INTEGRATED STEEL DESIGN: APPLYING LEAN CONCEPTS

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ABSTRACT

One of the major delays in the structural steel industry for commercial construction projects is the time-consuming process of preparing structural steel shop drawings after construction documents are completed. Owners and general contractors have complained that this delivery process has numerous inefficiencies that lengthen the overall construction schedule unnecessarily for many projects. Long advocated by others in lean production (Womack et al. 1990, Ward et al. 1995), fragmented sectors of the commercial construction market have developed where structural steel shop drawings are produced concurrently with the design/engineering drawings for a project. The concurrent process of preparing structural steel shop drawings and design/engineering documents is known as "Integrated Steel Design".

A case study is presented that documents the use of "Integrated Steel Design" on a commercial construction project in the Southern United States. This case study demonstrates an industry implementation of lean principles and essentially validates and supports previous lean construction theory of integrating design and detailing. Insight into this set-based concurrent engineering approach will help determine where inefficiencies have been trimmed and what inefficiencies remain. This paper infers from existing literature that the development of combined engineering and detailing within the commercial structural steel industry has occurred as the result of specific project requirements without significant influence from lean construction experts. Further analysis of the current state map identifies opportunities for improvement in practice through conscious and intentional application of lean concepts and techniques.

KEY WORDS

Integrated steel design, lean construction, shop drawings, specialty contractor.

INTRODUCTION

Since 1964, productivity of manufacturing in the United States has increased more than 100%. In this same time frame, construction has actually experienced a decline in productivity (Melnick 2007). Some have estimated that as much as $160 billion spent each year on construction in the United States is wasted in part due to poor productivity. This "muda", or waste, is very evident in the commercial structural steel market through the time-consuming process of preparing structural steel shop drawings after construction documents are completed.

Commercial construction projects within the United States typically require shop drawings to be produced by the contractor for major design elements. These shop drawings consists of drawings, diagrams, and schedules that intricately interpret and detail the specific design elements within the building. The structural steel frame is one example of a building element where shop drawings are required. Steel detailers take

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drawings prepared by structural engineers and architects and use them to develop steel fabrication shop drawings. Many in the industry have viewed the process of preparing, reviewing, and implementing shop drawings to be an arduous task resulting in frustration for all parties involved (Rutledge and Luth 2004).

To the construction industry, shop drawings can be expensive and time-consuming to produce. To the detailing industry, adequate information is often not available to produce the required documents, and schedules for preparation of the shop drawings are typically short. Detailers often work at an unsustainable pace to rapidly produce steel shop drawings to fill gaps of steel fabricators and meet tight project schedules. Design drawings that are incomplete or do not fully address the needs of detailers further compound scheduling issues as requests for information (RFIs) pass from detailer to fabricator to contractor to architect to engineer and back again. Once shop drawings are completed, engineers and architects often struggle to meet review schedules for steel shop drawings requiring review within hours or days. This process yields high levels of uncertainty regarding completion of shop drawings and shop drawing review.

Integrated steel design attempts to address some of these problems by including the detailer in the design phase of the project. Essentially, the detailer becomes part of the design team. The designer does not choose one particular solution and direct the detailer to match that solution. Instead, the detailer provides feedback to the engineer early in the project, and changes to the engineering drawings are relatively easy and inexpensive to implement. Details and designers communicate about sets of ideas as the work progresses essentially retaining a "subset of potential solutions" (Sobek 1996). As design progresses, the engineer and detailer narrow project specific requirements based on additional architectural, mechanical, electrical, and plumbing information. Team members discuss particular steel solutions and critique each idea. Input from the entire design team leads to a narrowing set of possible alternatives in parallel. As design and detailing conclude, the design converges on the shared set of solutions. This concurrent engineering approach, known as set based engineering, should lead to a more robust, optimized system with greater overall efficiency than the current approach to shop drawing production.

Research objectives of this study are to identify the current use of lean construction theory in the developing market practice of combining design and detailing for commercial structural steel projects. The development of the current market will be discussed, and opportunities for further implementation of lean techniques in this market will be identified.

BACKGROUND

In traditional construction practice, work is done through functional silos. "…, traditional thinking in construction suggests that people operate as if they cannot control materials supply. In some cases, material management practices are reduced to just telephone conversations with suppliers, primarily to confirm final delivery dates for large quantities of materials." (Arbulu et al. 2005) When the detailing is done after completion of engineering, it becomes part of the larger material management problem. In addition, the system of separating detailing and design is based on local optimization of resources and does not focus on overall performance.

In their July 1999 report to the International Group for Lean Construction, Tommelein and Weissenberger discussed "buffers" in steel supply and construction. They argued that steel procurement and delivery methods are not handled using a just-in-time process but are riddled with limitations to the flow of product through the supply chain. They argued that processes in steel supply focus on achieving high equipment and labour utilisation rates. Shop drawings are produced rapidly and the review process is often rushed in order to expedite fabrication of steel and delivery to the job site. Contractors believe they have done well when they have enough material on the job to keep the erector busy for months. Large buffers give job security to the erector and a comfort level to the contractor; however, they come at a cost.

Earlier research introduced the idea of overlapping phases of concept development and implementation states in design and production. "The integration of the concept development process with the fabrication of components and their assembly into a complete product is a principle applied in lean manufacturing systems" (Womack et al. 1990, Ward et al. 1995). Additional studies by Tommelein et al. (2000) examined this approach for high-tech facilities. The authors report that this approach gained speed while allowing flexibility to adjust to changing technology and market conditions. They also report that "most decisions and production choices designers make are primarily a function of the information they have at hand". These studies indicate that the involvement of detailers with engineers will allow input on items cost sensitive to fabrication prior to final commitment.

Previous studies show that involvement of specialty contracts can contribute positively to the construction process (Crichton 1966; Bennett and Ferry 1990; Pietroforte 1997). A recent study by Gil et al. (2004) studied a project delivery process in the environment of semiconductor fabrication facilities. Their simulation indicated that "to involve the specialty contractor from the project start on average expedites project delivery since it prevents delays caused by bidding and by contractors' unfamiliarity with the design product definition". These authors report that the contributions of specialty-contractor knowledge to early design fall into four main categories:

- Ability to develop creative solutions to design problems
- Knowledge regarding space considerations at construction/fabrication sites
- Knowledge regarding fabrication and construction capabilities
- Knowledge of supplier lead time and reliability.

HISTORY OF INTEGRATED STEEL DESIGN IN U.S. COMMERCIAL STEEL MARKET

"Combining detailing and design services has been done in special circumstances and relationships in the fragmented design and construction market for years." (Farrow, 2007) Rutledge and Luth (2004) identify a project where they worked together as early as 1982 in Denver where Rutledge Steel employed Luth's firm to provide stamped calculations for a steel framed curtain-wall they were fabricating for the 16th Street Mall in Denver, Colorado. Most relationships in the 1980's and 1990's involved structural engineers providing specialized component or connection design for fabricators without necessarily working together to complete design documents and shop drawings (Farrow, 2007). Thus, the working relationship was relegated to a "throw it over the wall approach" where one party handed completed work to another and requested a response based on a specific set of drawings provided.

This approach evolved over time on several projects toward a more integrated working relationship between detailer and designer. Nadine Post (2004) reported that the structural engineer was hired as the structural steel detailer for a high school in Tacoma, Washington. This method proved to be successful. In this 279,000 square foot project, all of the 1,900 tons of primary steel was detailed by the Structural Engineer of Record as design progressed. This approach set in place “a chain of events that … sliced at least three months off construction”. In this project, there were only thirteen requests for information associated with the structural steel compared to hundreds on similar projects of this size and complexity (Post 2004). ENR further reports that “…of 2,908 anchor bolts on the project,…, only four for one base plate required field modification. There were 15,256 bolts on the project with no mismatched connections. There were no mismatched connections, even though they contained 15,256 bolts. In the school building, there were no problems with 3,045 assemblies.”

Martin et al. (2004) discussed an addition to the north end zone of West Virginia University’s Mountaineer Stadium. March-Westin, the general contractor, provided design-build services for the project. March-Westin elected to employ the fabricator at the same time the design team was selected for the project. He stated, “We do it all the time on projects, because it can save time and money.” In this particular case, a secondary structural engineer, Allegheny Design Services, was employed to engineer the structural steel frame and work directly with the steel fabricator and primary structural engineer. David R. Simpson, P.E. for the project indicated, “We worked directly for March-Westin while maintaining coordination with HOK and Thornton-Tomasetti. To complete the design in a three-month period, we had to feed information to the fabricator as we were going along so that they could meet the mill schedules to order steel-while maintaining communication with HOK and their architectural requirements-and while communicating with Thornton-Tomasetti to determine what their foundations could and could not take.” “In this project, an early-release package was generated; however, the general contractor employed a separate structural engineer to design the frame and work directly with the fabricator.” (Farrow 2007)

The advent of software modelling and electronic data exchange in the commercial steel market has helped facilitate a switch toward more interaction between the engineer, detailer, and fabricator. This technology, known as CIS/2, is the product model and electronic data exchange file format for structural steel project information. It is intended to create a seamless and integrated flow of information among all parties of the steel supply chain involved with the construction of steel framed buildings. The American Institute of Steel Construction (AISC 2007) has adopted it as their format for Electronic Data Interchange (EDI). CIS/2 serves as a file import or export capability to many steel design, analysis, detailing, fabrication, and construction software packages. For example, a CIS/2 file could be exported by a structural engineer to a steel detailer and read directly into detailing software so that detailing could be expedited.

CASE STUDY

A large international company announced in late 2005 that it was building a large commercial office facility in the South-eastern United States (Farrow 2007). The new facility was designed to accommodate 1,300 employees and is scheduled to be completed by 2008. A top 500 *ENR* general contractor (GC) was hired for the project. Project cost including land development has been estimated at $120 million dollars. Names of companies included in the project have been withheld at their request.

The structure was designed as a composite steel building with estimated total steel tonnage of 3,200 tons. The GC was initially concerned about schedule on the project especially considering that the start of construction would occur during the winter months. In an effort to gain time, the general contractor contacted an umbrella Civil Engineering organization that offered steel detailing services and requested an integrated design approach. The manager at the GC's office stated, "The chief advantage to concrete is that we can start tomorrow. Steel requires shop drawings, and that process takes time. By using an early-release shop drawing process, concrete no longer has that advantage over steel." A contract was established directly between the GC and detailer to provide the steel detailing services for the main structural steel prior to completion of complete architectural drawings. The steel detailers worked directly with the AE firm to develop detailed steel shop drawings simultaneous with completion of structural documents.

Structural steel items critical to the schedule were identified by the GC. These items included beams, columns, girders, decking, and slab edge conditions. Stairs, railings, canopies, and other miscellaneous steel were excluded from the integrated design approach since schedule was less of a concern, and design of many of these items had not been completed by the architect at the time detailing occurred. The first segment of steel shop drawings was released immediately after the structural portion of the contract documents was completed. A construction sequencing plan was developed that required sequential production of steel in approximately 150 ton increments. The detailer matched this plan and produced a 150 ton sequence every two weeks after the initial release of the first set of steel shop drawings. The shop foreman at the steel fabricator's shop indicated that it was the first time he had seen shop drawings before the raw material arrived at the fabrication plant.

CIS/2 technology was used by the structural engineer (SER) and detailer to reduce the time it takes to detail the structure. Design of the structure was done in RAMSteel^{TM} with output files provided to the detailer as a starting point for detailing. These files were imported into SDS2^{TM} (3D automated detailing package) by the detailer providing a "jump start" to the project. This approach coupled with a close working relationship between detailer and designer reduced much of the inevitable RFI process which saving time on the project. Shop drawings were submitted/reviewed to the GC as done in a traditional arrangement.

According to a Principal with the detailing firm, integrated steel design "basically allowed us to realistically anticipate a December/January erection start date as opposed to a March/April start date. We estimate that we saved the owner approximately $500,000 in rental cost of their currently leased office space alone by using this approach." The senior structural engineer stated that multiple sets of design drawings were issued primarily to "identify and secure delivery issues with certain column shapes". All parties indicated that the synergy associated with a close working relationship between designer and detailer created an opportunity to improve the quality of documents. The schedule for this method compared to a more traditional process for detailing and fabrication is shown in Figure 1 (Farrow 2007).

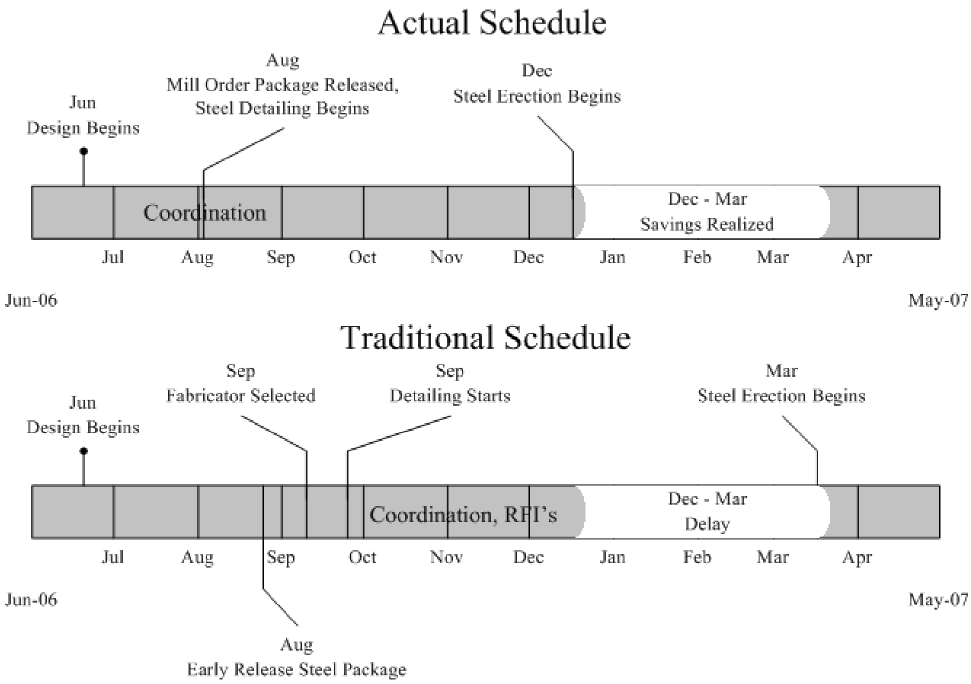

Figure 1: Comparison of actual and traditional schedule for case study project.

DISCUSSION OF RESEARCH RESULTS

Previous research and this case study essentially validate existing theory regarding the benefits of combining design and detailing for commercial structural steel projects. Procurement of steel through the use of integrated steel design can provide an effective way to shorten time, save money, and reduce errors on construction projects.

COMMERCIAL CONSTRUCTION AND INTEGRATED STEEL DESIGN

The current state of the construction market in structural steel has similarities with Toyota in the 1950's. The steel industry has numerous fragmented markets demanding many products in low volume. Contractors face tough competition with everyone competing on price and schedule. The cost of capital is high, including both human capital to produce the shop drawings and capital to construct the finished product. Technology is changing dramatically in the realm of design and detailing with the integration of Building Information Modelling (BIM) where designers and detailers can share the same computer model of a given structure. Market conditions coupled with rapidly developing software in this industry will support development of integrated steel design.

The integrated steel design approach is well suited to the commercial construction environment where much of the fabrication uses typical assembly components and relatively few highly specialized details that must be determined based on the fabricator's abilities. Most members are wide flange beams, tubes, or angles. Most connections are single or double angle clips. Variances do occur, but fabrication shops have the flexibility to adjust to these changes. When fabricators do need small adjustments made in the detail drawings to fit their unique needs, these changes are typically small and can be done in short order.

Integrated steel design should not be confused with a "push" approach to fabricating steel. Rather, it should be seen as a shift of detailing to the design phase of the project.

Once a customer requests design drawings for a specific commercial project, design and detailing occur simultaneously. As designers and detailers develop sets of alternatives, then communicate about these alternatives, better designs are found quicker. This concurrent engineering approach avoids the non-value-added exercise of generating shop drawings after design is complete. It "forces team members to deeply investigate and understand trade-offs among alternatives and gain a richer understanding of issues important to other functions as well as the impact of one's own design" (Sobek 1996). This shift of detailing to the start of the project adds only a small cost to the overall project and leads to a project that fits together more easily with less errors. Such an approach has been validated in manufacturing settings as evidenced by Toyota's set based design approach (Sobek 1996).

This approach allows firms to delay commitments and gradually refine a product solution based on the level of uncertainty from the project architect. Sharp product definition early in the process may not be desirable in an environment that changes rapidly (Gil et al. 2004). Overall projects and sectors of projects selected for use may require "screening" to determine if they are suitable candidates for integrated steel design (Farrow 2007).

IMPLEMENTATION OF INTEGRATED STEEL DESIGN

In the case study, the detailing for the project was done by a firm who was not directly associated with the steel fabricator for the project. They were not employed by the fabricator and were not a main supplier of detailing for the selected fabricator. In general, integrated steel design is not limited to an independent detailer. This method could be successfully implemented by an independent detailer, the fabricator, or the structural engineer.

The project considered in the case study was awarded as a negotiated project with a General Contractor. Integrated steel design works well in this scenario since the General Contractor, fabricator, and possibly the erector can have input into the production of design and engineering drawings. Specific shop requirements and erection sequencing issues can be resolved and coordinated to match the production of drawings. However, the approach of integrated steel design has merit in a bid setting. An owner or contractor considering the construction of a large steel frame can use this approach to obtain a more accurate bid on the project and take time off the schedule. Currently, "competitive bidding causes development of shop drawings to last longer because the awarded contractor needs to get fully acquainted with the design product definition, write requests for information, and submit shop drawings for approval." (Gil et al. 2004) With integrated steel design, fabricators can bid jobs off completed shop drawings. The exact tonnage of the job can easily be tabulated, and a better comparison can be made by a contractor comparing quotes from separate fabricators.

CONCLUSIONS

This paper infers from existing literature that the development of combined engineering and detailing within the commercial structural steel industry has occurred as the result of specific project requirements without significant influence from lean construction experts. Specifically, current integrated steel design has developed not from theory on lean construction but from close personal relationships between detailers, designers, and/or fabricators and specific time constraints that owners have placed on projects and construction professionals' aggressive attempts to meet those constraints.

As this market has developed, the evolution of interactive design between steel detailers and designers has been a system of "cherry picking" lean concepts and activities for a specific issue. As such, the opportunity for involvement by lean professionals in this sector of the market is high. Additional work is needed to move this sector of the market toward the ideals of lean construction. Improvements in the current state of integrated steel design can be realized by conscious and intentional application of lean concepts and techniques.

DESIGN FOR MANUFACTURING

Standards within this industry appear to have developed as a "methods engineering" approach as opposed to lean flow. Engineers, even on simple commercial steel buildings, often attempt to find a single best way. They quickly converge on a solution and then modify that solution to fit the project objectives. Even when integrated steel design is used, the combined group of detailers and designers have not been jointly involved in designing the work. Engineers are often located remotely from detailers. Little time and effort has been spent between detailers and engineers broadly considering sets of possible solutions and then narrowing the set of possibilities to converge on a solution. The current implementation developed as a modification to the traditional "throw it over the wall", point-to-point design mentality. Set-up and adjustment delays for detailers adjusting to a methods engineering approach are high, and the final design is one that is not designed for manufacturing. This approach would benefit by the implementation of a true set-based concurrent engineering approach.

WORK STANDARDIZATION

Steel industry standards are published in large manuals that often sit on the shelf of design and detailing firms. Standards rarely change, and only the experts can change them. These standards cover a large range of topics including all possibilities that may occur on a project. These approaches to design and detailing are not simple, clear, or visual in many instances and are not linked directly to action as required by a lean approach.

In many cases, typical details are created as unique items for each project based on the broad industry standards. Designers and detailers need to work together to develop typical standards that are easily communicated and recognized for the majority of conditions on commercial projects. These details can then be transferred over multiple projects. In commercial construction, the potential applications of this are numerous. Are single-angle or double angle connections standard for beam to beam connections? Are bolted-welded or welded-welded connections typical? How are braced-frame connections made including typical material selection and attachments?

DEVELOP STRATEGIC SUPPLY PARTNERS

The construction industry needs to help designers and detailers develop long-term relations. As designers, contractors, and detailers work together to provide an integrated steel design project, sharp focus will develop on areas where critical communication and coordination are needed. Where possible, the involvement of fabricators and/or erectors would aide in this process. A collaborative approach will then breed new ideas to drive integrated design to the forefront in this market.

DYNAMIC AND CONTINUOUS IMPROVEMENT

The commercial construction market remains focused on the isolated project. Minor adjustments are made from project to project as errors occur or issues are realized. No formal system for continuous improvement is in place in most commercial detailing or design firms. Simple systems need to be developed to help move the entire industry forward in lean construction.

SUMMARY

The current state of integrated steel design has not been developed by lean construction theorists. Opportunities for further improvement based on key lean principals exist. Figure 2 illustrates the current state of the integrated steel design approach and existing opportunities for improvement based on implementation of lean concepts. As discussed above, key delays in the current approach contrary to traditional lean practices include engineer's focus on methods engineering approach, high set-up times of the detailer, lack of simple and consistent standards, the evolution of the market to develop long-term relationships, and the lack of continuous improvement built into the system.

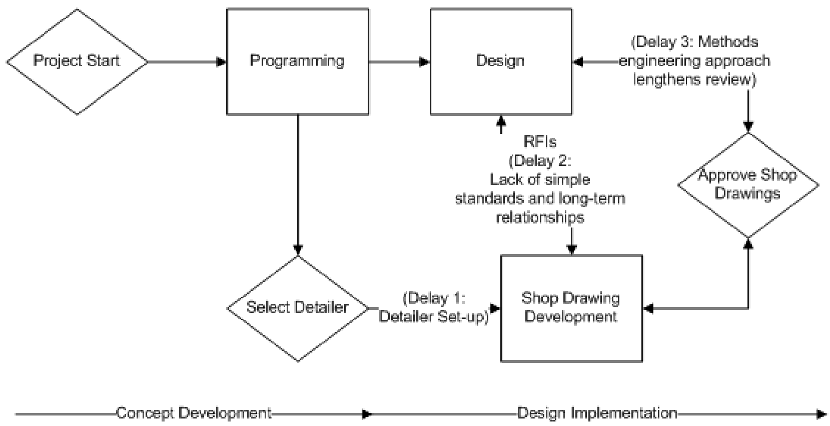

Figure 2: Process flow map for integrated steel design has opportunities for implementation of additional lean concepts.

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