BIM and Digital Fabrication

This whitepaper examines how structural building information models are being used for the digital fabrication of structural steel and the role of building information modeling (BIM) in that digital supply chain.

According to research data[1] from Stanford University's Center for Integrated Facility Engineering (CIFE), the building construction industry continues to experience falling productivity rates that seem to be getting worse—not better. This data points to fundamental productivity problems facing the building industry and is a major cause of unpredictable building outcomes.

To improve this situation, building information models that describe the design of a building are now being used to facilitate a variety of related building activities, including building construction and digital fabrication of building components. BIM is enabling digital design-to-fabrication workflows for all of the building disciplines, including the use of structural building information models for the digital fabrication of structural steel.

Model-based Design and Manufacturing

For decades the manufacturing industry has been using mechanical CAD systems to create digital models. These models not only describe the product design, they are also used for other applications like stress analysis, field support, and of course manufacturing. CAD models are used to generate files that control CNC (computer numerical control) machines, thus increasing the automation of mechanical manufacturing processes.

Similar approaches can also be used by the building industry to automate building construction processes. Although a building isn't "manufactured" in its entirety and then shipped to the owner—as is a car for example—many integral parts of a building *are* manufactured remotely, then shipped to the building construction site and assembled in the context of the overall building. Some common examples of this include building components such as doors and windows, precast concrete structures, and structural steel.

Steel Fabrication 101

To understand how BIM can be used to automate structural steel fabrication, it is important to understand how the structural steel components that make up a building's frame are created. First a steel mill uses a hot-rolling manufacturing process (typically) to create stock structural steel members. This stock material is purchased by steel fabricators who cut and prepare the stock structural beams and columns for building construction based on shop drawings—instructions that describe exactly how to fabricate each individual piece of a structure. Once they are fabricated, the steel members are shipped to the building site and put in place by steel erectors.

Where do shop drawings come from? The role of the structural engineer is to design, analyze and certify a building's structural frame and then create construction drawings that document the structural design. The structural drawings contain only general requirements for steel fabrication—instructions for typical steel connections. A steel detailer then takes those construction drawings and applies those general connection instructions to the specific structural components and the specific geometry of the building as represented in the construction drawings—creating shop drawings that instruct the steel fabricator exactly how to fabricate each piece of steel in the building. Shop drawings include detailed information pertaining to material specifications, sizes, dimensions, welding, bolting, surface preparation, painting requirements, etc.

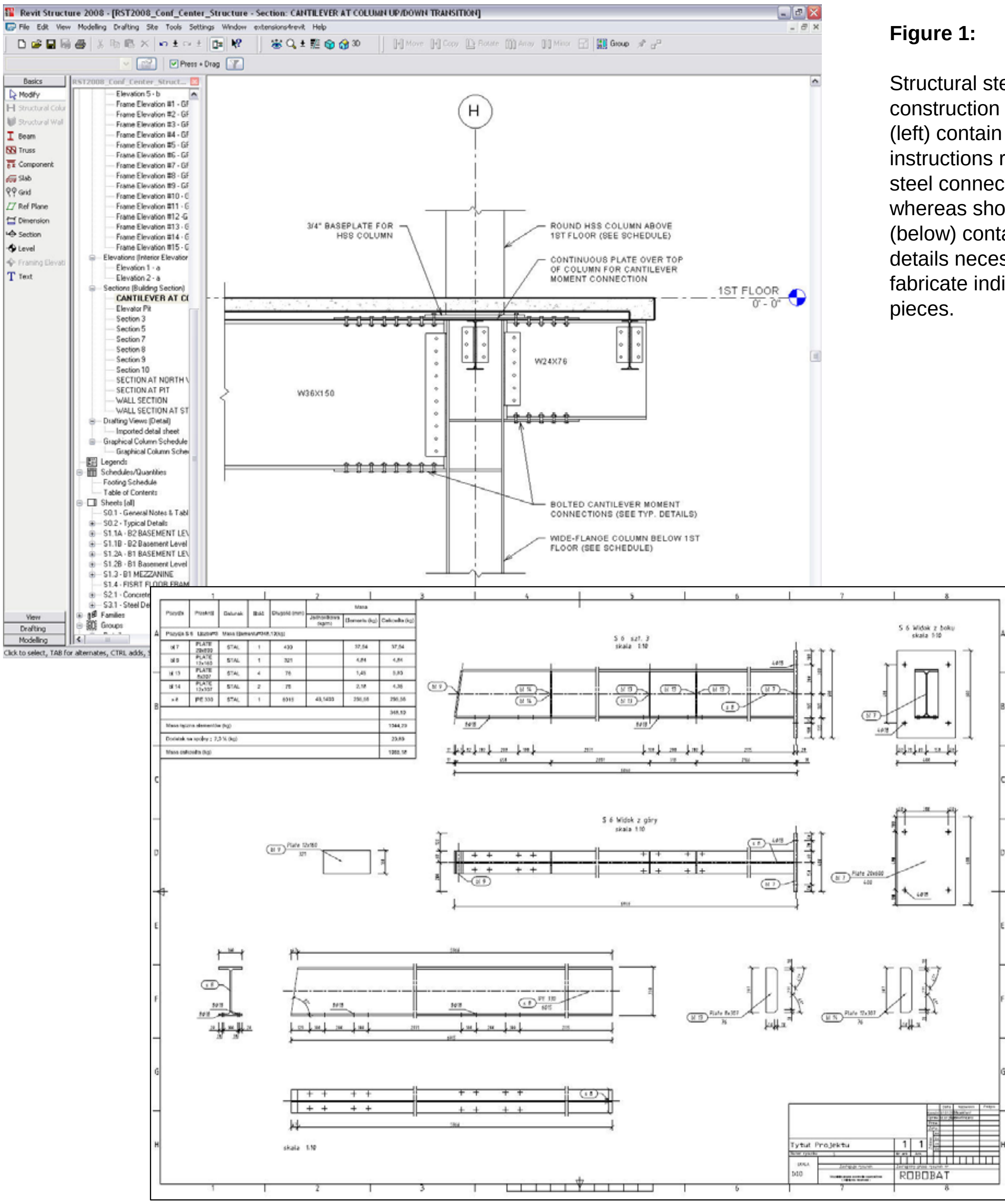

Figure 1:

Structural steel construction drawings (left) contain only general instructions regarding steel connections, whereas shop drawings (below) contain all the details necessary to fabricate individual steel pieces.

Shop drawings are either ‘manually’ created with drafting software or created with special steel detailing software such as Autodesk’s Robobat RCAD—a solution that uses a digital “fabrication” model to create steel details.

It’s interesting to note that the number of shop drawings for a building project far exceeds the number of construction drawings. For example, to document the steel frame of a 1,000-ton building (1,000 tons of steel) requires approximately 70 to 80 construction drawings versus 1,000 shop drawings. Prior to the release of the shop drawings for fabrication, the structural engineer checks each one to verify that the information matches the structural design.

Steel fabricators generally use CNC beam line machines that automatically cut and drill a beam. Some fabricators hand program the CNC machine based on the information from the shop drawing. Other fabricators use the digital fabrication models mentioned above (that are used to create the shop drawings) to automatically program the machine.

Extending BIM to Fabrication

How does BIM fit into all of this? Just as CAD-based models in manufacturing can feed the manufacturing process, a purpose-built building information model such as Revit® Structure can feed the structural fabrication process. All the geometry regarding the structural steel is already in the Revit Structure design model. This design information can be exported to a CIS/2 file (an industry standard data format for exchanging steel information), for reuse in a steel detailing application.

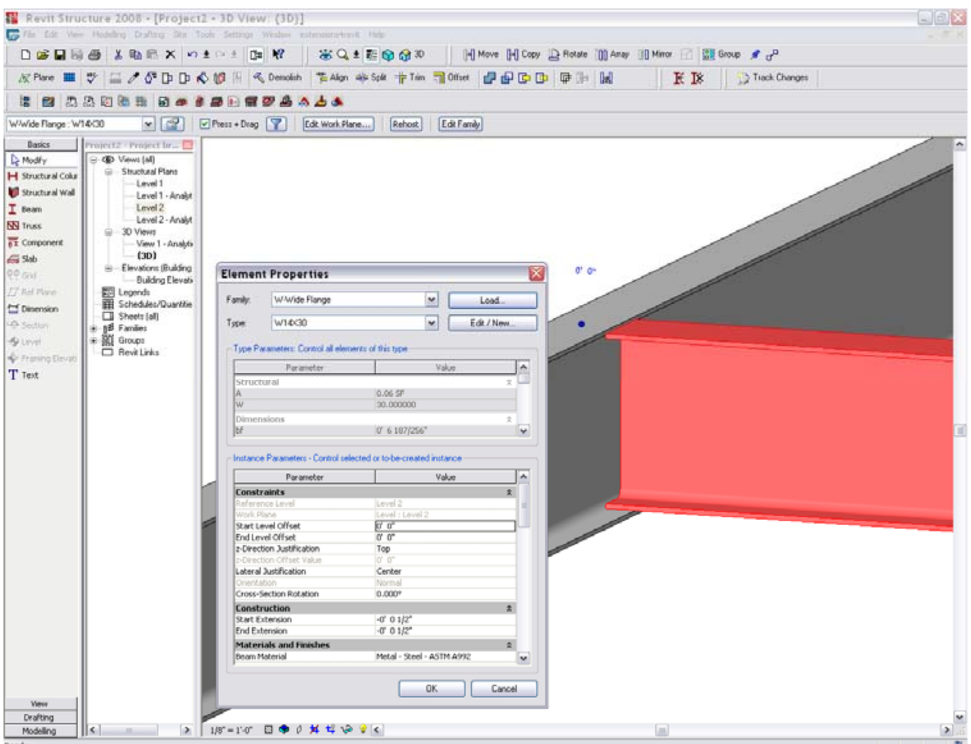

Figure 2:

Structural steel geometry and information from the Revit Structure design model can be exported via a CIS/2 file and reused in a steel detailing solution.

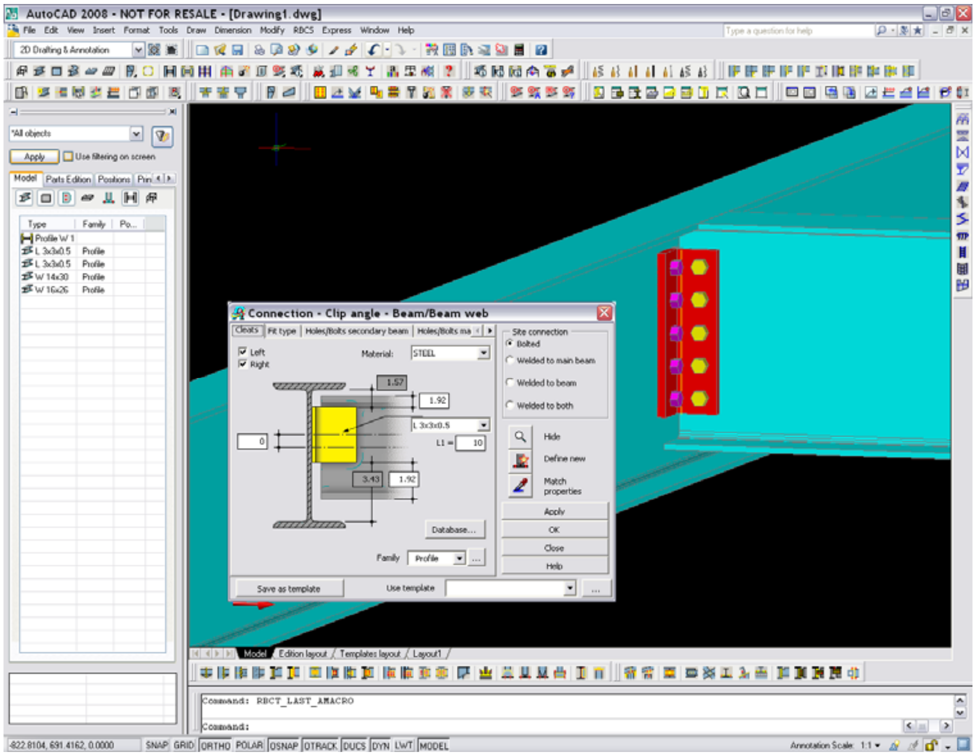

Figure 3:

Revit Structure design geometry and information can be reused in a steel detailing solution such as Robobat RCAD, shown here. Notice the additional fabrication information that has been added in the steel detailing application.

The use of the building information model for steel detailing and fabrication enables a fully-digital, design-to-manufacturing process. Reusing the design model in this fashion is inherently more efficient (time normally spent creating a fabrication model is eliminated) and produces higher quality results (discrepancies between the design and fabrication models are eliminated). In addition, the source of the information used in the steel detailing and fabrication software is digital design data based on a highly accurate, coordinated, consistent building information model—data worth sharing for related building activities.

Once the steel details are complete, the fabrication model can be used by the design team or the contractor for the purposes of 4D modeling as well as clash detection with other building disciplines and models (such as MEP and architectural). The fabrication model doesn’t necessarily represent as-built conditions; there are still changes that can occur during the steel erection process. But it does contain more detail than the structural model and therefore can be useful for interference checking, especially for building types or application where space is extremely tight.

Another advantage of using BIM in the structural supply chain has to do with the overall cost of the structural frame. In the past that cost has, in general, been equally distributed between raw material, fabrication, and erection. But in recent years the proportionate cost of fabricated steel and steel erection is rising—a trend that could be halted by considering ‘simplicity of fabrication’ during the design process (another parallel to the manufacturing world and its emphasis on ‘manufacturability’).

Using the design model directly for fabrication will create a natural feedback loop between fabricators and designers—and bring fabrication considerations forward into the building design process. Sharing the design model with fabricators for bidding will shorten the bid cycle and lead to more uniform bids based on consistent steel tonnages. And the coordination between the fabricated steel and the other building components will reduce the amount on onsite issues and drive down the rising cost of steel erection.

An important ingredient to a digital design-to-fabrication process is some form of collaboration between the structural engineer, the steel detailer, and the steel fabricator. In most cases, those 3 parties represent 3 different companies. The link between design and fabrication is therefore facilitated by alternate project delivery approaches—where cross-functional project teams representing owners, builders, engineers, and contractors collaborate through all phases of design, fabrication, and construction. Steps that were once sequential (design, detail, fabricate) can be done more concurrently. Thus the design model and shop drawings can be created in tandem. With the shop drawings done sooner, the mill order can be submitted sooner, the fabrication can start sooner and steel can be erected sooner.

Digital Fabrication in Action

One company at the vanguard of using BIM for digital fabrication is Rutherford and Chekene (www.ruthchek.com) , one of California's foremost engineering firms. Founded in 1960 and headquartered in San Francisco, this multi-disciplinary firm provides structural and geotechnical engineering services for a broad range of buildings including hospitals, sports facilities, museums, historic buildings and even aquariums. A Revit Structure user since 2005, Rutherford and Chekene (R&C) currently has 14 licenses of the software and are using the building information model for design, analysis (in conjunction with RAM and ETABS), and now for digital fabrication as well.

One of their most recent Revit Structure projects is the Sutter General Hospital Sacramento, a 425,000 square foot, 11-story replacement facility for the existing hospital. The building represents over 5,000 tons of steel, which will necessitate roughly 5,000 shop drawings. On this project, R&C has a partnering relationship with both the steel detailer (Dowco Consultants) and the fabricator (Herrick Steel) and is working closely with the construction company (Turner Construction) as well.

"The relative expense of hospitals—roughly \$600 to \$800 per square foot compared to \$150 to \$250 for commercial building—makes them a good candidate for alternate project delivery models and relationships," explains David Bleiman, S.E., Principal at R&C. "We're currently in the planning stages of how we'll all work together on this project, but our goal is to keep all the data digital for as long as possible and use digital data exchanges whenever possible."

Construction for the entire site started early in 2007 and will be complete in 2012. The work is phased over time, as replacement facilities come on line allowing demolitions to occur that provide space for the new facilities. As a result, collaboration methods and workflows among the various stakeholders on this project are also being phased in. "Phase one is comparing the rough fabrication model (in this case created using Tekla software) to our Revit Structure model," reports Bleiman.

The fabrication model was already underway before R&C and the steel detailer started their collaboration efforts—so the two models have to be manually coordinated. "We have to walk before we run, but the end result will be the same: a fabrication model that matches the design model and everyone working together during structural design, fabrication and erection to reduce costs and improve delivery schedules," explains Bleiman. Any questions that stem from original design—questions regarding dimensions, sizes, locations etc.—will be rectified earlier in the design process and result in fewer RFIs and change orders.

Once the steel detailing gets underway, the second phase of the plan will begin: a completely digital review of the structural steel shop drawings. Shop drawing review (normally done by hand entailing printing, shipping and checking multiple copies of each fabricated piece drawing) will be done electronically within the steel detailing software used to originate the shop drawings—eliminating the paperwork that would be approximately 30,000 sheets of drawings for a project this size.

In addition R&C will use Autodesk NavisWorks software to compare and coordinate the completed fabrication model and the original design model. In addition, Turner will also be using Autodesk NavisWorks—combining the structural fabrication model with models of other building disciplines for the purposes of clash detection.

Figure 4:

Rutherford and Chekene use Revit Structure building information models, such as the hospital project shown here and below, to facilitate digital fabrication.

Summary

The productivity currently enjoyed by the manufacturing sector was made possible in part by the use of digital data models to automate manufacturing methods. BIM and digital fabrication has the potential to do the same for the building industry.

Like integrated project delivery, digital fabrication is just starting to gain traction within the industry. “We all realize that there are challenges that need to be addressed,” concludes Bleiman. “But from my viewpoint, BIM solutions are definitely paving the way towards leaner building construction processes and more controlled project outcomes.”

1. Paul Teicholz, Center for Integrated Facility Engineering (CIFE), Stanford University, "Labor Productivity Declines in the Construction Industry: Causes and Remedies," AECbytes.com, April 14, 2004

About Revit

The Revit platform is Autodesk’s purpose-built solution for building information modeling. Applications such as Revit® Architecture, Revit Structure, and Revit® MEP built on the Revit platform are complete, discipline-specific building design and documentation systems supporting all phases of design and construction documentation. From conceptual studies through the most detailed construction drawings and schedules, applications built on Revit help provide immediate competitive advantage, better coordination, and quality, and can contribute to higher profitability for architects and the rest of the building team.

At the heart of the Revit platform is the Revit parametric change engine, which automatically coordinates changes made anywhere — in model views or drawing sheets, schedules, sections, plans… you name it.

For more information about building information modeling please visit us at *http://www.autodesk.com/bim*. For more information about Revit and the discipline-specific applications built on Revit please visit us at *http://www.autodesk.com/revit*.

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