CONNECTING TECHNOLOGY, INDUSTRY AND RESEARCH: A MECHANISM OF CURRICULUM INTEGRATION FOR BIM EDUCATIONAL OPPORTUNITIES

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ABSTRACT

**BIM** is utilizing CAD technology in a way that ultimately ties all the components of a building together as objects imbedded with information, and has been changing the way we design and build over the last 20-30 years. In Polytechnic Institute of NYU, there are four BIM courses offered which provide students with different levels of knowledge regarding BIM Technique, BIM Standards, BIM Guideline and Roadmap for Private and Public Implementation, BIM Application in Real Projects, the Cooperation of BIM and IPD for Public Works in New York City. With advanced BIM technology, BIM’s integration into the construction process and its incorporation into project delivery systems, especially Integrated Project Delivery (IPD) are the bridges between technology, industry and research. This paper presents an integrated BIM curriculum with three modules: 1) BIM functions and Bid Preparation; 2) Time-Cost Trade-off Analysis; and 3) Problems Solving in BIM/IPD Environment. In this project-based curriculum developed by the common efforts of academia, public agency and industry, the objectives are: 1) to provide the information and skills needed to successfully implement BIM into the construction phase; 2) to identify BIM’s role in construction and the project delivery system; 3) to develop a module in conjunction with leading BIM into project delivery system, particularly coordination between BIM and IPD; 4) to connect technology and research into industry. The course assessment was conducted and the results indicate that it is a successful reform in construction management education.

**Keywords:** BIM, Curriculum Integration, Project Delivery System, IPD

1. INTRODUCTION

BIM is becoming a huge success in design and construction firms worldwide, yet its true value remains in fully implementing BIM across the life cycle and bringing its full benefits to the industry by increasing technology use. BIM is changing the way projects are built and how business is conducted. We still have a long way to go before construction industry changes the business process. In addition to our standards and guidelines, the academic curricula also need to change to suit the construction industry culture change.
Educational institutions in many countries have started teaching BIM applications and have set up curricula for BIM related to the architect/engineer/contractor (A/E/C) industry. In the US, several educational government organizations are introducing BIM in their curriculum (Taylor et al, 2008; Autodesk, 2007; Wong K. A., 2011). There are a few ongoing modeling courses being offered at major universities in the US and a few shorter training courses in institutions and associations. But it is noted that the courses for BIM are more focused on the BIM applications and software products, and those courses concentrate on design domains and seldom the construction management of project delivery.

A vertical integral project course for BIM education was designed for the graduate construction management major at the Polytechnic Institute of NYU with four objectives: (1) to provide information and skills needed to successfully implement BIM into construction; (2) to identify BIM’s role in construction and project delivery system; (3) to develop a module in conjunction with leading BIM into project delivery system, particularly coordinating between BIM and IPD; and (4) to connect technology and research into industry. The course described in this paper was designed through a joint effort of NYU academic senior professors, the New York City Department of Design and Construction (DDC), the W.J. Northridge Construction Corp. and Group PMX in New York who are representing public project owner, designer and contractor respectively in this academic environment.

2. RATIONALE FOR THE INTEGRATED BIM COURSE

The goal of this integrated BIM course is to teach BIM in a way that transfers knowledge and skills in construction to solve real problems in a constrained project delivery environment. Several factors are essential for this integrated BIM course:

1. A broad understanding of basic BIM concepts, the available technology, its functions, legal constraints and insurance issues.
2. Identification of information and skills needed to successfully implement BIM into construction.
3. Determining BIM’s role in various project delivery systems, especially as aided by IPD principles.
4. A connection among academia, research and industry, and the connection among technology, knowledge and practices.

Skill learning and problem solving are two main domains in this course that use a case study project and participants for lectures and workshops. The request for proposal (RFP) constrained by New York State Law, issued by a case study public project owner, the New York City DDC, provides the public procurement environment to test the applicability of BIM technology and IPD principles for collaboration among all stakeholders to add value to the project and to benefit all case study participants. The case study project is the Systems Management Engineering Facility III (SMEFIII), located on the Hanscom Air Force Base in Bedford, MA, a three-story, 100,000 square foot steel framed masonry building constructed in 1986. Students will receive a 3D model of SMEFIII, consisting of over 100 drawings. Extrapolating from the 1986 engineer’s estimate of approximately ten million dollars, the case study estimate to construct the same building today is about $20 million. Particular location details of the case study building included special requirements for site access, material deliveries and work hours that would affect productivity. Figure 1 is a photograph of SMEFIII sometime after completion.

AutoCAD Revit Architecture and MEP suites were used for modeling (Figure 2). Autodesk Revit Architecture software is BIM software that promotes visualization of design options. The ability to change a schedule and automatically update the model is a key benefit of Revit Architecture, Revit Structure and Revit MEP (Autodesk, 2010). Given the 3D models in Revit formats, students are
responsible for performing various typical construction management functions with the model and all other relational databases. Three modules were designed in order to reach the course objectives. In module one, students are responsible for preparing the cost and schedule simulation for SMEFIII and submitting the bid based on the requirement stated in the solicitation issued by the owner, DDC. From this module, students will consolidate the modeling techniques, cost estimating and scheduling. In module two, Time-Cost trade-off analysis will help students understand the nature of construction, with many uncertainties and under many situations. In module three, a series of problems related with construction changes and design errors are given to class. Students are responsible for solving the problems using BIM technology and IPD principles.

3. EDUCATIONAL MODULES

3.1 Module 1: BIM functions and Bid Preparation

This Module follows a traditional project-based BIM course in which students improve the model and perform BIM functions. Since this course has two prerequisites, Construction Modeling Techniques and Construction Operations Using BIM, students are getting used to BIM and BIM-related software applications, some of which are available online via the class webpage and others directly from the software providers. Some of the software applications are Autodesk Revit and Navisworks, and Primavera Project Planner (P6) from Oracle. Microsoft (MS) PowerPoint presentation tutorials prepared by teaching assistants (TAs) provide easy to follow, step by step support.

For the first ten classes, the students are assigned to four-member teams. Each team is assigned the role of general contractor and is responsible for the following:

1. Develop a cost estimate for the project using the provided preliminary BIM model, including a work breakdown structure (WBS) for the project, allowances for not yet designed elements in the model, and prevailing wage rates for Bedford, MA.
2. Create a base schedule and alternative schedules, including WBS, a Budgeted Cost of Work Scheduled (BCWS) from 0 to 100 percent, and a labor resources usage matrix.
3. Produce a 4D model of the project based on daily progress that demonstrates the concepts for the project’s construction.
4. Prepare a construction management proposal, being as specific as possible, as to how to employ BIM and IPD.

Each team is acting as a general contractor and is required to submit a sealed bid, containing one original and two copies, to a specified office by a specified time. All bid requirements are stated in the solicitation form.
Lectures address planning, development, design, pre-bidding activities, bidding strategies and construction, including the challenges to be anticipated in each of these phases. Scheduling and cost estimating workshops are conducted to help students to:

1. Integrate schedules with the model using Primavera P6 and Navisworks;
2. Understand and demonstrate the concept of simulation;
3. Understand procurement and bid strategy models, and prepare a proposal and presentation.

3.2 Module 2: Time-Cost Trade-off Analysis

A time-cost trade-off analysis is a major endeavor for complex and large-sized construction projects. Schedule crashing is a technique used to reduce the duration of critical path activities by allocating more resources or changing the scope of the activities, without reducing quality, to meet a specific deadline with the least incremental cost (Gelisen, 2010). Total project cost is the sum of the direct and indirect costs of performing the project activities. Direct costs for the project are those associated with project activities such as labor, material, equipment, and subcontractor costs. Indirect costs are those which are not associated with any particular activity or a specific project, which includes both project indirect costs (e.g., general conditions costs) and home office overhead costs. Increasing the productivity of an activity to decrease project duration may increase the project direct costs, if more resources are consumed to accelerate the activity. But the indirect cost will decrease by decreasing the project duration.

The solicitation for SMEFIII issued to the class requires each team to prepare the base bid with a schedule duration of 545 days (18 months), and two alternative bids at 455 days (15 months) and 365 days (12 months), respectively.

<table>
<thead>
<tr>
<th>Days</th>
<th>Direct Costs</th>
<th>Indirect Costs</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>365</td>
<td>$13,190,786</td>
<td>$6,042,271</td>
<td>$19,233,057</td>
</tr>
<tr>
<td>455</td>
<td>$12,084,600</td>
<td>$6,519,822</td>
<td>$18,604,422</td>
</tr>
<tr>
<td>545</td>
<td>$9,960,062</td>
<td>$6,847,829</td>
<td>$16,807,891</td>
</tr>
</tbody>
</table>

Table 1: SMEFIII Direct, Indirect and Total Costs for Three Schedules

The project time-cost relationship can be represented graphically by plotting project duration against direct, indirect and total cost values. One team’s results are shown in Table 1 and Figure 3.

Reducing the duration of the project by 16.5% and 33% increases the total cost of the project by 10.7% and 14.4%, respectively.

In week ten, all teams submit bids with their base bid and two alternatives bid and the proposals to illustrate the strategies used to compress the schedules. The project owner is assumed to be DDC, which is a public agency, and the project is awarded to the lowest responsible and responsive bidder. The successful bid is used for the next module of the course.
3.3 Module 3: Problem Solving in BIM and IPD Environment

The last five weeks of the course are devoted to various fact patterns or “situations” designed for the students, acting in the roles of archetypal participants - owner, designer, contractor - to implement principles of IPD and BIM. Student teams are reconfigured for the IPD environment experiment. Each team is comprised of an owner, a designer, a contractor and a subcontractor. The following player guides are given to each team:

Owner Guide:
1. You feel you cannot relax the requirement to complete SMEFIII in one year. You gave your word to the user.
2. You have a 5% contingency ($800,000) available to cover increased costs.
3. Quality cannot be compromised.
4. You want to be fair with all parties. For this project to be successful, it must be successful for all parties.

Contractor and Subcontractor Guide:
1. You have to make money on this job. Losing money is not an option. You made a fair bid for a reasonable price.
2. You want the owner to have a successful project and you are willing to do everything possible to achieve the scheduled completion date, except violate the first point.
3. Quality cannot be compromised.
4. You want to be fair with all parties, as long as you do not violate the first point.

Designer Guide:
1. You have been paid your design fee and are being paid for providing design services during construction. You are responsible for ensuring that the contractor satisfies the design intent (i.e., you evaluate shop drawings and are responsible to the owner for quality control.)
2. You cannot lose money on this job. You run a low-cost operation and your credit is stretched to the limit. You took a mortgage on your house in order to finance your operations on this job.
3. You want to be fair to all parties, subject to the constraints above.

Once the integrated teams are established, the class begins the BIM and IPD experiment. The IPD method has all project stakeholders (owner, designer, contractor and subcontractor) involved in the construction process and all have an equal voice in project decision-making. The project teams must use BIM techniques and IPD principles to address the problems described in each of three “Issue Packages” set forth below (Table 2) in a manner that eliminates waste, saves time, improves productivity, and creates a “win-win” outcome for all the involved parties.

In the IPD environment, the student team acts as the project executive team. The project management team has been replaced, so that the day-to-day functions traditionally performed by the project management team are performed by the project executive team. The target cost for construction is the lowest responsive bid. Each of the three Issues Packages includes three construction issues, which the teams are required to resolve by using BIM coordination and IPD principles. Each week, for each Issue Package, the student teams present their solutions to the class and guest cast study participants and submit a written report.

<table>
<thead>
<tr>
<th>Issue package I</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Issue</td>
<td>Shop drawing submission has 2 weeks late.</td>
</tr>
<tr>
<td>Value Engineering</td>
<td>Foundation piles change from 12”φ to 10-3/4”φ.</td>
</tr>
<tr>
<td>Quality Control</td>
<td>Pile driving mistakes happen during construction.</td>
</tr>
<tr>
<td><strong>Issue package II</strong></td>
<td></td>
</tr>
<tr>
<td>Weather Issue</td>
<td>Heavy rain affects the construction process for 2 weeks.</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Payment Issue</th>
<th>Owner delayed payment to the contractor for 60 days.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Control</td>
<td>Efflorescence happens in the exterior brick wall.</td>
</tr>
<tr>
<td>Issue package III</td>
<td></td>
</tr>
<tr>
<td>Clash Detection</td>
<td>HVAC and Structure clash is found in third floor.</td>
</tr>
<tr>
<td>Clash Detection</td>
<td>HVAC duct conflict with Steel column with criteria 2”.</td>
</tr>
<tr>
<td>Scope Change</td>
<td>Owner change scope by adding bridge linking to an existing building.</td>
</tr>
</tbody>
</table>

Table 2 BIM and IPD Issues Packages

4. COURSE EVALUATION AND RESULTS

The evaluations are conducted anonymously. Instructors receive a summary report of the multiple choice responses and text copies of written comments. The evaluation is divided into three parts: general course feedback; whether course objectives have been met; and additional comments. In response to each question in the first and second parts, students choose one of the following: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, (5) strongly agree. General course feedback part contains ten questions and course objective questions are shown in Table 3.

Some of the first ten questions are about the general course information are:
- The course was effectively organized to promote the learning objectives.
- Instructor demonstrated mastery of course material.
- The difficulty of the course was appropriate or as I expected.

Questions 11 to 14 are shown in table 3.

<table>
<thead>
<tr>
<th></th>
<th>I understand the concept of (3D) and (4D) Building information models (BIM).</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>I can integrate the schedule to the BIM model using Primavera P6 and Navisworks.</td>
</tr>
<tr>
<td>13</td>
<td>I understand the concept of simulation, cost estimating, scheduling, procurement and information technology.</td>
</tr>
<tr>
<td>14</td>
<td>I understand the process of Project bidding and project handling.</td>
</tr>
</tbody>
</table>

Table 3: Course Objectives for Course Evaluation

Evaluation results are summarized in table 4.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Survey</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td></td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>27</td>
<td>27</td>
<td>28</td>
<td>28</td>
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<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>5.00</td>
<td>4.71</td>
<td>4.79</td>
<td>4.79</td>
<td>4.93</td>
<td>4.64</td>
<td>4.57</td>
<td>4.79</td>
<td>4.79</td>
<td>4.64</td>
<td>4.79</td>
<td>4.79</td>
<td>4.86</td>
<td></td>
</tr>
<tr>
<td>STD</td>
<td></td>
<td>0.00</td>
<td>1.07</td>
<td>0.58</td>
<td>0.8</td>
<td>0.27</td>
<td>0.97</td>
<td>0.76</td>
<td>0.8</td>
<td>0.8</td>
<td>0.5</td>
<td>0.43</td>
<td>0.43</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Course Evaluation Result Summary.

Evaluation results indicate that the course format was a success. The course will contribute further to a better and more comprehensive BIM program that will advance the department’s goal to be a leader in the development of the future of construction education.

5. CONCLUSIONS AND DISCUSSION

This paper has provided an integral project course in the Polytechnic Institute of New York University. A number of universities around the world are offering courses on various applications of BIM. Such courses often focus on design domains and software products. New mechanism of curricular integration for BIM educational opportunities were discussed which include three modules from the BIM
techniques to incorporate BIM and IPD. To implement BIM efficiently, one has to consider the real projects and the issues that most likely occur during the construction. Using BIM to solve complex and sophisticated problems will naturally lead to its use in collaborative settings in project delivery system.

BIM is being gradually and systematically introduced at many academic universities and research institutions to cater to the requirements from the A/E/C industry and to facilitate project delivery system. The integrated project course may be used in universities at other places as well. Assessment and course evaluations from the industry and from students showed positive results towards the BIM education in terms of its perceived benefits and further improvement of BIM education.

REFERENCES


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