The Confluence of BIM, VDC and IPD: Collaboration is the Essential Skill

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Abstract
The confluence of BIM, VDC and IPD has resulted in a requirement for a new set of skills for AEC practitioners. In addition to specific professional knowledge, an understanding of the context within which the other disciplines function is necessary. Even more than an understanding, the ability to work with other disciplines in an integrated manner is necessary. Specific technical knowledge must be joined with knowledge of collaboration. Recognizing the limitations in functionally focused curriculum a series of learning modules that address the process of collaboration across disciplines is proposed.

Keywords: *Collaboration, Pedagogy, Architecture, Engineering, Construction*

1. INTRODUCTION

The impact of Building Information Modeling (BIM) has been much more extensive than would be expected from a technology that initially focused on detecting clashes within a structure. The model has become part of Virtual Design and Construction (VDC) that allows practitioners to simulate the construction of the built environment just as a manufacturing process would be simulated before the start of actual production. The requirement for early and extensive involvement of the major project actors in order to maximize the efficacy of the VDC process has resulted in the development of new contractual forms that are grouped under the conceptual heading of Integrated Project Delivery (IPD).

The confluence of BIM, VDC and IPD has resulted in a requirement for a new set of skills for AEC practitioners. In addition to specific professional knowledge, an understanding of the context within which the other disciplines function is necessary. Even more than an understanding, the ability to work with other disciplines in an integrated manner is necessary. Specific technical knowledge must be joined with knowledge of collaboration.

Multi-disciplinary collaboration is recognized as a requirement for superior performance in the realization of projects in the built environment (Puddicombe, 2009). However collaboration between professionals with different disciplinary backgrounds is a complex and dynamic process defined by individuals from different 'thought worlds.' The result is a lack of

synthesis among experts and a reduction in the learning that is necessary for innovation (Dougherty, 1992). At the margins 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." (Sonnenwald and Pierce, 2000:461). Within the AEC industry this condition appears to be far from the exception (Puddicombe, 1997).

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." (Sonnenwald and Pierce, 2000:461) The success of these dynamic work groups is facilitated by interwoven situational awareness and dense social networks that facilitate frequent communication. (Sonnenwald and Pierce, 2000). In the context of this research we refer to this as a process of interdisciplinary 'knowledge creation' (Nonaka and Takeuchi, 1995).

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 seeks 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.

2. THE CURRENT STATE OF COLLABORATION

The perspectives and objectives of the project owner, designer team, and constructors are not always mutually consistent. Disparities in information, allocation of risk, loyalties, contractual rights and responsibilities, perceived responsibilities, and potential financial rewards result in differing perspectives and objectives for the various participants involved in a project. Research (Puddicombe, 1997) has indicated that Architects and Contractors have different beliefs as to the proper degree of integration between their functions and that they have different goals and success criteria for a project. LePatner (2007) states, "Clearly, the incentives of the major players on the supply side are not closely aligned, and the interests of the owner (buyer) and general contractor (seller) are antithetical." Fischer and Tatum (1997) note that architects and engineers often have an incomplete understanding of the construction process and its requirements, resulting in a lack of consideration of the effects of construction constraints on design. The fragmented delivery process may lead to a design that is optimized from the perspective of individual project participants, but has unfavorable constraints for construction or operation.

These conflicts are not limited to the world of practice. When the academy attempts to integrate the disciplines similar dynamics emerge. In December 2010, the BIMFORUM in conjunction with BuildingSmartalliance, a council of the National Institute of Building Sciences sponsored an academic workshop focused on discussing the core educational principles for technology-based collaboration in the Architecture, Engineering, Constructor, and Owner (AECO) Industry. The participants represented 21 universities and 4 countries. The papers and the panel discussions presented a state of the art view of collaboration in the AEC academy. What follows are brief reviews of the knowledge that was gained and challenges that emerged from collaborative efforts at a number of universities.

Scholars at Virginia Tech (Pishdad et al, 2010) believe that social change defined by a collaborative mindset is necessary to overcome the fragmentation that exists in the industry. "Academia is in the best position to drive such transformation through re-visiting the curricula and making required adjustments." They have established the Integrated Leadership Studio (Taiebat et al, 2010) that combines students from the AEC disciplines as well as students from

sophomore through graduate studies.

Penn State (Holland etal, 2010) has begun two experimental courses that integrate AEC students. In order to give the programs the greatest chance of success students were required to submit their academic credentials and were interviewed as part of an application process.

Despite prescreening the students 1/3 of the teams were described as 'highly dysfunctional', and all of the teams faced challenges to collaboration. In post course analysis the instructors found a correlation between the teams collaborative abilities and the quality of the work product. Going forward it was felt that it was important to teach '…techniques which encourage successful collaboration and break down "discipline silos" as well as the compartmentalization of the
design process."

The University of Washington has developed a problem based collaborative studio that also combines AEC students (Dossick and Pena, 2010). In their approach much of the learning resulted from the friction that took place as the students learned to come to grips with the different disciplines. They describe the task of synthesizing the three disciplines while maintaining a real world context as 'daunting' and identified the technical issues as simple in comparison to those characterized by interdisciplinary collaboration.

The University of Oklahoma (McCuen and Fithian, 2010) presented the results gathered over three years on an experimental intersession course that created teams of architecture and construction students. This course offering was unique in that it explicitly included exercises to socialize the students to each other's disciplines. Their experience suggests that explicit exercises in team building, while costly on the front end, pays significant dividends. In addition it is important that the students understand these 'soft' skills as having a basis in science and there importance within their disciplines.

The keynote presentation was given by Dan Friedman, Dean of the University of Washington's College of Built Environments and president of the Association of Collegiate Schools of Architecture. His keynote called for a radical reconceptualization of AEC education. The professions must either change or perish. Change is inevitable the question is where the academy will fit in. Fragmented teaching must give way to an integrated approach. The integration extends beyond the integration of disciplinary skills and requires the inclusion of organizational and social sciences. It is possible to keep the disciplines core values but they must be realized in the context of collaboration.

3. THOUGHT WORLDS: PROFESSIONAL CONTEXT AND ACCREDITATION

Each of the academic disciplines involved in this study is subject to accreditation by a separate organization: ABET for engineering, NAAB for architecture, and ACCE for construction. Given that licensure in engineering and architecture requires graduation from an accredited institution, the standards promulgated by these bodies has a significant impact on the philosophies, policies and procedures that define the pedagogical experience of the students. The development of a multidisciplinary learning environment needs to recognize the support and the impediments that are embodied in the accreditation process.

Below are the vision (ABET) and mission (NAAB, ACCE) statements of the three accrediting agencies. Not unexpectedly their emphasis is on their distinct professions. What is noteworthy is a lack of any mention of the context in which those professions will be practiced.

- ABET will provide world leadership in assuring quality and in stimulating innovation in

applied science, computing, engineering, and technology education.

- The mission of the NAAB is leadership in, and the establishment of, educational quality assurance standards to enhance the value, relevance, and effectiveness of the architectural profession.
- The mission of the American Council for Construction Education (ACCE) is to be a leading global advocate of quality construction education programs and to promote, support, and accredit quality construction education programs.

Examination of the specific requirements for accreditation shows evidence that although the multidisciplinary context of practice is recognized; it is emphasized to varying degrees. In the Program Outcomes for ABET EAC 'an ability to function on multidisciplinary teams' and 'an ability to communicate effectively' are two of 13 outcomes that students must attain. However, when specific programmatic requirements are examined the emphasis varies. In Civil Engineering programs students are required to be able to '…explain basic concepts in management, business, public policy, and leadership...". In Construction Engineering an understanding of legal and professional practice issues related to the construction industry; an understanding of construction processes, communications, (ABET EAC 2010-2011:10, emphasis added). This is in contrast to mathematics, sciences, and engineering where the terms proficiency and apply knowledge that indicate functional capabilities are used. Only in Architectural Engineering is a functional level of expertise required '… an understanding of architectural design and history leading to architectural design that will permit communication, and interaction, with the other design professionals in the execution of building projects. (ABET EAC 2010-2011:7).

The NAAB defines two levels of student accomplishment (NAAB Conditions for Accreditation 2004:11) that are used to guide program development. Understanding—the assimilation and comprehension of information without necessarily being able to see its full implication, and Ability—the skill in using specific information to accomplish a task, in correctly selecting the appropriate information, and in applying it to the solution of a specific problem. It also identifies 34 specific areas in which students must demonstrate either understanding or ability. Effective communications skills (1) are identified as a required ability, as is the ability to collaborate (7) in interdisciplinary teams. However, the collaboration is focused solely on the 'design team.' Understanding of human behavior (12) is required, but only in reference to the physical environment. Construction is referenced in terms of understanding cost control (25) and the need for understanding '... the need for architects to provide leadership in the building design and construction process."(32)

The ACCE requires curriculum to lead to '…a leadership role in construction … and the application of evolving knowledge in construction and in the behavioral and quantitative sciences.' (ACCE Document 103:7). The abilities to communicate as well as understand human behavior are identified as 'essential assets'. The construction professional is identified explicitly as a manager and '… must know how to manage the principal resources of the industry, i.e., people and money.'(Business and Management: 12). 'The Constructor must have an understanding of the contribution of the design disciplines' processes. The Constructor must be able to communicate with the design professionals, and should be capable of participating during the planning phase of design-build projects.' (Construction Science: 12) Curricula topics should address the constructor's role as a member of a multi-disciplinary team, the assessment of project risk, and the alternate methods that can be used to structure the owner-designer-constructor team. Course work will examine the various roles and responsibilities of project participants

throughout a project's life and the creative ways that project teams can be assembled. (Construction: 13)

The analysis above suggests that all of the disciplines acknowledge the need for multidisciplinary collaboration. However the degree to which it is emphasized varies dramatically. In both engineering and architecture the requirement is subsidiary to the achievement of design knowledge. This is in contrast to the constructor where the development of collaborative teams is a requirement. The differences in emphasis are likely related to the licensing requirement for architects and engineers and must be addressed in any curriculum model.

Collaboration will likely result in a conflict between ideas that interact in new ways. However, these new interactions offer the opportunity for new knowledge creation. Puddicombe (1997) offered evidence that performance within the built environment required a movement away from planning as an isolated linear process and a focus on an iterative learning process.

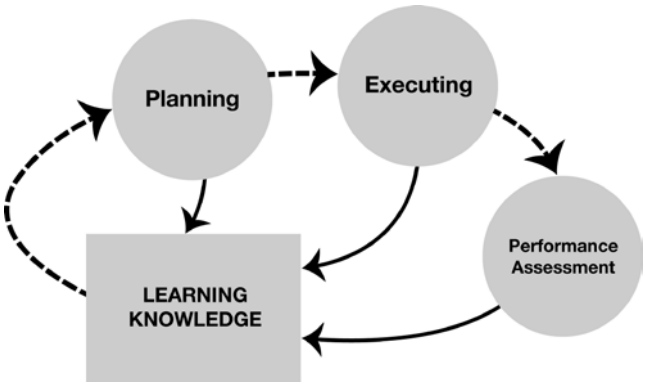

Figure 1. Learning Knowledge Feedback Loop

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 we propose to develop a model for the design of a collaborative learning environment. Our focus is designing a knowledge creation process that results in a superior physical (built) product.

The context of a knowledge creation process miust be accompanied by an understanding of the nature of knowledge, which we define as explicit or tacit, (Polanyi,1958; Nonaka and Takeuchi,1995). 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.

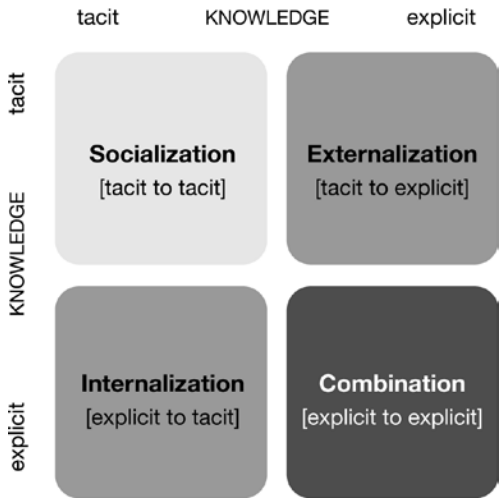

Figure 2: Modes of Knowledge Conversion (adapted from Nonaka and Takeuchi, 1995)

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). Our model needs to recognize and operationalize this process. The specific realization of this knowledge conversion process will vary from project to project. However we can develop some generic example. 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.

4. Learning Modules

This project addresses the problems arising from professional differences by adding lessons to existing Architecture, Construction, Engineering courses. The objectives of these lessons is to have the participants in a project more aware of the perspectives, requirements, and objectives of each party involved in a project. During this project there would be approximately 20 students from each discipline. Since lessons would be introduced into both semesters of junior level courses, there would be a total of six lessons to be taught to all sixty students participating in the project. The lessons are being developed initially as six learning modules distributed over the academic year.

While all three of the departments - Architecture, Engineering, and Construction Engineering Management – support the project, it was concluded that designing new courses would be inflexible and thereby prohibit implementation. The existing engineering, architecture and construction curricula make the accommodation of additional courses very difficult. As a result the curriculum content is being developed as portable 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 construction, assembly or project implementation.
In "The Knowledge Creating Company" Nonaka and Takeuchi speak about methods of knowledge creation and conversion. 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, and at the root of this project, 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.

One module each semester would be focused upon communication (knowledge conversion), mediation, and the social aspect of tolerance, subsequent modules would put these concepts into practice, as well address the action-based questions. The first module of each semester would be presented individually to each discipline. The subsequent modules would be taught to multi-disciplinary groups of students.

Module One: How do you ask the right question and get the right answer?
The first module will be administered to each of the three disciplines individually. The focus of this teaching unit is modes of communication, explanation and deliberation. Content will include modes of verbal, graphic and written communications. Case studies will include case studies of both good and bad methods and their outcomes, the differences between informal communication tools versus contractual materials, and good models for integrated project delivery. The primary learning objective is providing the students with clearer methods and communication paths to achieve the subsequent group work. Success will be evaluated based on student understanding of broad communication methods and specific understanding of how different communication methods both serve the AEC process.
Module Two: How do you navigate a process of specialized tasks?
The second module will be administered as a cross-disciplinary group project. The focus of this teaching unit is project delivery. The project will ask, "What do you need to do to get a project done within a limited time-frame and budget?" The project objective will require all the students to engage all phases of work including design, acquiring material, distributing labor, and execution. The objective of this unit is to help student see the benefits and shortcomings of a sequential process wherein team members engaged in the preceding and/or subsequent steps shape the outcome. Students will be asked to measure how closely the outcome is to the original design intent. Success will be evaluated based on the product outcome, individual student self-assessments and their ability to formulate a revised plan of action toward an improved outcome.
Module Three: How do you produce a better outcome?

This module will be a group project focused on the quality of an outcome. The focus of this teaching unit is measures of precision, performance, and craft. Case studies will include discussions of fine and rough tolerances, benchmarks for success and their variations through the design, engineering, and building trades. The project will ask, "What do they (other disciplines/trades) need to know from you in order for you to do your job well?" and, "What do they need to know from you in order to do their job well?" The objective of this unit is to help students understand the impact of properly aligned and misaligned tolerances and processes (as well as practice and experience) that are needed to produce a finer quality of output. The project will work toward a small to medium size construct wherein the level of craft will be balanced against the level of completeness (i.e. precise, but unfinished products will be weaker than a product that is moderately precise, but more complete). Student submissions will include the product as well as a narrative of the benchmarks established for design, engineering and construction.

Module Four: Buy-in, incentives, and risks.

The module will again be administered to each of the three disciplines individually readdressing methods of effective communication. Some detailed lessons regarding graphic tools and diagramming will be presented. The other content will discuss how to create buy-in between disciplines, risk assignment and management. Case studies will include recent models of integrated project delivery using BIM where integrated building documents are promoting smoother delivery and greater process economy. The primary learning objective is to develop communication skills that move beyond project delivery to project management and leadership. Answering, "How do I get you to invest in my goals?" Since this is best measured in an actual project outcome most of the module's assessment will follow from the two subsequent project-based modules.

Module Five: How large are your shoes?

This group project module will ask students to temporarily visit the goals and priorities of their peer groups. Construction Engineering Management (CEM) and Engineering students will design, Architects and CEM students will do engineering, and Architects and Engineers construct and manage. Several design/build projects will serve as precedents for this learning unit. The primary objective of this unit is to help students in all three groups to better understand the methods and modes of their peers with secondary goal is to create new bridges for communicating project intent and way-finding.

Module Six: What do you know? How do you know you know it?

The preceding group projects will be short and intense with development and execution taking place over one to three days. The final group project of the series will be longer, larger in scope and be preceded by a sequence of discipline specific tasks that require an information feedback loop between the team members. Students will record their communications and pass along content using project-dedicated blogs. This will be the most complex project with each student group demanding more discipline-specific input toward the final product. The objectives of this module are broad, with the intent that students practice the methods of collaborative conceptualization, calculation, and construction required to develop and deliver a compact but complex construct large enough to accommodate six adults in a standing position. Team roles will be more carefully defined, and allotted, than in previous projects: assessment will ask students to make both quantitative and qualitative records of their team members' efforts and effectiveness. The project outcome will be assessed for each component as well as the final artifact/construct.