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The Confluence of Information: Teambuilding is not enough to produce successful interdisciplinary teams

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Introduction

Multi-disciplinary collaboration is recognized as a requirement for superior performance in the realization of projects in the built environment[1]. However, due to their different "thought worlds," collaboration between professionals from different disciplinary backgrounds is a complex and dynamic process. The result is a lack of synthesis among experts and a reduction in the learning that is necessary for innovation[2]. A state of 'contested collaboration' can result '…where team members maintain an outward stance of cooperation but work to further their own interests, at times sabotaging the collaborative effort."[3]. Within the AEC industry this condition appears to be far from the exception[4].

The requirement for multi-disciplinary collaboration rests on the assumption that, "…no single individual (or firm) can acquire the varied and often rapidly expanding information needed for success. Individuals (and firms) must work together to collect, analyze, synthesize and disseminate information throughout the work process."[3] In the context of this research the researchers refer to this as a process of interdisciplinary 'knowledge creation'.[5]

As is evident in the litigious nature of the AEC industry, collaboration is not an innate skill of architects, engineers and constructors. It has to be learned and professional schools have an obligation to teach it. This paper reports on an effort to develop a theoretical and practical understanding of the issues associated with collaboration and suggest a process by which educators within the AEC disciplines can facilitate the learning of this critical skill.

The Learning Knowledge Model

Puddicombe[4] offered evidence that performance within the built environment required a movement away from planning as an isolated linear process (Figure 1). An iterative process based on learning was required.

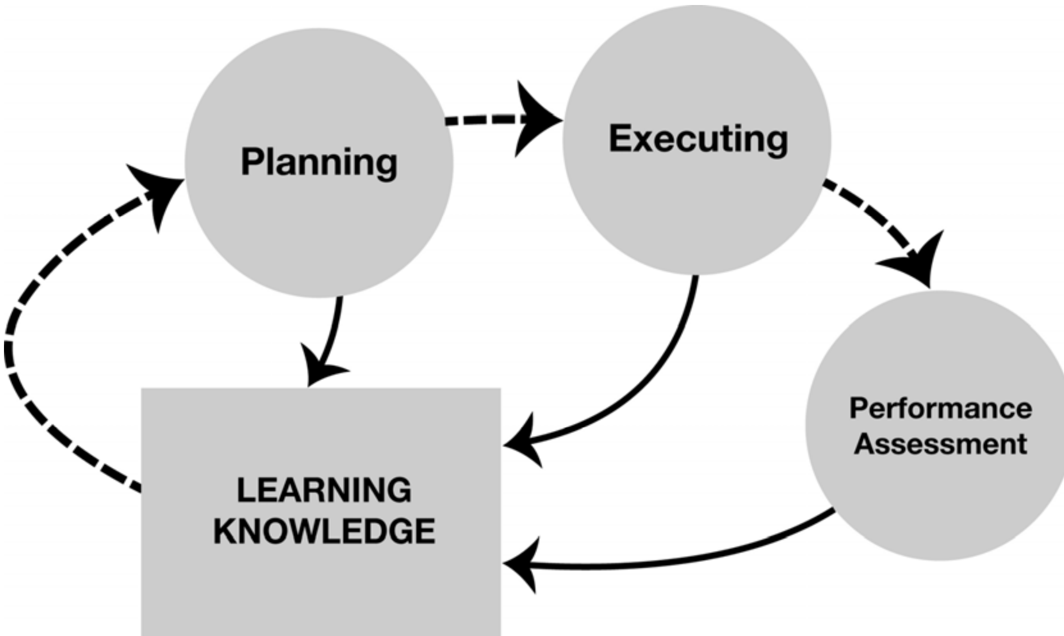

Figure 1. Learning Knowledge Feedback Loop

The reality of an academic environment places constraints on the amount of learning that can result from the actual execution of the plan. However, an interdisciplinary academic environment can readily support learning that results from the planning process itself. In that context the researchers have started developing a model for the design of a collaborative learning environment. Their focus is designing a knowledge creation process that results in a superior physical (built) product.

The context of a knowledge creation process must be accompanied by an understanding of the nature of knowledge, which is define as explicit or tacit[5,6]. Explicit knowledge is that which may be codified such as plans and specifications. It can be explicitly defined and captured in a concrete form. Tacit knowledge is something that is not easily expressed and is hard to formalize. The abilities of the project manager to deal with a recalcitrant sub-contractor or to intuitively re-schedule a set of complex activities that are delaying the project are expressions of tacit knowledge.

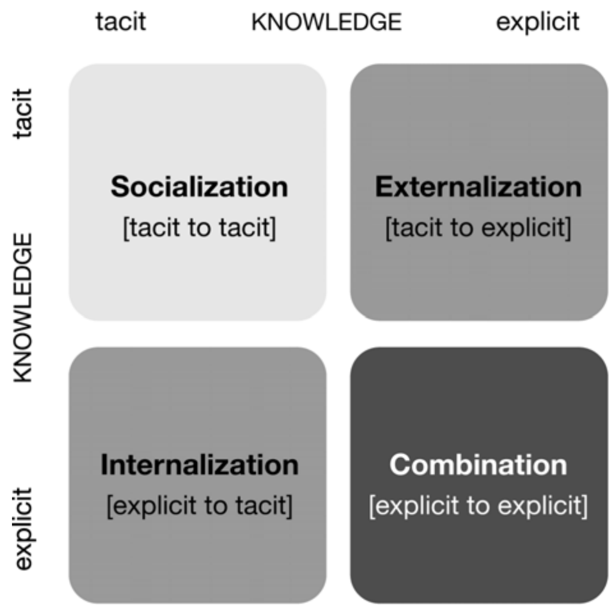

Figure 2: Modes of Knowledge Conversion (adapted from ref. 5)

The knowledge that different disciplines bring to the project will vary as to the degree that it is tacit or explicit. The pedagogical processes that define the student's disciplinary learning suggest the balance. Architecture with its emphasis on the studio and critiques as a learning vehicle conveys a significant tacit component. Engineering with its basis in math and science and the search for a correct solution conveys a significant explicit component. Construction with its emphasis on management (tacit and explicit), construction science (explicit), and construction process (tacit and explicit) combines both.

New knowledge is rarely created by a single individual, but rather by the interaction of individuals. As depicted in Figure 2, this interaction involves the conversion of knowledge from one form to another (Tacit to Explicit to Tacit). The model needs to recognize and implement this process. The specific realization of this knowledge conversion process will vary from project to project. However, generic examples can be developed. Socialization could describe the informal process by which the various actors learn to deal with each other. The underlying belief systems of the individuals will interact, resulting in a management process defined by adversity or collaboration. Internalization would be reflected in the development of the firms' underlying belief in the trustworthiness of each other as a result of the formal contracts. Externalization describes the process by which the architect translates the owner's thoughts into a set of plans and specifications. Combination describes the translation of the architect's plans and specifications into the contractor's budget and schedule.

The researchers are working on developing a set of learning modules that facilitate the development of a collaborative learning environment. The overall goal is designing a knowledge creation process that results in a superior physical (built) product.

Learning Modules

While all three of the disciplines - Architecture, Civil Engineering, and Construction Management – support the project, the existing engineering, architecture, and construction curricula make introducing new courses very difficult. Instead, the curriculum content is being developed as portable interdisciplinary modules, which while discipline responsive, will be adaptable to a range of courses and levels. Since the program centers on the processes and requirements of producing buildings, the modules are intended for classes where there is a thematic connection to design, construction, or project implementation. The root of this project is knowledge "conversion:" while some of the information required for any project is externalized through design and construction documents, the individual AEC disciplines have different tacit knowledge and objectives (as well as goals and measures of success). The issues being addressed in the modules are where tacit knowledge for one discipline is missing or ill-communicated.

The modules are developed to promote two kinds of knowledge conversion, either converting tacit knowledge of one discipline into accessible explicit knowledge for those in other disciplines, or through collaborative projects where broader project knowledge becomes tacit across the disciplines.

The proposed learning modules are intended to address the following questions:

- What do you need to know to communicate effectively with the other disciplines?
- What do you need to know from others in order to do what you want?
- What do they need to know from you in order for you to do your job well?
- What do they need to know from you in order to do their job well?
- What does 'A' need to know from you so 'B' can do their job?
- How do I get you to invest in my goals?
- How do we each define a high level of craft?
- What is the appropriate level of precision for the task? For the project?
- What are the appropriate tolerances: physically as well as socially?
- What are your incentives for the project? What do think are the other disciplines' incentives for the project?
- What are your risks for the project? What do you think are the other disciplines' risks for the project?

The first modules will focus on group interaction, communication, leadership and conflict resolution. These will include a personality self-assessment to help students identify their own behaviors with regard to group dynamics. Subsequent modules will involve inter-discipline knowledge, problem solving, and value assessment.

Theses first modules were initiated based upon input from students in the spring 2012 semester of an Organizational Behavior class that included students from a variety of disciplines. The major deliverable for the course was the development of learning modules that promoted the development of an understanding of, as well as a set of strategies for promoting interdisciplinary activities. The decision to employ students in the module development process resulted from discussions that occurred during the Ecobuild 2011 conference. Following the paper presentations, members of the audience pointed out the challenge of developing foundational modules for students who potentially had different value systems and organizational perspectives than were the norm in the industry. The wisdom of this approach became very evident as the class progressed and the instructor observed the similarities and the differences that existed between the students from various disciplines. One of the statements made during the class has informed much of the module developments. The students indicated that when they began their academic studies they all worked seamlessly with students from other disciplines. However as they progressed in their academic careers their instructors taught them to become functionally focused and isolated. With this in mind, the two first modules intend to establish an initial working relationship between students regardless of major and fostering a line of communication that supersedes disciplinary specialization. They are also is geared towards developing a set of strategies that will allow them to deal with the very real pressures to become functionally isolated. The first modules are being phased into the Introduction to Engineering/Introduction to Construction Management courses.

At present, courses with students from different disciplines fall into several categories: A course taught by one discipline might be a required course for students from several disciplines. These courses are often taught by faculty from multiple disciplines. Next, a course might a required course by students from some disciplines, while taken as an approved elective by students in other disciplines. These courses are the ones used by the students in one discipline to receive a minor in a second discipline. These courses are generally taught only by faculty from one discipline. Finally, a course taught by one discipline may be taken as special elective course for students from other disciplines. These courses are usually taught only by faculty from one discipline. For students not from the course's discipline, these courses are often taken as "Special Topics", and are not always used to fulfill a degree requirement. The researchers are working to distribute the learning modules across a wide range of courses, from freshman year through graduation.

An example of a course taught by one discipline that serves as a required course for students from some disciplines and as a special elective for students from other disciplines is CE475/480-Senior Design Project – 4 credits (two semester capstone project, 1st semester involves scope definition and scheduling, 2nd semester involves project design). This course is required for both CE and CM students and is taken as an elective by ARCH students. This course has had several issues related to integrating the work of the ARCH, CE, and CM students. This course typically has problems with work assignments, budgets, scheduling, deadlines and milestones, determining appropriate levels of detail, dealing with design changes, design documentation, design presentation, and group interaction. The first problem that typically occurs is in the determination of who will be the group leader for a team involving ARCH, CE, and CM students. Apparently, students from each discipline are taught that their discipline will always be the one in charge of a project. The single biggest problem concerns determining when each portion of the work is supposed to be completed, since significant portions of any one group's work will depend upon the timely completion of other's work. The next biggest problems involve dealing with design changes and determining the appropriate levels of detail. For example, an elevation view of a building might be drawn showing either a scale or dimensions.

The following Figure 3 and Figure 4 were taken from an interdisciplinary team working to design a low-cost, energy efficient modular home. The team consisted of eight ARCH students, two CE, students, and two CM students. The project leader was an ARCH student. The CE and CM students served as consultants, with the CE students being responsible for structural and site-work considerations and the CM students being responsible for cost estimations and ease of construction considerations.

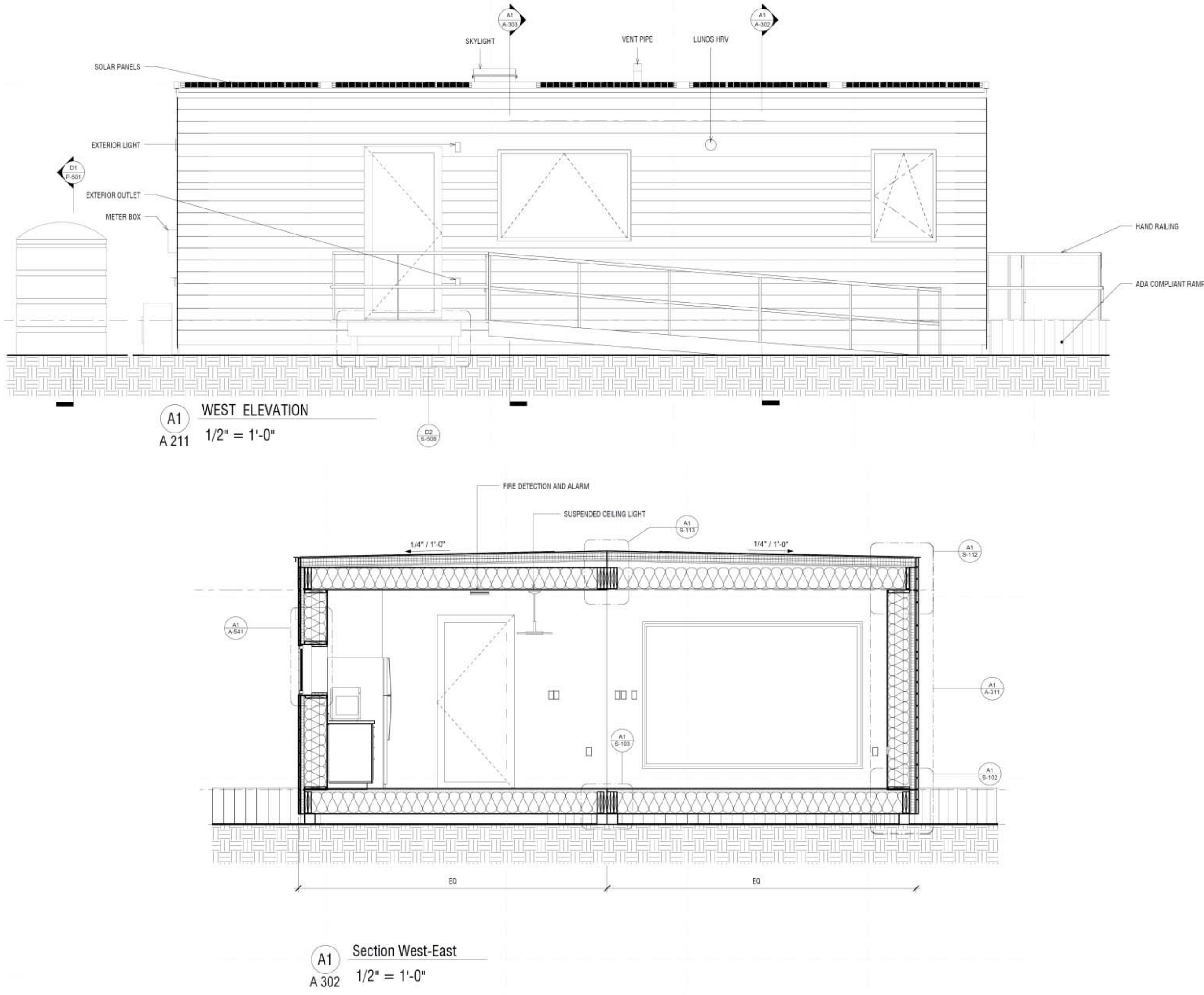

Figure 3: Architectural Drawings for Modular Home

The Architectural drawings for the project were drawn in CAD. Each structural element and architectural component was drawn to scale, with a tolerance of 1/16th inch. The drawings were created with the intent of printing the final drawings on 36”x48” (Architectural size E) paper. Therefore the drawing scale ½”=1’-0” is only accurate when printed on this size paper. This is not an issue for students working with electronic copies of the CAD file, but caused problems for the CM and CE students who did not have access to the CAD system in the ARCH studios.

When copies of preliminary work were distributed on 11”x17” (size B), the ARCH students were inundated with requests for information from the CM and CE students.
Since the Architectural drawings include information pertaining to both the structural elements and the architectural components, the ARCH students’ work often required input from the CE and CM students. In a similar manner, the CE students’ work required input from the ARCH and the CM students, and the CM students’ work required input from the ARCH and the CE students. Conflicts often arose when students made decisions about items outside their expertise without sufficient input from the students from the other disciplines.

In contrast to the Architectural drawings, the information needed by the engineering students so that they can begin calculating environmental loads on the structure is shown in Figure 4. The plan dimensions have been rounded up to the nearest foot, and the building elevation dimensions are rounded to the nearest 1/10th of a foot.

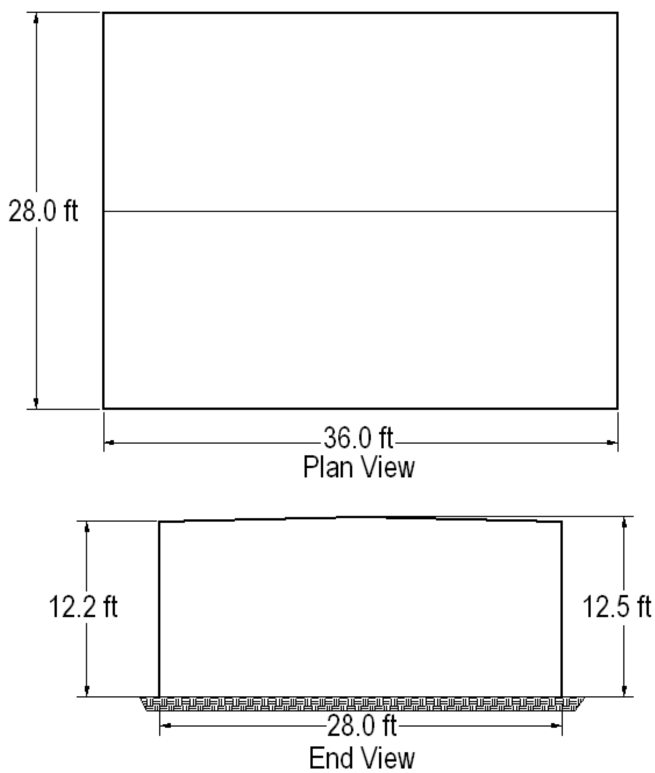

Figure 4: Engineering Drawings for Modular Home (Environmental Loads)

The building dimensions, and the tolerances on those dimensions, required by the engineering students so that they could start their work was much less precise than that needed by the architects to complete the architectural drawings. The lessons that the students learned was that the ARCH students did not have to be “finished” with a drawing before the CE and CM students could start meaningful work. In addition, the ARCH students had to be aware of the effects changing key dimensions or proportions.

Learning modules can range in size from problems spanning several class periods, to ones which take only a fraction of a class period. The following is an example of a module geared toward teaching CE students to be aware of CM requirements, and is incorporated into a lecture on connections for structural steel buildings.

Figure 5 shows the floor framing plan for a simple steel building. This floor plan shows that two floor beams are attached to the girder along column line B at the same location. This is a situation that commonly occurs in structural steel framing. Typically, a standardized connection,

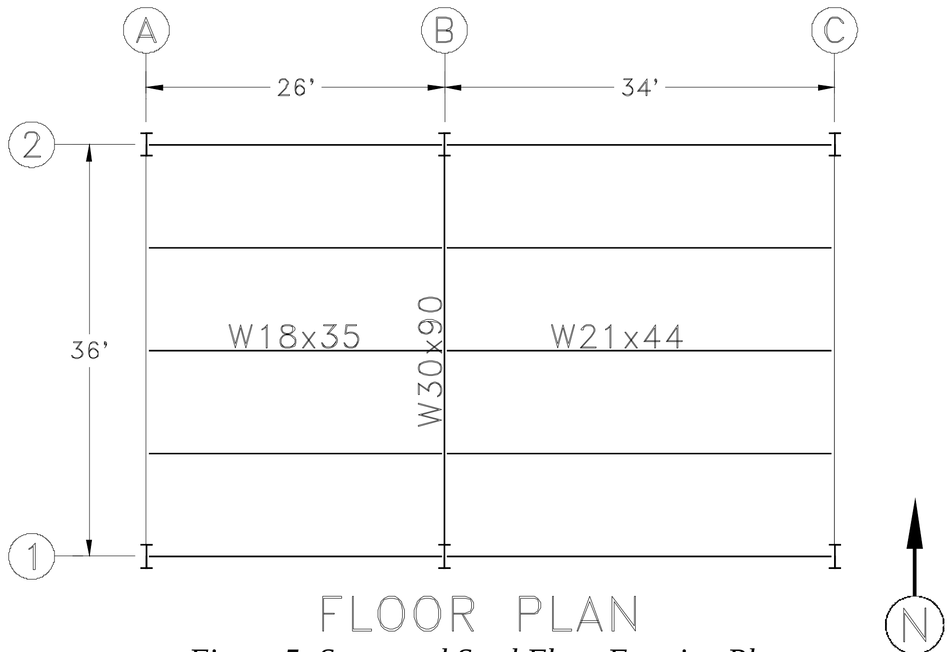

Figure 5: Structural Steel Floor Framing Plan

such as the one shown in Figure 6 would be used to connect the W18x35 floor beam and the W21x44 floor beam to the W30x90 girder. This connection uses structural bolts and double angles.[7] Unfortunately, while this connection is very economical in its use of material, it is very difficult to safely construct. When using a single crane, the bolts that are shared between the W18x35 and the W21x44 are almost impossible for a single worker to install safely. This connection has proven so problematic that OSHA has required that all steel framing have at least two bolts installed per connection before the hoisting line may be released.[8]

A safer alternative to this connection detail is shown in Figure 7. Note that this connection detail has two bolts that are installed in the connection for the W21x44 that are not shared with the connection for the W18x35. This connection detail also requires that W21x44 be installed before the W18x35. Allowing the CM students to suggest alternative connections, such as the one shown in Figure 8, may result in a safe connection that does not use bolts through the web of girder, eliminating safety issues, and possibly be more economical.

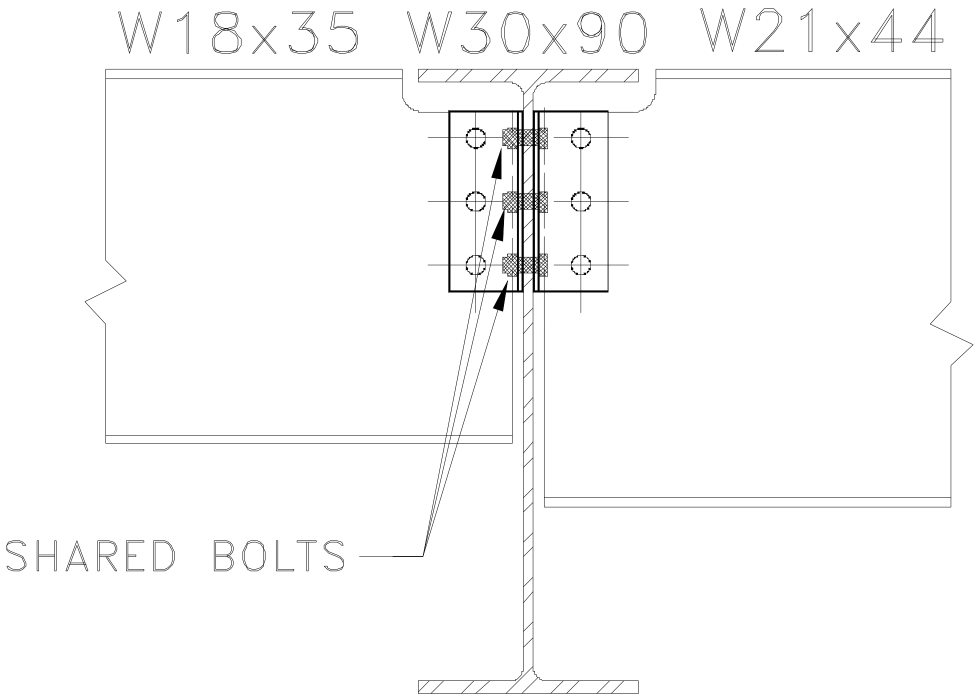

Figure 6: Two Beam Connection Using Double Angles

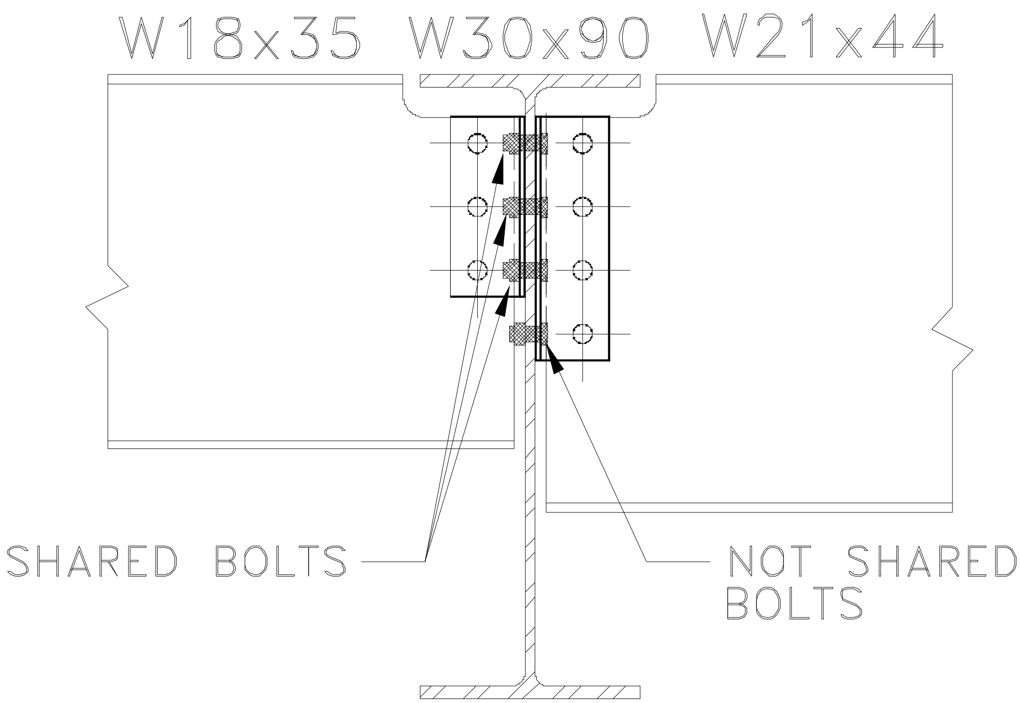

Figure 7: Modified Two Beam Connection - Safer Construction

Figure 8: Two Beam Connection Using Single Plates
(photograph by Edwin Schmeckpeper)

Conclusion

As can be seen from the previous discussion effective collaboration and optimal solutions do not automatically occur as a byproduct of interaction among the professions. However, optimal solutions can occur as a result of effective collaboration which recognizes the roles and requirements of each profession.

Understanding the limits and the requirements of the other professional is a key learning that will support effective collaboration. In the modular home example the architects needed to understand the degree of precision require by the engineering students. They also needed to recognize that there were limits within which they could modify their design. As opposed to dealing with absolutes they needed to recognize the range that they could work within. In the connection example the engineer attempted to develop the most cost efficient connection, defined in terms of minimizing weight or numbers. However from an erection standpoint constructability and safety were negatively affected by the design. The most cost effective design is not determined by minimizing material. It results from balancing the costs of material with the costs of erection. Constructability needs to be recognized as a major cost driver.

The examples demonstrate that optimal solutions emerge from the interaction of the disciplines. The researchers are working to teach the students to develop specialized knowledge and patterns of both problem solving and value assessment related to their disciplines while at the same time working to try to teach the students to think about how they interact with the other disciplines. The importance of a shared language (e.g. CAD files) can be seen. As we argue in our knowledge conversion model knowledge cannot be isolated it needs to be available to interact. We also need to recognize that we cannot predict the interactions. The knowledge that results from the interaction may result in one discipline needing to accept a “sub optimal” (connection) solution. However, in reality that solution is not sub optimal because it optimizes the whole.

The interaction between AEC professionals presents one of the greatest challenges to the industry. Teaching students how to optimize these interactions is one of the greatest challenges facing AEC educators.

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