Team Integration through a Capstone Design Course Implementing BIM and IPD

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Abstract

In recent years rapidly growing technology and project delivery methods such as Building Information Modeling (BIM) and Integrated Project Delivery (IPD) have had a significant impact on the building industry. As a result, practitioners and academia are beginning to realize that educating future engineers in these areas is a necessity. While it is unreasonable to expect that academia can fully duplicate industry practice in an educational setting; it is possible to develop specialized skill sets within students by implementing a focused problem-based environment.

This paper describes the first two years and proposed improvements for a third year offering of a multidisciplinary pilot program within Architectural Engineering (AE) at Penn State University. The primary discussion will respond to the concern of the current lack of multidisciplinary team collaboration in capstone courses as well as describe the reasons and methods behind the Penn State AE pilot. Emphasis within the course is on the interdisciplinary approach to design, with the BIM platform as a facilitator. This paper includes a discussion of the course deliverables, student generated trends in analyses, lessons learned, course management techniques, and a plan for moving forward for the third year and beyond such that other academic programs can gauge how best to incorporate BIM into some aspect of their curricula.

1. INTRODUCTION

The current standard for the senior design capstone course within the Architectural Engineering (AE) Department at Penn State is to have individual projects that span both the fall and spring semesters. Individual projects encompass a large degree of discipline focused depth work, eg. structural design, while somewhat limited breadth activities, eg. HVAC or electrical systems, in other building systems disciplines. Often closely related to the depth topic, these breadths are incorporated in part to address specific design related ABET outcomes and guidelines. As a result of the rapidly expanding technology and ideology of BIM and IPD on the AEC community the AE department developed and implemented a pilot capstone design program by creating multidisciplinary collaborative groups from each of the department's four disciplines.

The basis behind the formulation of the BIM pilot course created focused on the creation of a team atmosphere for collaboration, while maintaining the Problem Based Learning (PBL) approach that is a key component of the current program. One of the concepts incorporated into the format of the course using BIM is the idea of T-Shaped people which was described by Messner et al. (2010) for a similar studio initiative at Penn State. For the integrated capstone

pilot program Solnosky and Parfitt (2011) generated a similar idea regarding the T-Shaped people which state that individuals are deep in at least one field of study while knowledgeable in many others as well as employing a shifting in the learning curve in the academic sector similar to the shift occurring in industry. Often architecture and engineering curriculums work exclusively in the Schematic Design (SD) phase with the possible exceptions of capstone/senior design courses. However, in the case of BIM and IPD they allow for a shifting in the curve to the right. This rightward movement, as depicted in Figure 1 and compared to the industry shift, allows the team to address design questions that are generally associated with the Design Development (DD) phase or even the Construction Documentation (CD) and Facility Management (FM) (Denzer and Hedge 2008).

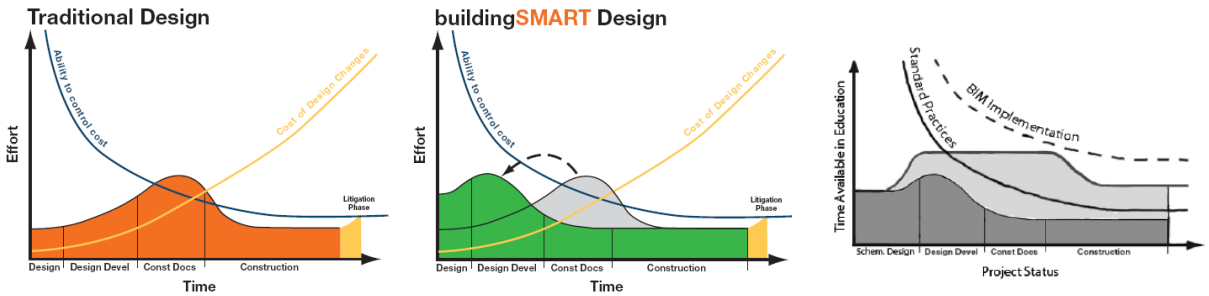


Figure 1: Comparison of Traditional, BIM/IPD industry and BIM education (McGraw-Hill 2007; Solnosky and Parfitt 2011).

2. FOUNDATIONAL BASIS O THE PILOT PROGRAM

As these concepts of T-Shaped people and the shifting of the curve to the right are applied in academia to the core of a new pilot program, proper structuring of the teams and assignments are needed to mimic and drive the results in the ideal direction. It was determined that for the pilot program, the four disciplines represented within Penn State's AE Program (Construction, Lighting / Electrical, Mechanical and Structural) continue to represent the depth areas while the integrated team as a whole binds the various disciplines to the breadth through a BIM platform. Team selection was implemented through a rigorous process in which the teams were balanced between software skills, knowledge level of discipline, previous BIM experience and a questionnaire related to personal work preferences. Details on how the teams were formed and the importance of the factors involved are described in detail by Holland et al. (2010), Parfitt et al. (2011), and Solnosky and Parfitt (2011). With the broad setup and structure of the course in place, the next step was to refine the learning objectives and develop the deliverables centered on team goals. By incorporating BIM and management techniques, a mutual theme was created shared by all team members which focuses on the interdependence of each building system and in turn affects the concepts to be explored within a particular discipline. With BIM assisting in the shift of the level of development, this concept allows for the possibility of students to consider late design, construction, and FM aspects of a project as appropriate. The deliverables developed, which are discussed in the next section, were created to include these late design areas.

3. LEARNING OBJECTIVES

As previously discussed, the basis of the pilot was to use IPD and BIM concepts to drive the course. As a result, it was necessary to clearly define learning objectives to help insure that students would acquire specific and desirable new skills. A fine balance of what was expected or required from students while maintaining the freedom of the team to explore self-generated team oriented goals needed careful crafting so as not to limit one or the other. Many of the learning objectives have a basis in the traditional AE capstone course while additional objectives were developed specifically for the pilot. A representative list of objectives for the BIM pilot are summarized as follows:

- Mimic, through examples, how system design choices affect other disciplines and the timeline of a project;
- Obtain the realization that the project team as a whole comes first over individual goals or recognition;
- Gain a better understanding of the BIM / IPD process including the management of the technology and associated information;
- Obtain a more powerful skill set revolving around modeling tools;
- Increase knowledge of discipline depth;
- Develop proper work processes and information sharing paths; and
- Become proficient in team communication, technical writing and speaking skillsets.

Specific individual and team assignments were created leading to student generated deliverables based on the learning outcome or objective.

4. REQUIRED DELIVERABLES AND EXPLECTATIONS FOR LEARNING

Similar to the traditional (individual) capstone course, it was determined that fall semester course deliverables should include three primary technical assignments and a proposal of what the open-ended spring semester will entail:

- Existing Conditions Confirmation and Modeling (Assign. 1)
- Alternative Schematic Systems Design Review with BIM Model Integration (Assign. 2)
- BIM Process Model Review and Procedural Evaluation (Assign. 3)
- Spring Semester Team Proposals (Assign. 4)
- Final Design and Execution of the Proposal (Assign. 5)

In addition to the technical assignments, a series of smaller project management tasks (communication and record keeping, etc.) were also assigned, including weekly meeting minutes, project specific website for managing information, ABET documentation, display posters of the projects and the final outcomes and surveys on effectiveness of the teams and the course.

In Assignment 1, students work together, particularly those in the same discipline, to populate and edit the overall electronic building model in an effort to better understand the building systems as well as re-familiarize themselves with the BIM tools they will use as they create a baseline model for future assignments. The basis of Assignment 2 is to have students work within their teams to research the design and construction of similar buildings or building systems, including calculations as appropriate, with an emphasis on generating new ideas for

potential building alternatives. Assignment 3, requires each team is to revise and fine tune their alternative conceptual design and construction ideas. Having generated the conceptual design information the teams work through the BIM Process Modeling Procedure (CIC 2009). The basis of this assignment is for the students to understand how collaboration and timely information sharing is critical to development of a process, which includes their spring semester work.

The previous alternative design ideas from Assignments 2 and 3 are revised based on feedback from faculty and outside practitioner consultants for Assignment 4. Student generated alternative technologies and goals for the building are discussed in a report and a presentation to the faculty for approval for spring semester. The teams are provided reasonable leeway in changes to the program as new ideas and limitations are encountered in the spring.

5. TRENDS RESULTING FROM STUDENT OUTCOMES

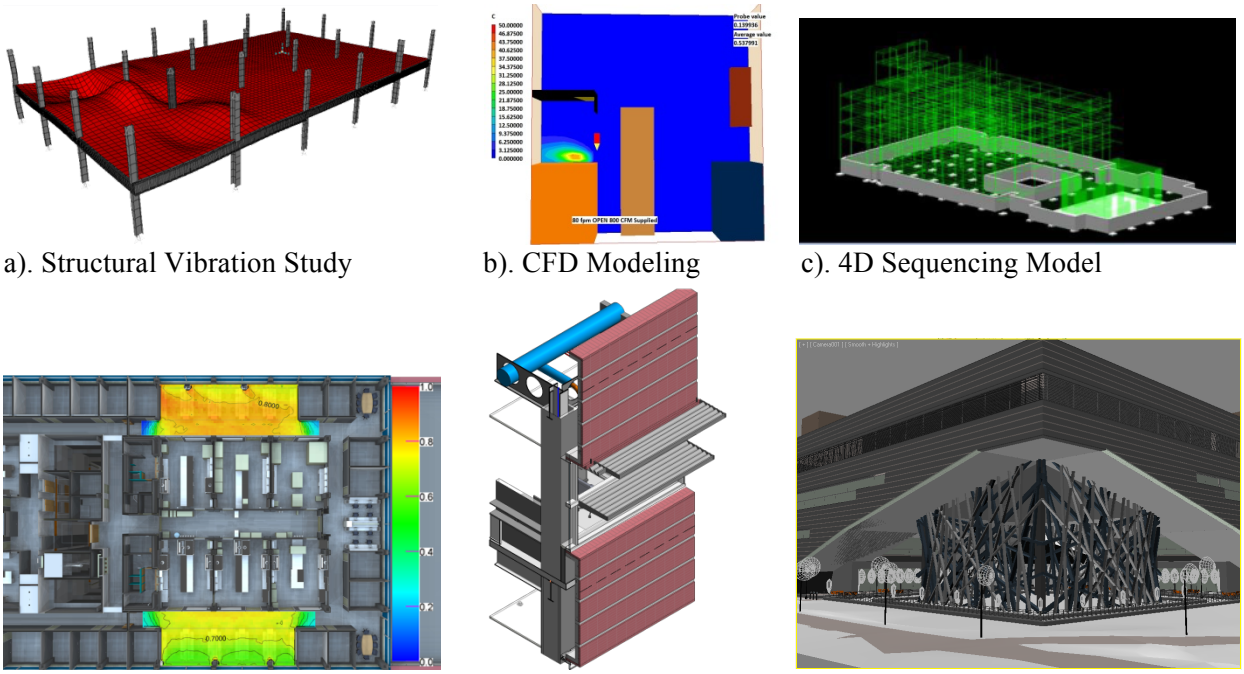
In both the fall and spring semesters the requirement for specific deliverables allowed for individual discipline depth investigations while also ensuring adequate integration for a more collaborative outcome across all systems. It was observed that a number of cross disciplinary trends occurred, and are illustrated in Figure 2, as a normal part of the educational process including:

1. Systems integration across disciplines
2. Advanced computer modeling skills were developed
3. Optimization or reconfiguration of systems

Systems integration across disciplines is the most collaborative among the three trends. Student generated designs require the input of at least two team members but can have as many as four providing input and suggesting design considerations. Topic studies that have been common over multiple teams and years to date include: architectural concept and façade redesigns, lighting and electrical system control design, lighting and mechanical system integration, Computational Fluid Dynamics (CFD) studies, structural system optimization, constructability aspects of building systems, sustainability studies, and detailed installation constructability through clash detection analysis.

Advanced computer modeling technology use was the second most prevalent trend that resulted in the teams. This does not come as a surprise considering much of the capstone learning experience involves BIM and related technology. The generated outputs organized into this area rely on computer modeling through analysis, design, and simulations of the project for different purposes. The models can be used collectively for the group decision making or customized for more discipline specific studies. Model uses have been common to date in this trend match the systems integration topics. This is unsurprising due to the modeling platform as the design integrator. Yet there are subtle distinctions between the two, primarily with advanced modeling having much more technical depth.

Optimization and reconfiguration of systems, the third trend, primarily takes place within individual disciplines. However this trend is present as a subset of the first two trends mentioned as to achieve these results often systems optimization needs to be conducted to maximize the potential for multiple players.



a). Structural Vibration Study b). CFD Modeling c). 4D Sequencing Model

d). Useful Illuminance Study e). Façade System Design f). Architectural Feature Creation

Figure 2: Student Generated Course Deliverables Integrating BIM and their Disciplines

At the conclusion of the spring semester, all three teams present their project findings to a jury of faculty and peers as shown in Figure 3. After reviewing each of the three presentations technical and team collaborative content, the faculty jury selects the top two teams to present to an invited, outside, jury of practitioners which are experts in their field as well as knowledgeable in BIM.

Figure 3: Final Spring Presentation by Students to Faculty and Peers

6. SURVEY RESULTS AND OPEN-ENDED FEEDBACK

A series of surveys developed by the authors and with the help of the Penn State Industrial Psychology Department were used in addition to verbal feedback from students to study the effectiveness of the pilot program. The surveys are broken into four distinct categories for evaluation. The categories are: peer evaluation survey, team performance survey, IPD/BIM and technology survey, and general course feedback survey. The metric used for all surveys follows a 5 point Likert Scale where 1 is strongly disagree, 3 is neutral and 5 is strongly agree. For brevity, only the team performance and IPD/BIM technology surveys for both years are included in the discussion that follows.

The team performance survey consisted of twenty three questions designed to measure five important factors found in high performing teams: Team Vision, Participative Safety, Support for Innovation, Task Orientation, and Task Cohesion (Holland et. al 2010). The results of this full survey were only collected for year 2 of the pilot and can be seen in Table 1 where they are broken down by team and also by discipline for comparison. The IPD/BIM technology survey was developed such that there are ten questions to measure the student's response to the Integrated Project Design / Delivery Process and eleven questions to measure response to BIM technology. Table 2 results represent a few selected questions from the survey that were determined to be the most relative to the evaluation of the deliverables from a learning and team approach. The format for Table 2 for teams is team number (T#) and Year number (Y#).

Table 1: Team Performance Survey Results for Year 2 (mean averages)[1]

	Team 1	Team 2	Team 3	Struct.	Mech.	L/E	CM
Team Vision	4.45	4	4.75	4.27	4.67	4.2	4.47
Participative Safety	4.2	4.55	4.5	4.47	4.53	4.2	4.47
Support for Innovation	4.3	4.4	4.45	4.67	4.33	4.2	4.33
Task Orientation	4.19	4.25	4.63	4.83	4.25	4.25	4.08
Task Cohesion	4.17	4.67	4.67	4.78	4.44	4.22	4.56
Overall Mean	4.26	4.37	4.60	4.60	4.45	4.21	4.38

Table 2: IPD/BIM and Technology Survey for Years 1 and 2(mean averages)[2]

	T1Y1	T2Y1	T3Y1	T1Y2	T2Y2	T3Y2
It was easier to design using IPD	-	-	-	3.5	3.75	3.75
Early understanding and agreement on workflows is critical to successful IPD	-	-	-	4	4.75	3.5
Understanding of "lead/lag" and interdependency is critical to successful IPD	-	-	-	4.5	4.75	4.5
Using IPD I gained a new understanding of other disciplines	-	-	-	4.5	4.75	4.5
Creating and sharing a BIM was relatively easy	2.75	4	2.5	3	3.5	3
Our actual workflows turned out to be similar to our plan	2.75	2.25	2.5	3.5	2.5	3
BIM improved the coordination and quality of our design	-	-	-	4	4.25	4.25
Using BIM increased the productivity of my time	3.25	3	2.25	3.25	3.25	3.75

The team performance survey results show that the pilot program is working effectively as an integrated team working towards a mutual goal based on the mid to high scores (4.26-

[1] For teams all have an n=4, for disciplines all have an n=3, all values are means unless noted otherwise.
[2] For teams all have an n=4, all values are means unless noted otherwise.
The values listed are an average of the four disciplines response to the question listed.

4.60). A particularly interesting aspect is that Team 1 and Team 3 made it to the final practitioner presentation and they have the highest and lowest average. The highest average was an expected result. The reason for the success of the lowest average team is attributed to the fact that Team 1 had a much stronger technical competency as compared to Team 2.

The IPD/BIM and technology survey was distributed at the end of the spring semester only, resulting in students summarizing a year's worth of reflections. The results vary considerably from question to question. This is likely accounted for by the semi-subjective nature of the questions themselves and how they are interpreted. Looking at the results from the survey we can see that both BIM and IPD did not increase the productivity and make the individual design easier as a result of having to compromise with other team members on design decisions. All teams responded agree to strongly agree that knowledge of work paths and the lead/lag of a design with multiple disciplines is critical to success; this is often left out of engineering education and first seen in practice. A particular note of interest is that the first year had, primarily, lower scores for model sharing as compared to the second year. This result has been attributed to the file size, complexity and format of the models. Year two had a much smaller building and base models to start with, and also received more training with BIM related software, a direct result of feedback collected from the first year students.

Upon completion of the two sets of final presentations and in addition to the survey results, verbal and written feedback was collected from each team and the jury members. The feedback from these sessions describe the positive aspects of what is working, what improvements can be made to better the educational experience, and what has not worked. This information is discussed below and will be used to enhance the third offering of the course.

6.1 Faculty Feedback and Comments

- The quality of the work, level of integration, and overall accomplishments exceeded expectations of all faculty present;
- Faculty time for the course administrators increased, rather than decreased, as a direct result of the many group and individual tasks to be managed;
- Student goals were centered on the team and aimed at providing a better end product for the owner; and
- Students learned by cooperation and coordination in a manner similar to what occurs in industry practice.

6.2 Practitioner Feedback and Comments

- Practitioners nearly unanimously recommended giving serious consideration to making this a requirement for all students;
- Acknowledged that the unbalanced numbers of students in the all options of the general class population will make it difficult to assemble teams if all students are required to participate;
- Students should be exposed to current BIM technology, planning and information management techniques and discipline specific software; and
- Practitioners acknowledged evidence that the student teams were well aware of the standard deliverables needed between disciplines as a part of the BIM process and that such knowledge would be a valuable asset when the students arrive in industry.

6.3 Student Feedback and Comments

- Felt pilot course gave those involved a chance to see firsthand how an integrated project team works together and achieves a common goal;
- Felt the overall experience made them more marketable to the profession during the search for their first full time position;
- Every student stated that if given the chance to participate in the pilot program again, they would;
- Students recommended having the other BIM team course (BIM Architecture Studio) be a prerequisite for this course;
- Noted that there is a misalignment between certain discipline requirements in regards to what the teams should be working on from a technical perspective as compared to keeping technical content the same as the individual capstone course; and
- Commented that, in the list of deliverables for technical reports and presentations, that a more specific set of guidelines of expectations should be provided. And, requested that more suggestions from faculty on team collaborative design areas that are innovative be provided.

Overall, positive atmosphere and feedback demonstrates that all three groups are in support of the pilot and how it is shaping the students to engage in team activities. The industry was particularly happy with how the students were creating very integrated designs while also experiencing some of the struggles that the practitioners themselves face from a technology standpoint. Feedback also points out some of the continued struggles with implementing a pilot: some students wanted more direction or guidance in how to begin tasks while others felt like they were doing unnecessary work, more related to the current individual capstone course. It has been confirmed that for this capstone pilot the faculty required involvement and time has gone up, including issues related to common scheduling times to meet and discuss projects. Overall, despite the remaining roadblocks, it has been concluded that the pilot produces an excellent capstone featuring cohesive and comprehensive team projects.

7. MOVING FORWARD AND THE THRID YEAR

Reviewing the results from the first two years shows trends and results are similar between the two offerings, with improvements noted in the second year. Overall, the team aspect and function of the course is effective in exhibiting the desired outcomes. The development of the assignments around a building that has already been fully designed, and in one case fully constructed at the time of the program, is confirmed as an effective tool in student learning. Assignments used are appropriate to achieve the desired objectives

This format, however, may limit aspects of creativity and freedom to explore trial designs from scratch to mimic the initial process of system comparison for selection. To try and incorporate this aspect of the design process, the third year of the pilot program is going to explore a slightly different direction. The direction chosen will be framed around a project where the students will be given the architectural model/design at the Design Development (DD) level, with limited existing engineering systems information. Each team will begin the design from that start in the fall semester. As a result, a secondary goal is to see if such a model is capable of producing results that will correspond to the design curve shifting as mentioned previously. To educate the students on how initial system selection occurs, the actual project team for the chosen building has agreed to give lectures and seminars on the primary disciplines including what considerations and tools are used in selecting systems.

8. RECOMMENDATIONS FOR INDUSTRURY AND ACADEMIA

Based on the feedback from the integrated collaborative team capstone thus far, it is believed that the pilot capstone model is an excellent tool in training young engineers. Based on literature reviews, it is noted that many in academia are still hesitant to adopt BIM and IPD practices into their courses. Our experience to date demonstrates that industry is urging academia to continue to move forward in this manner. To date, this pilot program has incorporated multidiscipline teams in a capstone project and generated many positive results, including team based and technology based skills. The authors feel the teaching model and lessons learned can be applied to fit a variety of other capstone courses customized to individual institutions and departments.

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