

AC 2008-356: ADVANCES IN THE PRODUCTION OF SHOP DRAWINGS AND THEIR IMPACT ON CONSTRUCTABILITY

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Advances in the Production of Shop Drawings and Their Impact on Constructability

Abstract

Over the last two decades, many advancements have occurred in the production of shop drawings due to advancements in computer technology. The developments in computer-aided drafting and building informational modeling (BIM) have impacted how shop drawings in structural steel, reinforcing steel and other trades are produced. Computer-based 3D modeling has impacted constructability issues and improved communication among the major players in the overall construction process. This paper highlights currently-used 2D and 3D computer technologies in the production of shop drawings, and emphasizes the importance of imparting requisite graphics skills in architectural, construction, and engineering students. Based on interviews conducted with a select group of fabricators, contractors, and engineers, the author concludes that shop drawings produced using 2D and 3D computer software is a positive step toward improving constructability.

Introduction

Since the 1980s, many developments have occurred in the production of shop drawings due to advancements in computer technology. The advancements in computer-aided drafting have impacted how shop drawings in structural steel, reinforcing steel and other trades are produced. The utilization of computer-aided drafting and 3D building information modeling (BIM) have impacted constructability and improved communication among the major players in the overall construction process.

“To the construction industry, shop drawings seem to be a necessary evil. Contractors find them expensive to produce and architects find them unappealing to review.”¹ Shop drawings, however, do serve the purpose of avoiding unexpected flaws in the constructed facility. Among the architect’s and engineer’s services, the contractor is obligated to submit shop drawings, and the architect/engineer obligated to review and approve. Shop drawings illustrate design concepts shown on the architect/engineer’s contract drawings, and bring to life the physical transformation of design concepts. Mistakes made in the shop drawings and not caught before construction have led in the past to structural disasters such as the Skywalk failure of Hyatt Regency Hotel in Kansas City, Missouri. This paper highlights the importance of producing technically sound shop drawings using the current available technologies, and emphasizes the importance of imparting requisite graphics skills in architectural, construction, and engineering students. With the reduction of graphics courses in the modern-day engineering and technology curricula, students are less likely to be prepared with the blue-print reading skills; hence there is every reason to emphasize the importance of producing and approving shop drawings that are technically correct.

This paper reports on the current practices of producing structural steel and reinforced concrete shop drawings using 2D and 3D computer software such as AutoCAD, and SDS/2 Design Data. “Design Data’s SDS/2 Steel Detailing System has simplified and automated the design, detailing, fabricating and erecting of structures across the globe,”² is a bold statement from the software

company that underscores the integrative nature of design, detailing and construction. The author conducted interviews with a select group of fabricators, contractors, and engineers, and sought their views on the current process of production of shop drawings. Based on his own experiences as an engineering consultant, and based on the input received from the A/E/C industry, the author concludes that shop drawings produced using computer software such as, SDS/2 (one of 3D modeling software for structural steel, which is a component of Building Information Modeling - BIM), is a positive step toward improving constructability. However, data-sharing among parties still remains a concern, and unless all parties involved, namely, architectural, electrical, mechanical (Plumbing and HVAC), and structural, are willing to share data, and are willing to work from a common database, problems in the production of shop drawings and constructability will remain. Nonetheless, the process of the production of shop drawings continues to evolve, and constructability issues are receiving much more attention than before.

Definition of Shop Drawings

To put the Shop Drawings in the proper perspective, it is important to recognize what the legal definition of Shop Drawings is, whose responsibility is it to prepare the Shop Drawings, who is responsible for its accuracy, and who is responsible for review and approval, and to what extent does an Architect's, or an Engineer's responsibility extend in the review and approval process. The AIA 201 Architectural Document, The Engineers Joint Contract Documents Committee (EJCDC) 1910-8, and the Associated General Contractors of America (AGC), AGC 200 establish procedures for submittal review but differ in some important areas. Below are some excerpts:

The 1997 AIA Document A201 Article 3.12.1 states, "Shop Drawings are drawings, diagrams, schedules and other data specifically prepared for the Work by the Contractor or a Subcontractor, a Sub-subcontractor, manufacturer, supplier or distributor to illustrate some portion of the Work."³

The AIA Document A201 Article 3.12.4 states, "Shop Drawings,...and similar submittals are not Contract Documents. The purpose of their submittal is to demonstrate for those portions of the Work for which submittals are required by the Contract Documents the way by which the Contractor proposes to conform to the information given and the design concept expressed in the Contract Documents. Review by the Architect is subject to the limitations of Section 4.2.7...Submittals which are not required by the Contract Documents may be returned by the Architect without action."

In so far as the Review and Approval of Shop Drawings are concerned, the AIA Document A201 Article 4.2.7 states, "The Architect will review and approve or take other appropriate action upon the Contractor's submittals such as Shop Drawings, Product Data and Samples, but only for the limited purpose of checking for conformance with information given and the design concept expressed in the Contract Documents. Review of such submittals is not conducted for the purpose of determining the accuracy and completeness of other details such as dimensions and quantities, or for substantiating instructions for installation...all of which remain the responsibility of the Contractor as required by the Contract Documents."

It is important to note that, “both the AIA and EJCDC indicate that submittal review by the design professional is for the limited purpose of checking for conformance with the contract documents, and such review does not extend to the means, methods, techniques, sequences, or procedures of construction, or safety procedures. AGC 200 does not clearly state the client or design professional’s level of responsibility for review of submittals.”⁴

Current Practice in the Production of Shop Drawings

Just as the design, drafting, fabrication, and construction practices vary from company to company based on the size of the company, and the types of civil works they are involved in, so does the practice of production of shop drawings. In one of the interviews conducted with a principal and co-owner of a small to medium-sized engineering company in the Midwest, in response to a question, “What changes, if any, during the last two decades, have occurred in shop drawings’ submittals,?” the author received the following response.

Engineer’s Response: “Typically shop drawings for reinforcing steel are still being done by hand; some structural steel is done by computers. We have seen some electronic 3D models done by steel fabricators that produce shop drawings. It is a long and tedious process to check and verify.”

Another Engineer’s Response (this one from a very large company involved in some mega projects): “Around 80-90 percent of shop drawings are currently CAD-drawn. We do still get some hand-drawn submittals, most commonly in reinforcement submittals. Most of the steel erection drawings are done using computer programs and models which automatically dump out the piece marks. It depends upon the size of the detailing company.”

Overall, the industry trends in the production of shop drawings are tabulated below.

Table 1: Trends in Shop Drawing Production

Type of Shop Drawing	Hand-Drawn	CAD-Drawn	3D Computer Model-Drawn	Submittal Paper Size	Remarks
Reinforced Concrete	Sometimes Yes	Mostly Yes	No	11 x 17 for CAD-Drawn	Still Some Hand-Drawn Submittals are received.
Structural Steel	Sometimes Yes but less frequently	Yes	Yes	11 x 17	Mostly CAD-Drawn or by 3D Computer Model
Other Submittals - (Other than concrete and	Report Type Forms, or Catalog Cut Sheets (Printed off from Internet and Copied)	No	No	8 ½ x 11 or 11 x 17	When a Supplier does a quick job,

steel)					engineer's eyes are more critically drawn to it.
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Current Trends in Shop Drawings Submittal

The old days of full-size shop drawings are now disappearing, and most of the shop drawing submittals are on 11 x 17 paper (Size B). It is a recent trend in the industry and is likely to continue...it is an evolutionary progress attributed to the computer age. It costs around 2 cents to print an 11x17 CAD drawing off a standard laser printer while a full size drawing off a plotter costs around a dollar. Printing or plotting a set of full size drawings consisting of several sheets, and with a distribution list consisting of several parties, the paper costs can be quite high. An 11 x 17 CAD drawing costs less and results in substantial savings. Though an 11 x 17 CAD drawing can not fit as much information as a full size drawing, nor can the letter size be as large, the CAD drawings can be printed smaller and still be quite readable.

The shop drawings can be submitted electronically. For example, the Texas Department of Transportation (TxDOT) has published a "Guide to Electronic Shop Drawing Submittal,"⁴ to provide information to fabricators, and contractors. The Guide provides the following 4-Step procedure for submitting the Shop Drawings.

Table 2: Electronic Shop Drawing Submittal

Step I:	The fabricator produces CAD drawings and distills them into a high-resolution PDF booklet of sheets.
Step II:	The fabricator transmits the email with attachment and a hardcopy.
Step III:	The reviewing office processes the submittal.
Step IV:	The fabricator and TxDOT finalize the shop drawings.
Note: This is specific to TxDOT requirements.	

It is to be noted that State DOTs' procedures are internet-based, and so are the practices of private companies where drawings in the PDF file format are sent over the internet for production and submittal of shop drawings.

CAD-Drawn and 3D Computer Model-Drawn Shop Drawings – The Constructability Issues

As noted in Table 1: Trends in Shop Drawing Production, not all shop drawings are 2D CAD-generated or drawn by 3D Computer Models. Large fabricators such as Ambassador Steel have mostly adopted CAD as their primary drawing tool for shop drawings. However, it needs to be recognized that each fabricator, has particular style for shop drawings and cut sheets, depending on the drafts-persons and computer-aided drafting systems.⁵

As an example, Design Data's SDS/2 Steel Detailing System has simplified and automated the design, detailing, fabricating and erecting of structures. The 3D Modeling Station component of SDS/2 Detailing System is the framing input area. With this module, one can review the details of members, sub-material and erection views. Any interference can be detected and constructability problems resolved among parties. The job status feature allows one to set the status of any member (e.g., complete or erected) and view the entire job status at any time.⁶

It is not uncommon to come across situations during the construction process when a superintendent detects pipes, ductwork, openings, and reinforcing areas of conflict, and steps have to be taken to issue change orders to rectify the situation. General contractors have begun to ask for computer models from subcontractors so that they can coordinate and mesh them into one model that would remove constructability problems. However, the problem is compatibility of models, and sharing of databases which participating parties are reluctant to share. Each fabricator has to develop their own 3D model from 2D drawings which is contrary to what the architects do, that is developing 2D drawings from a 3D model. Issues of risk, legality, and responsibility come into play, and seemingly easy solutions are difficult to achieve.

Evolution in Shop Drawings Approval Process

In the past, after the shop drawings were submitted by the contractor for approval, they were reviewed by the engineer, and stamped and signed with one of the following markings:

- a. Approved
- b. Approved with Changes Noted
- c. Returned with Corrections
- d. Return with Corrections Made (In case of major changes which required an engineer's second look)

However, since the late 1980s, and early 1990s, significant changes have occurred. The word 'Approved,' is no longer used; instead, the word 'Reviewed,' is used in the industry. For years, the legality of these terms has been discussed among the various parties namely, architects, engineers, contractors, detailers, suppliers, etc. Because of the issue, 'who takes the responsibility,' there is discomfort and disagreement as to the use of the word 'Approved.'

The contractor is required to review the drawings before they are sent to the architect/engineer for review, and the contractor stamps drawings stating that they meet the contract documents. Since the markings noted a through d above, are no longer used in the industry, the drawings are marked with the following stamps. This is a major shift from the past.

- i. No exceptions Noted (NEN)
- ii. Exceptions Noted (EN)
- iii. Return for Correction (RFC)
- iv. Record Copy (RC)
- v. Not Reviewed

The contractual responsibilities, and who is paid by the owner to take the responsibility for review and approval of the shop drawings are major areas of discussions among the parties involved. After the Hyatt Regency Hotel Skywalk failure in 1979 in Kansas City, duties and responsibilities of design and construction team members became more clearly defined, and the process has since been continuously evolving.

Are We Taking Shop Drawings Seriously?

The A/E/C industry takes shop drawings seriously. However, due to feverish time constraints imposed on the various parties due to self-created short construction cycles, some times attention to detail is missing, and some vital checks are not made. It is easy to resolve problems during the review stages before construction but it is much more difficult to resolve problems during construction. To begin with, the individuals (engineers, architects, and draftspersons) who prepare contract drawings must do a good job of preparing accurate and complete drawings. They must provide enough section details and views on the contract drawings so that RFIs (Request for Information) from fabricators and detailers are considerably reduced. As a rule, the designer must ask this question when the job is ready to be bid, 'Can the structure be built from these Contract Documents?' If the answer is no, it is an indication that more clarity is needed.

A Lesson for Civil Engineering and Construction Students – The Graphics Skills

The pre-1980 era of engineering curriculums emphasized considerable engineering graphics skills in civil engineering students. Similarly, engineering technology programs in civil engineering/construction technology curriculums initially were also heavy in graphics skills but since the late 1990s, have become thinner and require less graphics due to 124-hour degree requirements and shifted emphasis in other areas. The time allocations for development of blue-print reading skills in the engineering and technology curriculums have dwindled, and graduates of these programs have to develop these skills on the job. Although engineering and technology graduates do a fine job in catching up, it would be advisable to have students develop good blue-print reading skills by developing full-project drawings for a small project while going through school. The experience of preparing a complete set of drawings gives the students an opportunity to reflect on cost, and constructability issues. It is possible to have the students go through this experience in a capstone project. The EAC and TAC criteria for accreditation of engineering and technology programs call for programs to graduate students with requisite skills of their profession. In the opinion of the author, graphic skills for engineering and technology graduates are the most fundamental skills, and will enable them to produce more complete and accurate project drawings.

Conclusion

The accuracy and precision of shop drawings is vital to the success or failure of an engineering project. The contractor is responsible for production of shop drawings and is required to review the shop drawings before transmitting them to the architect/engineer. The Architect/engineer is not obligated to review any shop drawing unless it has been reviewed by the contractor. This is also done to weed out the submittals that are seriously missing significant information, or do not agree with the contractor's means and methods. With the advancement of computer-aided

drafting and 3D modeling technologies, and electronic submittals and review processes, positive steps have been taken to enhance the overall process of shop drawings. In the long run, if all the parties involved in the process can share their data and their 3D models so that all parties can work off of the same data base, it will immensely improve the accuracy and quality of the shop drawings.

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