Steel Connections: Fun is Fondling the Details

Terri Meyer Boake, University of Waterloo
Vincent Hui, Ryerson University

The Problem:

The last 40 years have seen a remarkable change in the nature of the design of steel framed buildings. Steel framing prior to the onset of the High Tech movement in the 1970s, which can be characterized by buildings such as Foster's Sainsbury Center for the Arts and Piano and Rogers' Pompidou Center, depended on simple geometries and predominantly standard detailing – detailing that closely mimicked the sort that is outlined by the American Institute of Steel Construction in their detailing handbook. From the perspective of the type of steel design that is seen in contemporary architecture, styles have changed significantly. Complex geometries, diagrids and curves have become the norm. Connections have since become increasingly complex and bear little *direct* resemblance to standard framed methods.

Where students seem willing to attempt to incorporate these highly articulated steel framing methods into their architectural discourse, they often fall short of carrying through their detailed design to include highly developed, articulated details that engage the realm of constructability. The drawings and renderings that are produced appear to make widespread use of seemingly "welded" connections that use nondescript looking steel members as this seems to be the easiest way to avoid coming to grips with the reality of the detail. The drawing or rendering scale is often kept quite small, as also to avoid having to add definition to either materiality or line work. This might be called *"connection avoidance".*

If one of the most difficult issues that students face when they are preparing to design a steel building is the detailing of the connections, we maintain that the major roadblock to engaging architectural students in steel connection design (and steel design in general) rests in the way that it is normally taught. If referencing the pure engineering-driven "steel design" courses, this lies in an education formed of elemental calculations and disparate "bits" that are taught with little reference to either actual or innovative buildings. Students learn about connections from the point of view of load transfer and bolting requirements, but are never taken to the more advanced step of understanding how that simple connection can become something more complex and interesting, as well as the role it plays in the overall context of the design of a building. If considering the steel content in materials and methods based courses, an examination of the majority of texts would confirm reference to fairly typical "base case" architecture, and very traditional, simple framing methods. The diagrams in these texts outline the typical means to connect members, and normally include photographs of relatively generic looking steel framed buildings. This is an essential starting point when learning steel design, but does not elevate learning to a uniquely "architectural" level.

The Proposal:

In preparing our own students to undertake the annual *Steel Structures Education Foundation Student Design Competition*, through our parallel Building Construction (Boake) and Digital Design (Hui) courses, we began to create synergies and exercises

Figure 1. Samples of some of the digitally rendered steel connections from the first year students, completed for their digital communication course

that created a new way of looking at steel details. An exercise was given in the Digital Design class where students were asked to work in groups, examine the steel details of some steel framed buildings that had more innovative connections (introduced in the Building Construction class), and render connection "families" in FormZ. The idea underlying the exercise was for the students to work in small groups to create and share 3D aspects of the details in order to understand how a degree of uniformity could be created in the aesthetics of the joints that was in part derived from the way that they were put together in terms of steel detailing (Figure 1). The lecture on steel design in the materials and methods class was given parallel to the exercise, resulting in a degree of cross-fertilization. It was recognized that these 3D details actually provided more information than the sets of static photographs from which they were derived as the digital files could be transformed into interactive VRML "movie" files, which would allow for the rotation and manipulation of the details (including zoom functions). In fact, the resultant movie files allowed the user to "fondle" the details.

The idea behind the nature of the resource was derived from this exercise. The idea behind our proposal to the Steel Structures Education Foundation of Canada was quite simple: use a multi media interface to demonstrate to students how to go from the "standard" connection to the "elaborate detail". In doing so, we would create a resource that would be captivating enough to get students more interested in designing steel structures by showing them how some of the complex details of more renowned buildings were derived from the language of basic steel connections. Most existing resources and texts illustrate the basic methods used to create steel connections (shear, moment, tension, welded and bolted joints), but never provide students with an explicit means to help them understand the way they can leverage the "basics" to create something more elaborate. This project will help the students both work from the basics forward, and from the complex case studies in reverse, to see how simple the manipulation of the ordinary to the extraordinary might be. The resource is based on the initial photographic case study work presented in the website "Steel: Fun is in the Details[1]", that has documented a gallery of intriguing steel structures that largely use AESS or innovative structural steel as a key feature of their designs.

The engagement resultant from being able to manipulate or fondle the details gave rise to the core idea of the proposed resource, that of using a series of details drawn from the online gallery, to create a series of interactive "details" that show the

Figure 2. A detail from Polshek Partnership's Rose Center (original photo in top right) explored in different manners through an interactive 3D PDF model

transformation of the more complex details from the basic connection types from which their essence has been drawn. The initial thought was to create MOV or VRML files, to allow for rotation and zoom functions. These interfaces proved too "bulky" to be put directly into an online web interface. Despite the ability to navigate around these details, the models remained static and failed to provide a robust framework for students to understand assembly and detailing. Experimentation led to the adoption of an interactive PDF file format as it is much smaller, ubiquitous, and also provides the user with the ability to manipulate the view as well as look at simple orthographic drawings of the same detail. Rather than encumber audiences with inaccessible complexities of conventional CAD applications, the interactive PDF empowers the viewer with a great deal of flexibility in examining steel details as an assemblage of components within a structural system. Through a matter of clicks, users may navigate assemblies from any perspective, remove elements to understand component systems, and even create virtualized sections in order to fully understand the design intent and the detailing rendering it feasible (Figure 2).

Significance of the Mini Case Study:

Although the proposal is intended to focus on the connections, we felt it important to frame the connections within the context of the smaller case study. Putting the referenced complex connections used in the examples in the resource in the context of the building and its construction process is also critical to gaining a proper understanding of the choices that were made in designing the detail or connection. The following example illustrates simple jointing and a basic W to column connection from Frank Ching's "*Building Construction Illustrated*". The images beside are for the framing of the steel substructure for Foster's Leslie Dan School of Pharmacy and the lifting of the fragment of the pod into place (Figure 3). Where the tube to tube welded connections in the Foster work might be geometrically logical, the splices, their location and frequency can be explained by understanding the construction and assembly requirements. The simple fact that the steel is ultimately clad, relieved the design of the responsibilities of AESS finishes, but also meant that it had to be "sleek" enough to permit the ease of finish application.

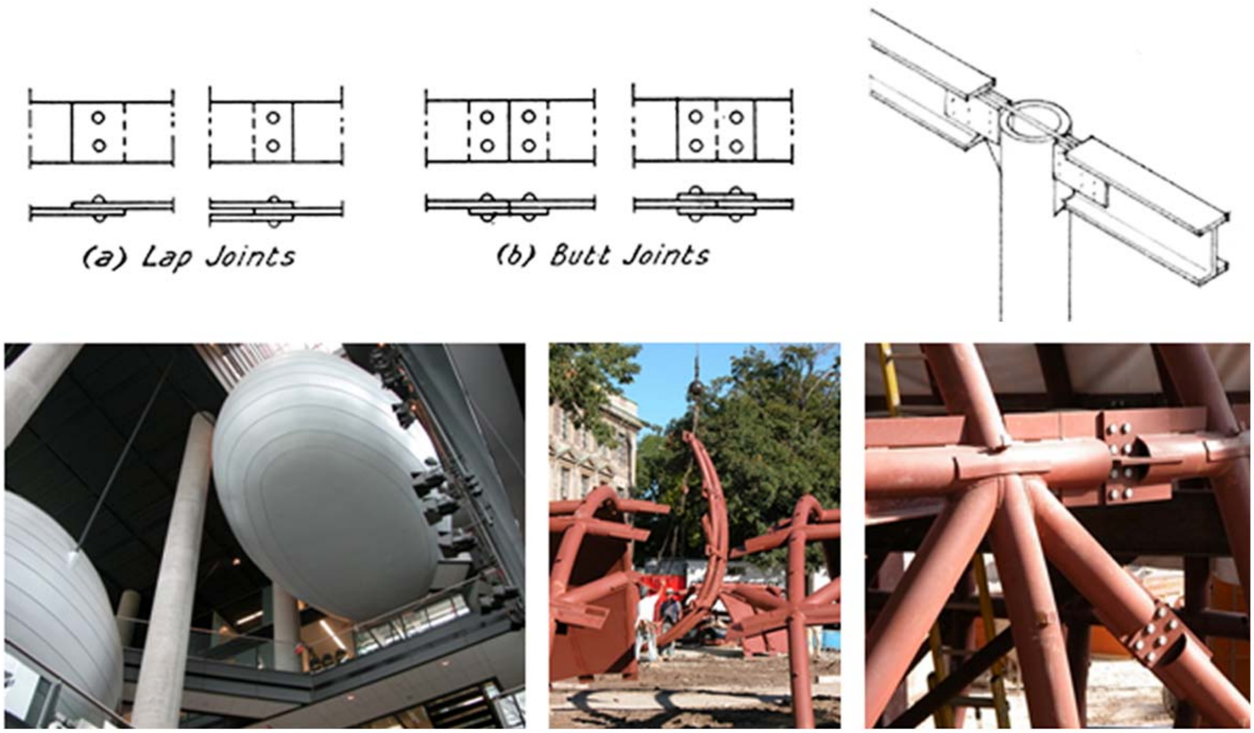

Figure 3. (clockwise from top left): Classic connection, detail from F. Ching ofa type of tube to W connection, detail of tube to tube connection with plate on the Leslie Dan School of Pharmacy, crane lifting pod segment for placement, and finished building – pods clad in gypsum board with painted finish

Our examples propose to take students from basic details to those that use more complex geometries, varying steel shapes and hollow sections, as reflected in a range of intriguing built examples. We will take approximately 20 different innovative steel framed buildings and break them apart into key connection details, developed in terms of their connection types, and to varying levels of detail as required.

Navigation of the Content:

The content of the resource will make use of the web interface to allow for navigation to be carried out in various ways. Given the current shift from categorized order toward relational groupings, the resource will empower students with what Weinberger refers to as metadata classification – that topics may be sorted based on a multiplicity of taxonomies.[2] It is felt that students would engage the content to a) figure out how to understand basic connections methods; b) investigation a certain type or style of connection (hinge, tension, moment) and c) see the range of connections that have been used within a particular case study building. The "basic connection methods" will be illustrated in very generic terms and be annotated to demonstrate the stress and failure typologies associated with the connections (tension and compression forces, shear planes, bolt shearing and plate pull through, for example). The connections that have been derived from the 20 case studies will be subdivided into AESS versus structural steel buildings, as well as the details within each case study into their specific connection type (framed, moment, tension, cast). The ability to make hot links in a web based interface will allow the user to jump from the case study to the connections, or from the connection to the steel building, so this section will briefly walk them through these issues and reflect on how this impacts the decisions we make regarding designing connections, of how we

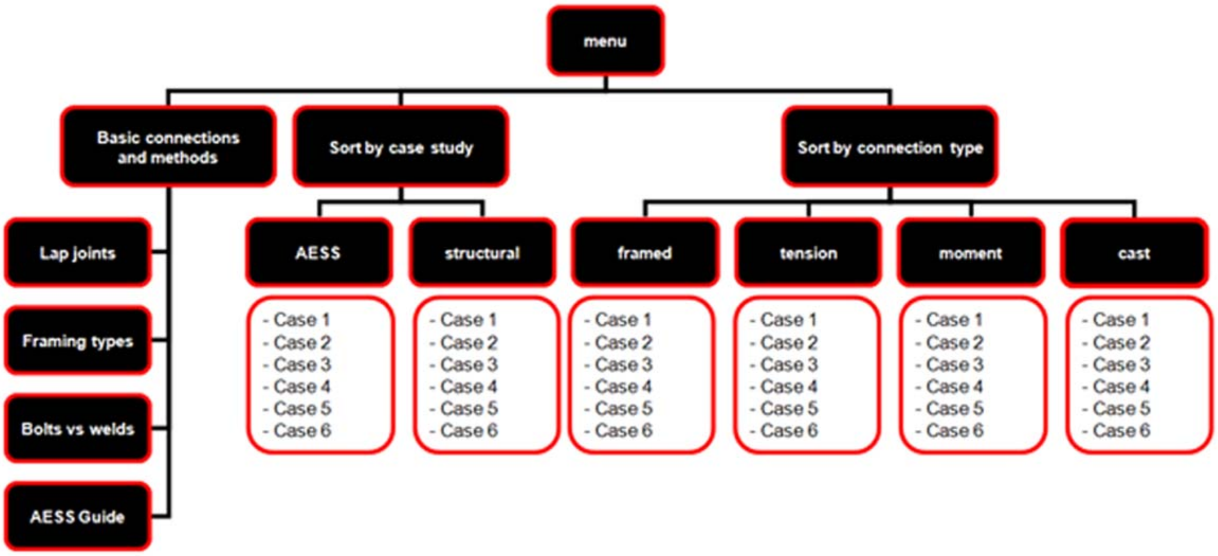

Figure 4. The flow chart of the navigation of the resource

more general information of the case study, and back to the explanation of the basic principles, and vice versa. From within each "basic connection method" outlined, there will be linkages provided to the elaborated details from within the case studies where this connection method is employed (Figure 4).

Basic Connections and Methods:

Within this category we will begin with a brief overview background to steel construction. This is intended to be complementary to the Materials and Methods or Steel Construction text, so will *not* focus highly technical background material related to steel manufacturing or specifications. Within this section we will examine basic jointing, framing types, and the rationale behind the choice of bolts and welds. Bolting and welding issues will be shown to include fabrication, constructability, transportation, and erection issues. Most students are not familiar with the logistics of the physical construction of a connect steel -- bolting and welding background -- lap joints, butt joints, etc. We will begin with a matrix of standard connection details, modeled upon the AISC Connection Types. They will be broken down into framing types (beam to column, column to column, truss, tension, moment resisting, etc.) These will be redrawn in orthographic (plan, section elevation) as well as 3D axonometric views. *The emphasis will be towards understanding the how and why, so sizes will be purposefully omitted throughout the resource. This could also be considered a liability issue lest someone try to copy these.*

A discussion of issues in the design of AESS - as reflected in an upcoming Canadian CISC Guide will be included in this section. The elaboration of AESS requirements is extremely important as it frames many of the subsequent choices that must be made in detailing and understanding the physical and financial implications of the connections.

AESS: Not all Steel need be Created Equal…

Architecturally Exposed Structural Steel (AESS) has grown in its use and brings with it a range of considerations that are quite different from those associated with regular structural steel design. Terri Boake has been working with the Canadian Institute of Steel Construction Task Group to write a new specification and Guide to assist architects interested in design with AESS.[3] This resource goes well beyond the AISC Guide that was published as an issue of Modern Steel Construction in 2003.[4] The findings of this[5] Task Force and key information from the Guide will be integrated into the project. Although students seldom are required to carry out detailed costing of their projects, there are some significant cost implications connected to AESS design that related to the level of finish and other aspects of the fabrication of the joints. The multimedia resource will be used to highlight this part of the design process associated with AESS connections.

Architecturally exposed structural steel specifications place a higher level of requirements on ironwork that lie above and beyond the regular structural and safety aspects of steel construction, in their additional address of aesthetic and design considerations. Not only must more care be taken during the shop and field fabrication of AESS product, but other operations, beyond those of normal fabrication, are necessary to raise the aesthetic and tectonic level of the steel for purely visual and tactile goals. The steel must be seen to be smooth and defect free. It may also be required to be touched and felt to be smooth and defect free if situated at the public level. If bolted connections are used, this may not be a difficult requirement as the tectonic characteristics of bolted connections are perceived to be somewhat "busier", and the structural steel or tube itself is unlikely to require more than proper paint finishing. However, when welded connections are specified, extra expense is usually incurred by the addition of grinding operations. This has much to do with the perception of welded connections as being smooth and physically seamless. Welds, particularly if done by an unskilled worker, can be seen to mar the fluid appearance of the final product. Specialty elements that require steel to be cast into unusual shapes, or bent into complex curves, also places additional requirements on the fabrication and installation that will increase the cost of the steel well beyond the norm.

Such information needs to be conveyed to architects (and architectural students) so that they understand the impact of "line items" in specifications. Grinding and filing operations are time consuming, hence costly, and can be quite unnecessary if the steel in question is not in a position for close scrutiny, via sight or touch.

Sorting by Case Study:

In order for students to appreciate the relevance of any detail or connection type, they need to both see and understand it in the context of the building. For them to potentially become engaged, the building or "mini case study" needs to be of a building that has the potential of capturing their attention. The projects that will be used as the basis for the resource will include works by Frank Gehry, Norman Foster, Richard Rogers, Daniel Libeskind, Will Alsop, Rem Koolhaas, Santiago Calatrava and the Polshek Partnership, amongst others. These types of buildings are not typically part of the normal Materials and Methods texts, so should help to draw the students into the resource. The projects will be divided between those that use Architecturally Exposed Structural Steel and those that use innovative structures that are not exposed. The projects will include a range of connection types and member shapes, so that their various connections can feed into the portion of the resource that examines the connection types in great detail. A variety of finishes will be represented so that issues of paint finish (impact of degree of gloss), intumescent coatings and galvanizing can be addressed.

A simplified case study will be developed of each of the buildings. These will primarily be photographically based, and also include some 3D interpretive diagrams of the way that the structure of the building "works". This will be in keeping with a basic explanation of the structure of the building, but will not go into great detail as the purpose of the resource is not to create detailed case studies, but more to use the buildings as a vehicle that can generate innovative steel connections that can be dissected and used as a tool for learning. The base case study will be broken apart into connection details that are viewed as photographs. The photographic detail from the real building will then be will be modeled in FormZ and orthographic blackline, and annotated with explanations to describe the roles and functions of the connection detail, jointing systems, and how it is part of a larger language of connectivity in the overall building. The write-up will speak to some of the other choices that have been made in the design of the detail in terms of constructability, modularity, fabrication, costs, replication, workmanship and erection. The interactive PDF files go beyond allowing users to simply "spin around" the details. That users can manipulate the detail by turning on and off specific components to reveal assembly, arbitrarily cut sections to understand construction details, and take measurements from these models are but a few technically robust qualities that the medium has to offer. As design educators, it is important to emphasize the design value of this medium as it also allows audiences to engage a multiplicity of considerations ranging from viewing the detail from macro and micro levels, removing components to alter its visual appearance, to even witnessing the impact of a detail in different lighting conditions (Figure 5). The synergy of these elements create an engaging and comprehensive package for students.

Sorting by Connection Type:

We would imagine at this point that the set would include around 20 fully developed details, as well as a range of lesser developed or simpler details. The final number will depend upon how many unique base details can be isolated from AISC and Allen, and how many interesting finished details we identify in the case study projects (including time/resource limitations associated with the project). There are similarities in the details that will allow grouping various projects in order to use some of the basic ideas and show how they may lead to variations. This will show students how a standard detail can be turned into a number of different solutions that start off with the same principles.

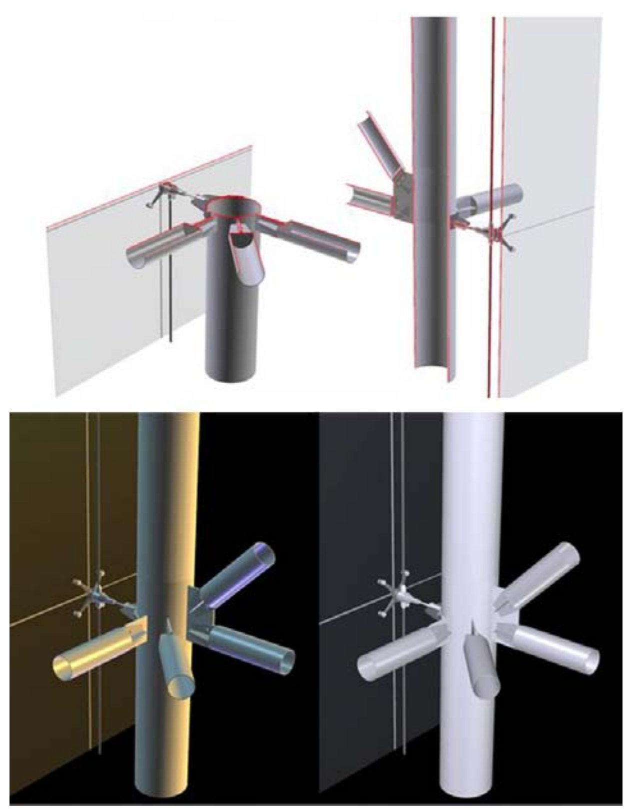

Figure 5. 3D PDF files allow for interactions that better inform design ranging from arbitrary and real-time section generation (top) and even lighting conditions (bottom)

The connections that have been developed as part of the mini case studies will be sorted by their characteristics so that the user can browse the collections by connection type: framed, hinge, moment, tension, cast, etcetera. The benefit of the web based media is that it will allow navigation and regrouping of the (same) material under different headings within the site, in a way that a text would not allow for the same regrouping of intense image based material due to the constraints of printing associated with books.

Summary

The resource is currently in production and its release is anticipated in March 2010 to coordinate with the Steel Structures Education Foundation Educators Meeting to be held in Vancouver. The meeting brings together professors of Architecture and Engineering within a forum to exchange teaching initiatives and information. As educational and building technologies continuously evolve in parallel with each generation of students, educators must continue to offer resources that address the interactive and interconnected mindsets of contemporary students. The SSEF resource we propose negotiates the interactivity demanded by students with media that provides a robust data set easily that is both accessible and user-friendly through case study images, text, and 3D PDF's. The navigation through a web-based interface is not only intuitive but also conducive to the interconnected and metadata-driven society we find ourselves in. The culmination of this accessibility, interactivity, and technical information in the SSEF resource empowers students to bridge the gap they face between technical feasibility and design creativity. To design is to have an intimate knowledge of one's ideas down to the finest details. Allowing the details to be fondled and engaged encourages students to understand construction as not only a critical part of design, but also a driving force behind its overall aesthetic. Rather than awkwardly manipulating details in force fits of building technology into their designs, the resource grants students the ability to integrate technical knowledge in a deliberately considerate and sensitive manner.

References:

Ching, Frank (Francis D. K.). Building Construction Illustrated (3rd Edition). New York: John Wiley, 2003

Weinberger, David. Everything is Miscellaneous: The Power of the New Digital Disorder. New York: Times Books, 2007.

Notes:

---

[1] Boake, Terri Meyer. Steel: Fun is in the Details. 5 May 2009. <http://www.architecture.uwaterloo.ca/faculty_projects/terri/steel.html>

[2] Weinberger, David. Everything is Miscellaneous: The Power of the New Digital Disorder. New York: Times Books, 2007.

[3] CISC AESS Information. 5 May 2009 <http://www.cisc-icca.ca/content/aess/default.aspx>

[4] AISC AESS Guidelines. 8 May 2009 http://www.aisc.org/newsdetail.aspx?id=11550