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COLLABORATION AND COORDINATION LEARNING MODULES FOR BIM EDUCATION

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SUMMARY: *Building Information Modelling (BIM) is the trend of the future, with increased use documented in the construction industry in the last few years. To sustain the momentum of BIM, effective workforce development that aims to balance the supply-demand equation in the labor market is essential. For many, experience with BIM begins in academia. The challenges reside in the classic gap between academic focus on disciplinary principles and the industry needs for specific application proficiency. As a result, architecture and civil engineering education needs to embrace the opportunities provided by BIM and overcome the challenges presented by BIM to remain current and relevant. A growing number of architecture, engineering, and construction programs have begun to offer courses that include BIM-related content, and a few programs have strategies in place to fully integrate it. This paper presents a modular approach adopted by the Department of Civil, Architectural, and Environmental Engineering at Illinois Institute of Technology (IIT) to promote BIM-enabled learning. Experiences in creating and adapting Collaboration and Coordination Learning Modules to BIM education respectively in the Construction Management and Engineering Graphics programs at IIT are presented and discussed. The content created to implement and facilitate the learning and understanding of BIM are evaluated. The objective is to educate the both the engineers and architects of the future who will be actively using BIM routinely. This strategy relative to BIM Learning Modules is expected to help architecture, engineering, and construction professionals be prepared for the needs of the industry in the future.*

KEYWORDS*: BIM, construction management, engineering graphics, learning modules, sample courses.*

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1. INTRODUCTION

As defined by the US National BIM Standards Committee (NIBS, 2007) Building Information Modelling (BIM) is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from earliest conception to demolition. BIM is also considered as the process and technology used to create the model. Regardless of the chosen project delivery method a BIM process can always be used. Because of the collaborative nature of Integrated Project Delivery (IPD), BIM processes and technologies can be a catalyst in design and construction. In a BIM process, communications are improved, risk is both shared and reduced, and better decisions can lead to increased profits and an overall better experience for the stakeholders.

A BIM process needs competencies based on a technology environment consist of software platforms and tools. However, BIM is a human activity that ultimately involves broad process changes in the construction industry based on both user skills and experience. Furthermore, delivery of building projects has become more complex and technically demanding. We need to recognize that all sorts of people populate the territory of BIM: (1) design professionals such as architects, architectural engineers, structural, civil and mechanical, electrical and piping (MEP) services engineers, specialists, subcontractor designers (cladding, building envelope design, MEP building services, and environmental technologies), specialist consultants (acoustics, environmental applications) and technologists; and (2) construction professionals such as the quantity surveyors, project managers, construction managers, planning consultants, regulation specialists and others those all have to be integrated into the project delivery process.

Understanding the importance of "I" -information- in BIM as the key, enhancing knowledge without practical experience which brings technology use into the arena, is not very persuasive. The technology is advancing in a rapid fashion. Although knowledge and skills can always be acquired and learned, the real skill needed is to adapt the change and see possibilities in new situations. Working with Building Information Models (BIMs) increases the skills and needs for collaboration of design and coordination of construction processes in terms of management practices.

Professional bodies, industry and academia are the key stakeholders of BIM education. It is the role of the professional bodies to represent the BIM professionals and create attractive job positions in the construction industry for those who are skilled and talented. They need to ensure that BIM is a career choice. The professional bodies accredit degree courses provided by universities, and then inspect them to ensure that they come up to their required published standards. There should be a dynamic interaction between the professional bodies and academia, which should be informed by the requirements of industry as the end user (Demirdoven and Arditi, 2014; Demirdoven, 2015).

A growing number of architecture, engineering, and construction programs have begun to offer courses that include BIM-related content, and a few programs have strategies in place to fully integrate it. This paper presents a modular approach adopted by the Department of Civil, Architectural, and Environmental Engineering (CAEE) at Illinois Institute of Technology (IIT) to promote BIM-enabled learning. The objective is to educate the both the engineers and architects of the future who will be actively using BIM routinely. The strategy relative to BIM Learning Modules is expected to help architecture, engineering, and construction professionals be prepared for the needs of the industry in the future.

2. LITERATURE

The concept of BIM is considered to be originated, from the work of Charles Eastman in the 1970's (Eastman, 1975; Eastman et al., 2008; and, Reddy, 2012). The SmartMarket Report (McGraw-Hill, 2012) shows a rapid increase of BIM usage in North America. The percentage of companies using BIM is 71%, increased from 49% (2009) and 17% (2007). However, the role of BIM is not fully understood neither in the construction industry nor by a large segment of educational institutions that specialize in architecture and engineering. According to the National BIM Report (2013) there is still further work to be done in regards to preparing the industry for full adoption of BIM.

Current literature and local research conducted with employers strongly indicates that skills associated with BIM will rank highly in skills demanded of future graduates in the built environment disciplines (McLernon et.al. 2015).

Educational institutions are either already providing, or preparing to provide, BIM education at both undergraduate and graduate levels. The industry's reluctance to change, and a shortage of experienced/educated BIM practitioners/ technicians/ educators is slowing the inevitable uptake of BIM in the AEC industry (NATSPEC 2013).

According to Turk and Gerber (2011), the rapid movement from CAD to BIM by professional architects, engineers and construction managers has created several challenges and opportunities for educational programs. Most of the programs started offering BIM courses during the 2006 to 2009 timeframe. Architecture programs started offering BIM courses earlier than the engineering and construction management programs.

Eastman et al. (2008) considered BIM professionally being used as a tool that allows users from multiple disciplines to create, share and view other designers/trades information relating to the project and to compile this information into one common database. Studies have cited one of the key benefits of BIM to be a tool facilitating collaboration across the disciplines (Azhar et al., 2008; Krygiel & Nies, 2008; Ku & Mills, 2010; Taylor & Olsen, 2012). It is important that education responds to this industry trend and leverage the technology to achieve multiple objectives across construction programs.

Studies also placed considerable emphasis on inter-disciplinary teams, group-work, integration and collaboration and Richards and Clevenger (2011) indicates that in today's integrated world, the necessity for architects, engineers and construction managers to have an understanding of each discipline's responsibilities and tasks is becoming increasingly important.

The SmartMarket Report of Dodge Data & Analytics (2015) on the impact of BIM indicates a growing consensus around key BIM benefits such as constructability improvement and better design understanding. As contractors continue to implement BIM the need for BIM knowledge and skills expected of construction graduates is increasing. The use of BIM for job site planning, 3D coordination, 4D planning, cost estimating, and safety planning have all gained momentum. The findings on success factors For the use of BIM on complex projects reveal that all respondents—owners, architects, engineers and contractors-see collaboration and teamwork as key success factors, but that the majority of the AEC respondents still do not prioritize the early contributions of other players.

Many of the outcomes of BIM are primarily related to design activities, such as "increased owners' understanding of proposed design solutions," "Improved constructability of final design" and "improved quality/ function of final design." Importantly, though, design-related improvements such as "generated better construction documents" drive better contractor engagement, which is suggested by the strong performance of "increased contractors' understanding of proposed design solutions." Their enhanced understanding contributes to numerous benefits later in the construction process, such as "improved ability to plan construction phasing and logistics," "increased predictability/fewer unplanned changes" and "reduced rework." The researches also show that BIM analysis and simulation capabilities produce a more well-reasoned design (Dodge Data & Analytics, 2015).

The only obstacle related to technology deployment selected as having a significant impact on the success of complex projects by more than half of owners, architects, engineers and contractors is lack of team member skills at using advanced tools and methods. A high percentage of engineers in particular (63%) consider this obstacle significant. The second most significant obstacle for AEC firms is insufficient technology training for inexperienced team members. The two top obstacles for AEC firms demonstrates that knowledge of how to use the technology across the project team, rather than the technology itself, is the most important obstacle for these firms (McGraw-Hill 2014; Dodge Data & Analytics, 2015).

Wu and Issa (2013) indicates that the underlying supply-demand relationship between universities and the industry has been more reliant on students' intellectual and technical readiness, especially in the case of BIM. Therefore, the effective inclusion of BIM into college curriculum has become both a pedagogic and practical imperative in preparing future employees for the AEC industry (McGraw-Hill 2009; and, Crumpton and Miller 2008).

To equip current and future industry professionals with the necessary knowledge and skills to engage in collaborative BIM workflows and integrated project delivery, it is first important to identify the competencies that need to be taught at educational institutions or trained on the job. Succar and Sher (2013) describe the individual BIM competencies as the personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome.

3. BIM LEARNING MODULES

The increased use of BIM has brought about new roles such as the BIM specialist, manager, coordinator, leader, champion, trainer, consultant, expert, technologist, etc. The BIM professional's competency could cover technology, process, commercial, and personal skills. Those skills define the professional's role depending on the entry conditions into the construction industry and the qualifications and background of the professional. It is realistic to recognize different BIM professional roles in various stages: (1) project initiation (defining the scope/customer needs), (2) preconstruction (design information for project procurement), (3) construction (construction and installation information for project delivery), and (4) facilities management (in-use building information for project operation).

A study conducted by Yalcinkaya and Arditi (2010) investigated the extent to which BIM was being taught in civil engineering programs in the US and came to the conclusion that a set of courses need to be offered that cover not only the basic aspects of BIM but also the management of a project designed using BIM . The potential for an undertaking was then explored both for the Engineering Graphics Program and the Construction Engineering and Management Program at IIT. Finally, the Department of Civil, Architectural and Environmental Engineering incorporated BIM into its curriculum in 2011 through the introduction of two course offerings: (1) EG 430 - Introduction to BIM, the senior level elective in the Engineering Graphics Program; and (2) CAE 573 - Construction Management with BIM, a graduate level elective in the Construction Engineering and Management Program.

Project initiation and preconstruction roles cover the design process which is essentially iterative and creative. In contrast, construction management roles cover the construction process, which are essentially orderly and linear. According to Demirdoven and Arditi (2014; and, Demirdoven, 2015) the role of the BIM profession is to form an interface between the design and construction processes by minimizing information overload and producing only what is needed. The BIM Collaboration and Coordination Learning Modules created for Department of CAEE at IIT targets improving BIM software skills (ability to create, understand and interpret building information models), for both design and construction processes, respectively collaborating and coordinating with models, in an integrated-communication environment, and stimulating students' interaction with BIM professionals. Gaining the momentum of two different BIM learning modules, this program helps students to understand the plurality in the construction professions.

BIM Learning modules are planned and created to cover the abilities and deliverables expected from or realized by the students (as future design and construction professionals), organizations and projects when using BIM tools and workflows. These modules are based on the experiential learning which is defined by Felicia (2011) as the process of learning through experience, and is more specifically defined as "learning through reflection on doing". Early in the 1970s, the theory was proposed by David Kolb who was influenced by the work of other theorists including John Dewey, Kurt Lewin, and Jean Piaget.

Kolb (1984) states that experiential learning focuses on the learning process for the individual. The concrete experience forms "the basis for observation and reflection" and the learner has the opportunity to consider what is working or failing (reflective observation), and to think about ways to improve on the next attempt (abstract conceptualization). Every new attempt is informed by a cyclical pattern of previous experience, thought and reflection (active experimentation). "Learning by doing" which results in "changes in judgment, feeling and/or skills" for the researchers and it is discussed how this study can provide a direction for the BIM-enabled learning methods. The students are individually encouraged to directly involve themselves in the different and diverse experiences in using BIM learning tools, and then to reflect on their experiences using analytic skills, in order that they gain a better understanding of the new knowledge of BIM in design

The demographic structure of the participants using the BIM learning consists of graduate and senior undergraduate students from various disciplines such as civil, structural, mechanical, electrical, plumbing, and architectural engineering; architecture, construction management and information technology management. This multi-disciplinary gathering also drives the integrated communication among them. According to Richards and Clevenger (2011) the knowledge students gain regarding the ideas and concepts of their fellow construction disciplines makes them more well-rounded future employees and capable of comprehending the complexity of the construction industry with greater ease.

3.1 Collaboration Module

Collaboration Module is intended for design with BIM purposes. The module targets BIM designers to (1) understand the concepts of BIM, (2) understand project process and model offerings, (3) understand project standards and deliverables, (4) understand model management standards, (5) identify technology considerations, (6) create and use discipline specific models, and (7) create and use discipline specific content and template.

Collaboration Module covers the integrated design process by focusing on the BIM terminology and design workflow. The module provides students with the cognitive tools they will need to work with BIM. Students are presented with complex, novel and authentic tasks. Instruction occurs in technology specific issues as well as in the more discipline specific technical issues. Autodesk as the selected software platform provides support for interoperability, integration, and information exchange. In addition to instruction about the desktop solutions, instruction is also focused on a web-based solution.

Collaboration Module is an ongoing experimentation applied in “EG 430 - Introduction to BIM” course with mostly undergraduate-senior or graduate standing- and some graduate students from different majors including civil/structural engineering, MEP engineering, architectural engineering, architecture, and construction management. This course aims to demonstrate how architectural and engineering design functions are impacted by (BIM). It helps students to understand the fundamentals and practical uses of information technologies in design and construction.

Architectural and engineering design with BIMs is a process in which 3D software is used to develop a data sharing based criteria that is important to the translation of the building's design. Design authoring tools are used to create BIMs and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules. Through architectural design authoring tasks, students experience the potential value created by BIMs such as: (1) transparency of design for all stakeholders, (2) better control and quality control of design, cost and schedule (3) powerful design visualization, (4) true collaboration between project stakeholders and BIM users, and (5) improved quality control and assurance.

3.1.1 Collaboration Knowledge Set

Although BIM is best utilized as a collaborative tool with models shared between team members, until there is full integration of BIM it is reasonable to expect an incremental implementation approach for construction. The modelers must be very knowledgeable, understand the modelling process, and construction phases and processes. The primary competencies in Collaboration Knowledge Set include: (1) design review, (2) design authoring, (3) structural analysis, (4) MEP engineering analysis, and (5) energy analysis. In addition to those primary knowledge areas secondary competencies such as (1) phase planning, (2) quantity take-off and cost estimation, (3) sustainability evaluation, (4) existing conditions modeling, and (5) code validation are covered.

One of the core values for students in this module is the Collaboration Workshop held by an industry partner. Students experience worksharing and the integrated design environment by using an I-room and a shared project repository. The workshop involves solving a real life problem and is facilitated by the instructor and a BIM manager. In this workshop, students not only experience being a part of an integrated design team, but also understanding the use of information in different formats such as design files (DWG, DXF, RVT, RFA, DGN, DB1, etc.), spreadsheets, word documents (DOC), adobe systems (PDF), and all kinds of files containing multi-media information such as rendered images (JPEG, BMP), animations (AVI), and 3D webpages in Virtual Reality Modelling Language (VRML). After the workshop, students are expected to understand that (1) implementing BIM is much more than learning how to use a software suite, (2) effective BIM requires integrated teamwork and collaboration, and (3) interoperability between platforms is a key issue.

Design review is a process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects such as evaluating meeting the program. As a result through design review tasks practiced in the workshop, students experience and understand the potential value created by BIMs such as: (1) eliminate costly and timely traditional construction mock-ups, (2) different design options and alternatives may be easily modelled and changed in real-time during design review base on end users and/or owner feedbacks, (3) create shorter and more efficient design and design review process, (4) evaluate effectiveness of design in meeting building program criteria and owner's needs, (5) enhance the health, safety and welfare performance of their projects, (6) easily communicate the design to the owner, construction team and end users, (7) get instant feedbacks on meeting program requirements, owner's needs and building or space aesthetics, (8) greatly increase coordination and communication between different parties, and (9) more likely to generate better decisions for design.

TABLE 1: Collaboration Module

	Knowledge Set	Skill Set			
	Competencies	**Learning Methods**	**Practices**	**Learning Tools**	**Module Assessment**
Primary Set	Design Review	• Collaboration Workshop with Industry Partnership • Hands-on	• Model Visualization • Model Review • Interactive Space Use • Design Integration • Interdisc.Communicat.	• Revit (Worksharing) • Navisworks • I-Room (Industry) • Workstations (in-lab)	• Participation: Team Work
	Design Authoring	• Lecture • Industry Partnership/In-lab Vendor Training • Hands-on • Self-Learning Tutorial	• Data Use • Discipline Specific (Arch./Str./MEP) Model and Content Creation and Use • Model Presentation and Documentation • Interdisciplinary Communication	• Revit Arch./Str./MEP • ACAD • Bentley/ArchiCAD	• Customized Assignment(s) per Disciplines • Term Project: Commercial Building • Midterm Exam
	Structural Analysis	• Lecture • Hands-on • Self-Learning Tutorial	• Model Export and Use • Str. Model Analysis • Data Interpretation • Cloud Use	• Revit Str. • Robot	• Assignment • Term Project: Commercial Building
	MEP Engineering Analysis	• Lecture • Hands-on • Self-Learning Tutorial	• Model Use • MEP Model Analysis • Data Interpretation	• Revit Systems (MEP) • Revit (Analyze)	• Assignment • Term Project: Commercial Building
	Energy Analysis	• Lecture • Hands-on • Self-Learning Tutorial • ASHRAE 90.1 Standards	• Model Export and Use • Whole Building Energy Analysis • Building Performance Analysis • Daylight Analysis • Data Interpretation • Understanding ASHRAE Standards • Cloud Use and Reports	• Revit (Analyze and Massing) • Green Building Studio • Sefaira Architecture • Sefaira HVAC	• Assignment • Term Project: Commercial Building
Secondary Set	Phase Planning	• Lecture • In-lab example • Case Video • Case Reading	• Understanding 4D Model Information Exchange • Understanding Mobility and Logistics • Creating and Adjusting Schedule • 4D Model Creation and Review • 4D Simulation • Data Interpretation	• Revit • Synchro Professional	• Midterm Exam • Term Report: Interoperability of A BIM Software
	Quantity Take-off and Cost Estimation	• Lecture • In-lab example • Case Video • Case Reading	• Understanding 5D Model Information Exchange • Understanding Cost Estimation • Creating Quantity Take-off Schedule	• Revit • Vico Cost Planner	• Midterm Exam • Term Report: Interoperability of A BIM Software
	Sustainability Evaluation	• Lecture • Case Video • Case Reading • LEED Standards	• Understanding Sustainability • Understanding LEED Process	• Case with Revit Credit Manager	• Midterm Exam • Term Report: Interoperability of A BIM Software
	Existing Conditions Modeling	• Guest Speaker • Lecture • Case Video • Case Reading	• Understanding Laser Scanning and Data Collection • Understand Surveying	• Trimble Showcase	• Midterm Exam • Term Report: Interoperability of A BIM Software
	Code Validation	• Lecture • Case Video • Case Reading	• Understanding Model Parameters and Validation of Project Specific Codes	• Case with Solibri Model Checker	• Midterm Exam • Term Report: Interoperability of A BIM Software

3.1.2 Collaboration Skill Set

The Collaboration Skill Set includes practices with various software and technology as learning tools those promote learning methods for accomplishing the competencies in the knowledge set of collaboration module as given in the Table 1.

Besides the lectures, the primary skill sets are designed as hand-on sessions in detail to cover the competency targeted per each knowledge set and supported by vendor training for design authoring with a learning tool like Bentley BIM or Graphisoft ArchiCAD additional to Autodesk Revit. The secondary skill sets are a combination of lectures, in-lab examples supported by case studies using related videos and readings and invited guest speakers. Students see the best project examples and showcases. Thus, they understand how their design authoring skills go along with the other BIM purposes and processes using other tools such as Navisworks, Green Building Studio, Sefaira Architecture, Sefaira HVAC, Synchro Professional, Vico Cost Planner and Solibri Model Checker.

Autodesk Revit, Robot Structural Analysis, Green Building Studio, Sefaira Architecture and HVAC software packages are provided both through institutional licenses and instructor's effort to get educational support from vendors. Software related online training and support materials such as video tutorials, webinars, help files, training manuals and community networks are used to investigate the design process practicing BIMs for collaboration.

3.1.3 Collaboration Module Assessment

Collaboration module assessment is held through key measures such as (1) grades in online mid-term exam (40%), (2) performance in preparing and presenting customized assignments per disciplines (%10); (3) performance in creating a term report (25%); and, (4) performance in creating a term project (25%) in terms of given criteria. All knowledge set competencies are covered as subjects in the mid-term exam. Practices in primary skill set are evaluated by the commercial design model submitted as the individual term project which is created through discipline specific assignments and interdisciplinary communication during the lab sessions. Secondary knowledge and skill sets are evaluated by the term report which is basically a research study on interoperability of the BIM tools.

3.2 Coordination Module

Coordination Module is intended for construction with BIM purposes. The module targets BIM professionals in construction to (1) understand the concepts of BIM, (2) understand project life cycle, areas of coordination and model offerings, (3) compile a composite model and perform clash detection, (4) create and optimize schedule for coordination, (5) adjust BIMs for quantity take-off, establish cost targets and cost analysis; (6) understand construction coordination and reports using BIMs, (7) understand site utilization planning and simulation, , (8) compile information for record modeling, (9) understand facility management with models, and (10) identify technology considerations

Coordination module is an ongoing experimentation applied in "CAE 573 – Construction Management with BIM" course with graduate students specializing in construction management from different majors including civil, structural, mechanical, electrical, plumbing, and architectural engineering; and, architecture. It covers the post-design process by focusing on the BIM terminology and construction workflow. This course aims to demonstrate how to (1) understand the concepts of BIM, (2) review software and technology available for BIM, (3) use a model created by a BIM software in construction management, (4) use BIM to check for interferences and conflicts on a building construction project, (5) explore construction scheduling and phase planning using BIM, (6) explore cost estimating using BIM, and (7) explore how BIM can assist in facility management.

Cost estimating and analysis is practiced as a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project. This competency session allows the students to see the cost effects of their changes, during all phases of the project, which can help curb excessive budget overruns due to project modifications. Specifically, BIM can provide cost effects of additions and modifications, with potential to save time and money and is most beneficial in the early design stages of a project. Through cost estimating and analysis tasks, the students experience and understand the potential value created by BIMs such as: (1) precisely quantify modelled materials, (2) quickly generate quantities to assist in the decision making process, (3) generate more cost estimates at a faster rate, (4) better visual representation of project and construction elements that must be estimated, (5) provide cost information during the early decision making phase of design and throughout the lifecycle, including changes during construction, (6) save time by reducing quantity take-off time, (7) more value adding activities in estimating such as: identifying construction assemblies, generating pricing and factoring risks, which are essential for high quality estimates; (8) added to a construction schedule (such as a 4D Model), a BIM developed cost estimate can help track budgets throughout construction, and (9) easier exploration of different design options and concepts within the owner's budget and (10) quickly determine costs of specific objects, and (11) easiness to join new estimators through this highly visual process.

Phase Planning is practiced as another core competency in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. 4D modeling is a powerful visualization and communication tool that can give a project team the including owner a better understanding of project milestones and construction plans. Through phase planning and simulation tasks, the students experience and understand the potential value created by BIMs such as: (1) better understanding of the phasing schedule by the owner and project participants and showing the critical path of the project, (2) dynamic phasing plans of occupancy offering multiple options and solutions to space conflicts, (3) integrate planning of human, equipment and material resources with the BIM model to better schedule and cost estimate the project, (4) space and workspace conflicts identified and resolved ahead of the construction process, (5) marketing purposes and publicity, (6) identification of schedule, sequencing or phasing issues, (7) more readily constructible, operable and maintainable project, (8) monitor procurement status of project materials, (9) increased productivity and decreased waste on job sites, and (10) conveying the spatial complexities of the project, planning information, and support conducting additional analyses.

3.2.1 Coordination Knowledge Set

Coordination module provides graduate level learning with the applicable managerial skills that are required by the construction industry and is relevant to the realities of an ever evolving technology environment. The students who are enrolled in this course gain strong coordination and teamwork skills for developing and executing a BIM strategy, a broader perspective of social, environmental and economic issues, and finally construction management knowhow that goes along with BIM practice. The primary competencies in Coordination Knowledge Set include: (1) 3D coordination, (2) phase planning, (3) cost estimation, (4) site utilization planning, and (5) 3D control and planning. In addition to those primary knowledge areas secondary competencies such as (1) field / space manage tracking, (2) record modeling and its use in facility management, (3) sustainability evaluation, (4) existing conditions modeling, and (5) digital fabrication are covered.

One of the core values for students in this module is the Team Project presented in terms of a project based BIM Execution Plan. The BIM Project Execution Plan provides a framework for the fundamental coordination strategy that the student teams can use for their projects and a template for the teams to define the BIM goals and uses, the execution process, the deliverables and also the infrastructure for the implementation of the projects (CIC, 2011). Teamwork begins with identifying the BIM goals for the given project. The teams are formed at the beginning of the semester with each team member defining their primary role in the group. The students are aware of the general project background. This information allows them to develop and complete the BIM Project Execution Plan and practice it. With this team study, students are expected to understand that (1) implementing BIM is much more than learning how to use a software suite, (2) effective BIM requires integrated teamwork and coordination with model, and (3) model accuracy and data analyzed throughout the life cycle of the project is a key issue for strategic planning in construction.

Clash detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation. A Clash Detection Workshop held with an industry partner helps participants to experience problem-solving in the real-world project environment. Through clash detection tasks, students experience the potential value created by BIMs such as: (1) coordinate building project through a model, (2) reduce and eliminate field conflicts; which reduces RFI's (request for information) significantly compared to other methods, (3) visualize construction, (4) increase productivity, (5) reduced construction cost; potentially less cost growth (i.e. less change orders), (6) decrease construction time, (7) increase productivity on site, and (8) more accurate as built drawings.

3.2.2 Coordination Skill Set

TABLE 2: Coordination Module

	Knowledge Set	Skill Set			
	Competencies	**Learning Methods**	**Practices**	**Learning Tools**	**Module Assessment**
Primary Set	3D Coordination	• Clash Detection Workshop with Industry Partnership • Hands-on	• Model Visualization • Model Coordination • Interactive Space Use • Design Integration • Interdisciplinary Project and Team Work	• Navisworks • Vico Clash Detection • I-room (Industry) • Workstations (in-lab)	• Participation • Team Project: BIM Execution Plan • Term Report
	Phase Planning	• Lecture • Hands-on • Case Video • Case Reading • Self-Learning Tutorial	• 4D Model Information Exchange • Creating and Adjusting Schedule • 4D Model Creation and Review • 4D Simulation • Data Interpretation • Reporting	• Revit and Tekla Str. • Vico Schedule Planner • Vico Report Editor	• Assignment • Team Project: BIM Execution Plan • Term Report • Midterm Exam
	Cost Estimation	• Lecture • Hands-on • Case Video • Case Reading • Self-Learning Tutorial	• 5D Model Information Exchange • Cost Estimation • Cost Comparison • Creating Quantity Take-off Schedules • Using Cost Data • Cost Report	• Vico Cost Planner • Vico Report Editor	• Assignment • Team Project: BIM Execution Plan • Term Report • Midterm Exam
	Site Utilization Planning	• Lecture • Hands-on • Case Video • Case Reading • Self-Learning Tutorial	• Identifying Construction Phases • Site Utilization Planning	• Revit • Synchro Professional • Vico Report Editor	• Assignment • Team Project: BIM Execution Plan • Term Report Midterm Exam
	3D Control & Planning	• Lecture • Hands-on • Case Video • Case Reading • Self-Learning Tutorial	• Modeling Alternative Methods • Compare and Select Options • Understanding Construction Sequences	• Revit • Vico Production Control • Vico Report Editor	• Assignment • Team Project: BIM Execution Plan • Term Report • Midterm Exam
Secondary Set	Field / Space Manage Tracking	• Guest Speaker • Lecture • Case Video • Case Reading	• Understanding Space Management and Tracking • Understanding and Using Field Management Devices (Pad, Tablet, etc.)	• Trimble Showcase	• Term Report • Midterm Exam
	Record Modeling and its use in Facility Management	• Lecture • Case Video • Case Reading	• Understanding Facility Management • Understanding Building Automation Systems	• Case with EcoDomus	• Team Project: BIM Execution Plan • Midterm Exam
	Sustainability Evaluation	• Lecture • Case Video • Case Reading • LEED Standards	• Understanding Sustainability • Understanding LEED Process	• Case with Revit Credit Manager	• Team Project: BIM Execution Plan • Midterm Exam
	Existing Conditions Modeling	• Guest Speaker • Lecture • Case Video • Case Reading	• Understanding Laser Scanning and Data Collection • Understand Surveying	• Trimble Showcase	• Team Project: BIM Execution Plan • Midterm Exam
	Digital Fabrication	• Lecture • Case Video • Case Reading	• Understanding Fabrication with Digitized Information	• Case with Tekla X-Steel	• Team Project: BIM Execution Plan • Midterm Exam

The Coordination Skill Set includes practices with various software and technology as learning tools those promote learning methods for accomplishing the competencies in the knowledge set of coordination module as given in the Table 2. Besides the lectures, the primary skill sets are designed as hand-on sessions in detail to cover the competency targeted per each knowledge set and supported by vendor training for design authoring with a learning tool like Synchro Professional or Navisworks additional to Vico Software. The secondary skill sets are a combination of lectures, in-lab examples supported by case studies using related videos and readings and invited guest speakers. Students see the best project examples and showcases. Thus, they understand the effect of BIMs in the life cycle of a project by using other tools such as Trimble field management tools, EcoDomus, Revit Credit Manager and Tekla X-Steel.

Autodesk Revit, Trimble Vico and Synchro Professional software packages are provided both through institutional licenses and instructor's effort to get educational support from vendors. Software related online training and support materials such as video tutorials, webinars, help files, training manuals and community networks are used to investigate the construction process practicing BIMs for coordination.

3.2.3 Coordination Module Assessment

Coordination module assessment is held through key measures such as (1) grades in online mid-term exam (40%), (2) performance in preparing and presenting assignments (%10); (3) performance in creating a term report (25%); and, (4) performance in creating a team project (25%) in terms of given criteria. All knowledge set competencies are covered as subjects in the mid-term exam. Practices in primary skill set are evaluated by the commercial design model submitted as the individual term report which is created by using the selected software planning, control and documentation tools. All knowledge set competencies and skill sets are evaluated by the team project which is basically a research study on BIM execution plan.

4. CONCLUSIONS AND DISCUSSIONS

Curriculum coverage of BIM had significantly improved and a stronger BIM market had created an impetus for more effective and efficient recruiting. To sustain the momentum of BIM, effective workforce development that aims to balance the supply-demand equation in the labor market is essential. For many, experience with BIM begins in academia. The challenges reside in the classic gap between academic focus on disciplinary principles and the industry needs for specific application proficiency.

There is a need to establish and improve BIM knowledge, skills and experience of current engineering professionals. There are many BIM competencies that need to be learned by professionals involved in the design, construction and operation of facilities. Besides, advances in software and technology continue to empower people to transform how and what we design and build (design-to-fabrication, automation, 3D printing, component-based design and construction); attract new talent; improve productivity, quality, safety, and speed to market; and, make innovation an everyday value.

An academic framework informed by BIM research, BIM professionals and other industry stakeholders is a prerequisite for delivering BIM education in universities. The rising market demand for competent BIM professionals would eventually force companies to adjust their recruiting practices through enhanced and more proactive collaboration with BIM educators. Critical steps to be taken via an academia industry partnership for a continuity to improve BIM education in universities with more direct input of established BIM professionals to bridge the gaps between theory and empirical experience.

Advanced training of current workforce through competency and skill based programs leads to mastery and performance improvement. Furthermore, a safer industry attracts more workforce. In addition to technology selection process and criteria for learning modules, the value that both undergraduate and graduate degree educational modules add to the BIM professions needs to be determined and discussed in a latter study. The IIT strategy relative to BIM by using the learning modules approach is successful and expected to help architecture, engineering, and construction professionals to be prepared for the needs of the industry in the future. Efforts should continue and expand to provide exposure, skills and opportunity to students.

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