planner methodology. The two complement each other and are executed concurrently in the course of project delivery.

Previous Work Structuring research highlighted how upstream decisions may either create or eliminate downstream problems. Focusing on the Lean Assembly triad of the LPDS, the case study on Hollow Metal Doors discussed how project participants lost sight of a systems-oriented perspective and worked instead within a purchasing mentality (Tsao et al. 2000). They designed, fabricated, and installed the walls and door frames of a correctional facility as “uncoordinated suboptimized components” (Paulson 1976a). By changing their perspective to view the walls and door frames as interdependent elements within a comprehensive enclosure system, researchers and practitioners were able to develop numerous alternative Work Structures that had potential in improving performance in overall project cost, schedule, and quality. Since then, the Construction Manager in this case study has implemented some simpler Work Structures on other correctional facility projects and is looking to try more complex Work Structures on college dormitory projects.

Focusing on the Lean Supply triad of the LPDS, the case study on Indirect Light Fixtures explained how New Product Development efforts by the Fixture Fabricator resulted in a restructuring of *who* should do *what* and *when* in the supply chain (Tsao and Tommelein 2001). Consequently, the Metal Fabricator performed work normally done by the Fixture Fabricator, and the Fixture Fabricator performed work normally done by the Electrical Contractor. This scope realignment shifted on-site work into shop conditions (Ballard and Howell 1998). It also restricted site construction to final assembly work. Other fixture fabricators have since introduced competing products but to our knowledge they have yet to replicate the advancements in fabrication, assembly, packaging, and installation achieved by the Fixture Fabricator involved in the study.

Both studies illustrated the Level of Influence concept in which commitments made during the early phases of a project have “orders of magnitude greater influence on what later expenditures will actually be” (Paulson 1976b). However, it seems that project participants continue to miss opportunities for more global optimization because they have difficulty foreseeing the impact of their upstream decisions.

To address this problem, this paper presents a methodology to help project participants understand and manage the relationship between upstream design decisions and downstream production processes. A case study on Curtain Walls is presented. It relies on observations of existing design practice and thus focuses on the Lean Design triad of the LPDS. With this study, our research efforts thus move further upstream in the LPDS. We intentionally selected our three cases to pertain to systems of increasing complexity in order to demonstrate the scalability of the Work Structuring methodology.

In this study, we use tables to capture Work Structuring issues that surface during design coordination meetings. We use process maps to identify the Last Responsible Moment for specific design decisions. The Last Responsible Moment is “the point at which failing to make the decisions eliminates an alternative” (Ballard 2000a). We are promoting a flow-oriented perspective in terms of project planning and execution by stressing that hurdles encountered in design can be bottlenecks in production. The purpose of this paper is to describe the design development process for curtain walls and to demonstrate how we may help project participants increase Work Structuring transparency to facilitate better management of their Level of Influence in this process.

## **IMPORTANCE OF WORK STRUCTURING TRANSPARENCY**

Shingo (1989, p. 80) commented: “we cannot find and eliminate waste if we are not looking for it... much waste remains hidden in process and operations”. Increasing transparency in Work Structuring may help overcome the inertia of traditional work methods and begin identifying alternative ways of planning and executing projects. Transparency reveals flow, and, as dos Santos et al. (1998) noted, “when construction is viewed as a flow many factors that before were considered unimportant, come to the surface and become very important to the production effectiveness”. We propose that Work Structure transparency, highlighting the impact of each design decision, will make project participants more production focused.

Although projects in the past have used Work Structuring to identify *who* should do *what* work and *when*, only a handful of high-level planners representing the owner, architect, and sometimes the general contractor might be involved in establishing the initial Work Structuring direction, i.e., the project’s organizing principle. Project participants brought into the project at a later time will then feel an obligation to work within the previously established Work Structuring direction. Due to lack of further guidance regarding specific needs of the project at hand, they will tend to resort to resurrecting methods from past projects because they know which problems to anticipate and they have experience resolving them.

An alternative is for owners to recognize the value of pre-qualifying essential specialty contractors and fabricators so that they can observe and contribute to developing an initial Work Structuring effort catered specifically to the project at hand. This is an important step in collaboration: as Schmaltz (2003, p. 87) remarked, “If you’re not involved in the

organizing, you will never fully comprehend the intended organizing principle.” Furthermore, “Centrally planned economies invariably create a tenacious disorder by excluding from the organizing effort the ones who must most deeply understand the organizing principle” (Schmaltz 2003, p. 87). Without truly understanding a project’s Work Structuring direction, project participants will tend to be more product-oriented and provide suggestions that may seem reasonable at first but are actually flawed at the systems level.

This notwithstanding, many projects still view the selection of specialty contractors and fabricators as a product-oriented purchasing decision as opposed to a planning team development decision. We need methods to help all project participants feel comfortable with proposing alternatives that may alter the initial Work Structuring direction, and we need to develop ways to reward them accordingly. Increasing the transparency of a project’s Work Structuring direction during design development serves as one method to help participants better understand the project status and, in response, develop alternative systems-level solutions to address production-related problems.

During design, project participants can make unintended purchasing decisions based on their decisions in product design (Sadonio et al. 1998). Purchasing decisions define the structure of supply chain and process designs because selected products have certain lead times and installation requirements (Gil et al. 2001). By making these times and requirements explicit, we aim to help project participants understand the production implications of their design decisions. Thus, we developed a methodology to help project participants manage the information that emerges during design development so that they can move back and forth between systems-level and component-level considerations.

## **PROJECT BACKGROUND**

Our study describes development of the curtain wall for the J. David Gladstone Institutes medical research building located on the University of California San Francisco Mission Bay campus. The six-story \$72 million facility provides 18,600 m<sup>2</sup> (200,000 ft<sup>2</sup>) of lab and office space to help the nonprofit group take on additional projects and double its staff of scientists (Doherty 2001, Oshiro 2003, and York 2004). In the course of 3 months, we attended 6 curtain wall design coordination meetings. Meeting participants included representatives from the Gladstone Institutes, NBBJ Architects, Rudolph & Sletten General Contractors, Rutherford & Chekene Structural Engineers, and Walters & Wolf Glass and Precast divisions. NBBJ Architects handled the aesthetic design issues while Walters & Wolf worked out the technical design issues. Walters & Wolf served as both fabricator and installer of the curtain wall. We decided to study this project because Walters & Wolf identified it as a representative example of a more collaborative environment that practitioners may encounter during curtain wall design development. Appendix 1 provides background on the delivery of curtain walls, component product variety, and supply chain participants.

## **WORK STRUCTURING ANALYSIS**

### **MAKING WORK STRUCTURING ISSUES TRANSPARENT DURING DESIGN**

We reviewed our coordination meeting transcriptions and identified any discussed Work Structuring issues that dealt with design challenges. For each issue, we created a tracking code of the meeting date and a letter. Then, we determined (1) how each issue affected supply chain, product, process, and operations design and (2) its impact in terms of safety, quality, schedule, and budget. Table 1 provides a sample of our work. If an issue is a reconsideration of a past issue, we note the tracking code of the past issue and generate a new tracking code in bold to indicate the re-emergence of the issue. This shows how often project participants address an issue before resolving it.

For this study, design and project impact is based on the researchers' perspective. However, in practice, impact should be defined by all meeting participants as design issues are made explicit in real time. Also, we list 4 types of design on our table as a tactic to make meeting participants move back and forth between systems- and product-level considerations. Project participants should pay special attention to Work Structuring issues that address 2 or more facets of design because in these situations, it might be possible to reconsider *who* should be doing *what* work and *when*.

We identify action items related to each Work Structuring issue. By making action items explicit, we increase production process transparency. Action items also encourage project participants to identify constraints that could prevent them from completing their commitments. Thus, within a design environment, we try to foster the discipline of capturing information for making realistic commitments to achieve reliable work flow.

### **MAPPING THE DESIGN AND FABRICATION PROCESS**

Based on a literature review, scheduling data, and discussions with practitioners, we mapped the design and fabrication process of stone panels, aluminum extrusions, and insulating glass for the punched window wall. We recognize that better data (e.g., data gathered from fabrication plant and job site records) would improve the quality of our analysis so in future research we plan to examine alternative approaches for gathering data for process maps. The purposes of the maps are: (1) identifying work and required resources, (2) clarifying the expected durations for work, and (3) establishing work sequence. We did not include a sample process map in this paper due to length constraints. Instead, we discuss one type of analysis developed from our maps (Table 2).

### **SUMMING DURATIONS OF SUBSEQUENT WORK**

Using our process maps, we traced paths between resolution of the Work Structuring issues of stone finishes, extrusion color, and glass type to project completion. Then, we calculated the sum of the durations for all work found along each path. The highest sum represents the *minimum* time required, once the issue has been resolved, to completion. For example, project participants discussed the glass type in Work Structuring issues "December-17-C" and "January-14-C." Its sum of subsequent work of 200 days means that when they finally decide on glass type, it will be *at least* 200 days before the project can complete. Comparing

this value to the schedule, project participants can decide whether to adjust the production system to ensure the project will complete as planned.

Summing the durations of subsequent work begins to hone in on the Last Responsible Moment for design decisions. For example, stone finishes should be resolved early on because subsequent work requires at least 292 days. Note however that, while we expect this value to be accurate in order of magnitude, it is unrealistic to expect that a Last Responsible Moment could be pinned down with such precision.

Project participants discussed finishes often during meetings even though they acknowledged decisions could only be finalized during “the Stone Trip” (explained in Appendix 1). Although this may seem wasteful, it is actually an important facet of design because project participants create knowledge and understanding through conversations that facilitate conversion from tacit to explicit knowledge (Nonaka et al. 2000).

Table 1: Making Work Structuring Issues Transparent during Design Coordination Meetings

Work Structuring Issue	DESIGN					IMPACT			
	Supply Chain	Product	Process	Operations	Safety	Quality	Schedule	Budget	
GLASS TYPE December-17-C	Glass choice determines Fabricator's suppliers.	Glass type classified in estimate. <b>Action item:</b> Architect to confirm glass.						Fabricator revised budget estimate.	
GLASS TYPE January-14-C December-17-C		Section GL3 - standard frit pattern. <b>Action item:</b> Architect to select tint.		<b>Action item:</b> Fab informs Glass Fab about frit, get samples for glass tint.		Architect prefers less of a green tint.		Reduces cost.	
STONE FINISHES January-21-K January-14-H January-14-A December-17-I December-17-D		<b>Action item:</b> Owner and architect to select light or medium water jet on quarry trip.		Selection of stone finishes affects Stone Supplier's operations design.		Stone finishes have great impact on aesthetic quality.			
ALUMINUM EXTRUSIONS January-14-Q		<b>Action item:</b> Owner decides on extrusion color after viewing mockup.		<b>Action item:</b> Fabricator to inform extruder of color after owner decides.			Extruder won't extrude until you settle on color.		

Table 2: Summing Durations of Subsequent Work (values are in “days”)

<b>Stone finishes</b> January-21-K January-14-H, A December-17-I, D	<b>Extrusion color</b> January-14-Q	<b>Glass type</b> December-17-C January-14-C
Slab, finish, cut, drill – 87 Ship to fab – 15 Install onto trusses – 40 Lift trusses into place – 65 <u>Install windows – 85</u> Total subsequent work – 292	Procure custom color – 15 Paint extrusions – 20 Cut, notch, and drill – 30 Pre-glazing – 45 <u>Install windows – 85</u> Total subsequent work – 195	Develop fab drawings – 30 Cut to size – 10 Frit, coat, heat, insulate – 30 Pre-glazing – 45 <u>Install windows – 85</u> Total subsequent work – 200

By making this value explicit, project participants can now see it will be about one year after they decide on finishes before they can expect all curtain walls to be installed.

## CONCLUSIONS

The proposed methodology may appear simple: it is by intention because our format needs to structure complex information in a useful way. We want all project participants to be able to follow what is going on during the design coordination meetings. Then, by identifying action items and tracking how reliably they are completed, one can begin to manage the complexity of the design process. This is one step towards developing a framework for design coordination meetings that encourage collective planning—i.e., all project participants participate in task of Work Structuring and, as a result, develop a common understanding of the project’s organizing principle. This process encourages discipline in structuring information and commitments that surface within an often ambiguous design process. By using our methodology, we hope project participants will place more emphasis on releasing pieces of design information rather than drawing deliverables (e.g., “100% Shell and Core” drawings).

Our methodology lists all 4 facets of design along the top of our tables to provide a constant reminder to project participants that moving back and forth between systems-level and component-level considerations may help uncover alternative work methods. This table format also forces them to make explicit safety, quality, schedule, and budget implications for each issue discussed. Often, these implications surface during design coordination meetings, but they are rarely captured except perhaps in personal notes of meeting participants. By making them explicit to the group, project participants may assess them with more care so as to help owners and architects make more appropriate decisions for important Work Structuring issues.

Process mapping combined with making explicit the sum of durations for subsequent work helps: (1) clarify component lead times, (2) illustrate work flow and reveal how design decisions can act as bottlenecks in the production system, and (3) explain the cause for urgency behind certain decisions. If specialty contractors and fabricators want owners and architects to understand the cause for urgency behind certain design decisions, they may have to reveal information regarding their production rates, work load, as well as lead times for



procuring materials. These are factors that contribute to competitive advantage so sharing them must be done with reason.

Our presentation of this methodology aimed to bring attention to Work Structuring and put it in the context of the planning process that takes place during design coordination meetings. As mentioned, Work Structuring is to go hand in hand with Production Control in order to result in successful project delivery.

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## **APPENDIX 1: BACKGROUND ON CURTAIN WALL DELIVERY**

The \$6.6 million stone-on-truss curtain wall consists of 8,400 m<sup>2</sup> (90,000 ft<sup>2</sup>) of stone panels, aluminum extrusions, insulating glass units, and aluminum panels. It represents the high-end of curtain walls as stone procurement is expensive and time-consuming. In recent years, fewer projects have used stone-on-truss curtain walls because of cost.

To make our study manageable, we narrowed our scope to examine design and fabrication of punched window walls. These sections consist of stone panels, aluminum extrusions, and insulating glass units, and they make up at least 25% of the curtain wall.

### **DESIGN OF STONE PANELS**

#### **Stone Selection**

First, the Owner and Architect selected 2 or 3 samples from different quarries. Then, the Fabricator helped them narrow their choice. On Gladstone, the Architect selected limestone, but the Owner selected granite that mimicked limestone to cut down on costs.

#### **Joint Location, Panel Sizing, and Penetrations**

Usually, Architects establish the wall design and Curtain Wall Fabricators determine where to break the wall into panels. However, they often negotiate joint locations since the Architect wants to limit the number of joints as an aesthetic goal whereas the Fabricator prefers to increase the number of joints to better manage structural design, stone fabrication, curtain wall assembly, delivery, and installation limitations.

On Gladstone, the stone design called for 315 stone panels with 117 different sizes, and the Architect used 40 to 50 of those sizes repeatedly throughout the building. Since different sizes require an adjustment of the cutting equipment, increasing panel size variability affects the ability to fulfill orders as planned. With the Stone Fabricator having better equipment

than the Curtain Wall Fabricator, decisions regarding panel penetrations were better completed earlier in the design process, or the Curtain Wall Fabricator risked breaking the hard-to-replace panels.

#### **FABRICATION OF STONE PANELS**

The Stone Fabricator was Campolonghi based in Montignoso, Italy where their “main plant [covers] a total area of 70,000 m<sup>2</sup> (750,000 ft<sup>2</sup>)” (Campolonghi 2004).

#### **Slabbing and Finishing**

Once the Curtain Wall Fabricator submitted the order, the Stone Fabricator ordered stone blocks from the Quarry. After receiving the blocks, the Stone Fabricator used diamond disks, wires, and gangsaws to slab the blocks according to the required panel thicknesses. For Gladstone, the Stone Fabricator cut stone slabs at 3 cm (1.2”) and 5 cm (2.0”) thick.

Common stone finishing methods include polished finish (smooth and shiny), honed finish (almost as smooth as polished but not as shiny), waterjet finish (rough), and flamed finish (similar to waterjet but rougher). The Stone Fabricator shipped 4 pieces representing each finish to the Curtain Wall Fabricator for viewing by the Owner and Architect. However, the stone finish decision did not get finalized until “the Stone Trip.”

#### **“The Stone Trip”, Cutting, Beveling, and Drilling**

The Owner and Architect joined the Curtain Wall Fabricator on a visit to the Stone Fabricator. Touring the Stone Fabricator’s facilities and seeing the stone blocks in person helps Architects develop a better understanding of the limitations of the stone fabrication process. During the Stone Trip, they selected samples to represent the range of allowable imperfections and finalized the stone finish decision. Then, the Stone Fabricator began processing the order by finishing the slabs and cutting the slabs down to the panel sizes. Then, they beveled the edges and drilled penetrations and slots for the anchor bolts.

#### **Shuffling, Crating, and Shipping**

The Stone Fabricator “shuffled” stone panels before packing them into shipping crates. This is necessary because Curtain Wall Installers tend to erect panels in the order that they appear in the crates, and Architects prefer that similar-looking panels do not get installed side-by-side. Then, the Stone Fabricator sent out the crates in multiple shipments based on their ability to fill entire shipping containers.

#### **Receiving, Staging, and Attaching Anchors**

The Curtain Wall Fabricator used a moving crane to receive and stage stone panel shipments. Then, they epoxied 0.64 cm (1/4”) stainless steel anchor bolts into the slots drilled earlier by the Stone Fabricator.

#### **Fabricating Trusses and Attaching Angles**

After finalizing panel sizes, the Curtain Wall Fabricator developed a steel truss design in coordination with the Structural Engineer to support the curtain wall. Then, based upon their facility’s capacity, they either fabricated the trusses or subcontracted the work. On

Gladstone, they decided to fabricate the trusses. They welded procured steel pieces to form the trusses and added stainless steel angles for the anchor bolts on the stone panels.

#### **DESIGN OF INSULATING GLASS**

The Glass Fabricator was Viracon based in Owatonna, MN. Their main facility covers 93,000 m<sup>2</sup> (1 million ft<sup>2</sup>) and produces more than 4.8 million m<sup>2</sup> (52 million ft<sup>2</sup>) of architectural glass annually (Viracon 2004). On Gladstone, the Architect worked directly with the Glass Fabricator to develop the design for the insulating glass units consisting of two “plies of glass, separated by a desiccant-filled spacer and sealed with an organic sealant” (Viracon 2004).

From a standard set of samples, the Architect developed aesthetic requirements for the glass. Then, after investigating local energy codes, the Glass Fabricator produced a 2<sup>nd</sup> set of samples based on one color family to show color and coating variations. Next, the Glass Fabricator produced a 3<sup>rd</sup> set of samples to test silkscreen patterns and ways to reduce the required coatings since they add weight and darken the glass color. After reviewing the 3<sup>rd</sup> set, the Architect selected the final glass design for the insulating glass.

For frit design, project participants can select from standard patterns and colors. On Gladstone, the Architect chose a standard white frit pattern, so the Glass Fabricator did not need to produce a 4<sup>th</sup> set of samples for customizing silkscreen patterns and colors.

#### **HANDOFF FROM DESIGN TO PRODUCTION**

The Glass Fabricator makes glass to order, so they require the following information before beginning production: glass type, conventionally or structurally glazed, coating type, heat strengthening/tempering requirements, fritting type, exact size, configuration of insulating glass units, shipping requirements, and installation schedule.

Strategies for shipping glass to the customer include releasing according to: (1) building faces (e.g., the south side), (2) volume – it is easier for the Glass Fabricator to run orders in this fashion, and (3) floors with the same curtain wall – this is popular for taller buildings that use different curtain walls at certain heights.

#### **FABRICATION OF INSULATING GLASS**

The Glass Fabricator takes 7 to 8 weeks from customer order confirmation to completion of insulating glass units. The Glass Fabricator has an automatic and a manual production line pulling from the same group of raw materials in one building. They have a second manual production line pulling from another group of raw materials in another building.

#### **Procuring Raw Materials, Cutting, Washing, and Fritting**

The Glass Fabricator keeps 8 standard types of raw materials in stock. If the order exceeds raw materials on hand, they submit orders to their Float Glass Suppliers. While procurement generally takes 1 to 2 weeks, unique glass types can take up to 6 weeks.

The Glass Fabricator cut the glass to size using automated cutting machines. Then, they washed the pieces that required fritting (Viracon 2004). Next, with the frit pattern and color selected, they silk-screened a ceramic frit onto one side of the glass.

## **Heat-Strengthening and Coating**

Float Glass Suppliers supply “annealed glass.” Heat-strengthening annealed glass makes it 2 times as strong and tempering it makes it 4 times as strong. The Glass Fabricator puts both fritted and non-fritted glass in a furnace to heat strengthen or temper the glass. This also serves to permanently bond the frit onto the glass.

Coating equipment magnetically applied a low-emissivity (Low-E) coating onto both non-fritted and fritted glass. Viracon is one of the last fabricators to perform all glass fabrication steps (i.e., cutting, fritting, heat treating, coating, and insulating) under one roof. Newer glass fabricators purchase pre-coated glass to compress their lead times. However, the newer glass fabricators cannot silkscreen ceramic frit over Low-E coated glass because the glass will alter in appearance during the heat treating process. They work around this problem by placing the Low-E coated glass as the #2 surface and then silkscreening the #3 surface of the insulating unit (NB: The exposed outdoor surface is the #1 surface).

## **Insulating, Shipping, and Receiving**

Insulating equipment positions 2 panes of glass 1.3 cm ( $\frac{1}{2}$ ”) apart and applies sealant around the edges to form a sealed air space. In this fashion, the Glass Fabricator processed 4 types of 0.64 cm ( $\frac{1}{4}$ ”) Clear glass to form 2.5 cm (1”) units of fritted and non-fritted insulating glass.

The Glass Fabricator built custom crates for shipping. The maximum weight allowed in a crate is 900 kg (2,000 lbs), and a crate can hold up to 5 insulating glass units. After receiving the crates, the Curtain Wall Fabricator staged them in their assembly plant.

## **DESIGN OF ALUMINUM EXTRUSIONS**

Once the Architect establishes the outward appearance of extrusions, the Curtain Wall Fabricator designs extrusion profiles for structural performance. Custom extrusions require expensive new die fabrication. The Curtain Wall Fabricator typically ends up with 20 to 30 extrusions per project. On Gladstone, the punched window wall sections required a total of 8 standard and 10 custom extrusions.

## **HANDOFF FROM DESIGN TO PRODUCTION**

Buildings can contain 5 to 6 different curtain walls due to thicknesses, spans, profiles, and shapes. Each type could represent an extrusion order release as fabricators want to submit orders as soon as possible. However, since aluminum extruders charge a lot for set-up, fabricators may try to combine extrusion orders to optimize on die runs.

Due to tight schedules and large order volumes, fabricators might procure extrusions from multiple vendors for a single project. Also, since only 3 extruders exist in California to serve multiple industries, fabricators might look overseas to procure extrusions.

## **FABRICATION OF ALUMINUM EXTRUSIONS**

### **Fabricating Dies**

Extruders are usually responsible for die fabrication. They may subcontract out die fabrication if they have limited in-house capacity to handle the resource-intensive task of

milling the dies out of steel. Depending on design complexity, it may take 6 to 12 weeks from die extrusion design by the Extruder to die approval by the Curtain Wall Fabricator. Then, die fabrication typically takes 6 weeks.

### **Procuring Raw Materials and Running Extrusions**

Extruders use aluminum billets (NB: billets resemble metal logs) as the raw material for extruding aluminum. They either procure billets from outside vendors or have a separate branch in their company that is responsible for billet production.

The Extruder can run the extrusions once the dies have been fabricated. They push aluminum billets through a press to form the aluminum extrusions. They take anywhere from 4 to 8 weeks to finish running extrusions for an order from curtain wall fabricators.

### **Shipping by Aluminum Extruder and Receiving by Curtain Wall Fabricator**

The Extruder packed the extrusions on pallets before shipping the order to the Curtain Wall Fabricator. Then, the Fabricator staged the pallets in their fabrication plant.

### **Cutting, Notching, and Drilling**

In their fabrication plant, the Curtain Wall Fabricator took care of cutting, notching, and drilling extrusions. They cut each extrusion to the lengths required by the project. Then, they added notches and drilled holes (e.g., weep holes) as necessary. It may take 4 to 6 weeks to finish these steps for the extrusions on one project. Then, the Curtain Wall Fabricator moved the extrusions to the assembly plant.

### **Pre-Glazing (i.e., Window Pre-Assembly)**

In their assembly plant, the Curtain Wall Fabricator pre-glazed the punched window walls. The advantages of pre-assembly include: (1) controlled work environments, (2) higher production rates, and (3) less expensive shop labor. Trucks that transport curtain walls provide the constraint for prefabrication because pieces cannot exceed 12 m (40 ft) in length and 1.5 to 3 m (5 to 10 ft) in width.

The main pre-glazing steps include (Amstock 1997): (1) connecting the extrusions to form the frame, (2) applying sealants and gaskets, and (3) installing the insulating glass units. Curtain wall fabricators manage shop labor based on each unit's elements (e.g., number of extrusions, length of gaskets and sealant, and panes of glass). It typically takes 4 to 6 weeks to pre-glaze the punched window walls for one project.

### **FINAL ASSEMBLY AT CURTAIN WALL FABRICATOR**

At this stage, the Curtain Wall Fabricator has the punched window walls in 3 pieces: (1) stone panels with anchors attached, (2) steel trusses with angles attached, and (3) pre-glazed window units. In their assembly plant, they installed the stone panels onto the steel trusses. Sometimes the design allows for window units installation at their facilities. However, the Gladstone window units spanned across 2 stone-on-trusses. As a result, they shipped the stone-on-trusses and pre-glazed window units to the job site.

### **INSTALLATION AT JOB SITE**

Curtain wall installers generally have 3 tasks to manage: (1) unloading, (2) hoisting, and (3) distributing. On Gladstone, the Curtain Wall Fabricator also served as the Curtain Wall Installer. Using a crane, they first lifted the stone-on-trusses into place. Then, they hoisted the windows to each floor and set them temporarily inside the building. They used bolt-up connections to install the windows and shims to tighten the fit. Finally, they installed backer rods and sealant to cover the joints between stone panels and windows.