Interoperable Learning Leveraging Building Information Modeling (BIM) in Construction Management and Structural Engineering Education

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In a joint-discipline collaboration, a prototype educational module was developed to teach students in the departments of construction management and civil engineering about the integrated nature of information used to design and construct buildings. The educational module uses Building Information Modeling (BIM) to create an interoperable learning environment where students gain experience utilizing academic concepts by applying them to a building information model. The authors discuss the advantages of such an experience including having student gain interoperable skills and develop an understanding of the information and concepts utilized by other disciplines. Using Adobe® Captivate® 5 along with Autodesk's Revit Structure, a demonstration video and assessment tool were created using a professionally developed BIM to expose students to information contained within BIM and to the software's general functionalities. The educational module uses interactive exercises to engage students and requires them to perform basic calculations and information gathering exercises related to their discipline as well as explore concepts typically associated with other disciplines. The module encourages students to develop an understanding of construction processes as a whole by illustrating how information associated with their specific discipline is used by others.

Keywords: BIM, construction management, structural engineering, interoperable learning, e-learning

Introduction

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 (Gallaher et al., 2004). All disciplines share the common goal of designing and constructing a building that meets design intent, is safe, constructed on time, and within budget. With the complexity of today's buildings and the uncertainty of today's economy, there is an even greater need to educate future architects, engineers and construction managers about basic concepts and to increase their knowledge of the overall building process. The advent of Building Information Modeling (BIM) provides architecture, engineering and construction management students a valuable learning environment for viewing the information available to other disciplines and to see how it is used to aide decision making. Professionally, BIM is 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 (Eastman et al, 2008). As BIM technology becomes industry standard, it is important that academic institutions train future architects, engineers and construction managers in the capabilities and advantages of BIM technology. Research shows that BIM technology enhances communication and reduces omissions in plans and errors in the field when the design and construction team uses the capabilities of BIM software (McGraw Hill, 2009). It is important that education responds to this industry trend and leverage the technology to achieve multiple objectives across construction programs.

The 3D interface of BIM software creates a learning platform that enables students to visualize and develop a better understanding of the entire construction process. At Colorado State University (CSU), a host of faculty and students are working together to create a suite of teaching modules that will allow students across multiple construction related disciplines to not only experience BIM as applied to their own discipline, but to also experience interdisciplinary education in the form of information and concepts incorporated into building information models by their construction counterparts. These teaching modules explore the information created and analyzed in BIM

and illustrate how various forms of information differ and/or is shared across disciplines. The teaching modules consist of two parts: 1) An automated demonstration video showing students a tutorial describing information contained within a BIM and how one accesses it, and 2) A self-guided e-learning assessment where students interact with a real-life BIM to gain experience using the software while further developing concepts discussed in the classroom. Together, these two parts of the teaching module reinforce, enhance and assess the fundamental concepts being taught in the traditional classroom but in an interactive, 3D e-learning environment. The modules also serve to highlight information used for multiple construction purposes throughout the building delivery process.

The modules are created using Adobe® Captivate® 5 and do not require teachers or students to have prior BIM modeling skills. The Adobe software creates interactive animations where the students feel as if they are using software without actually accessing the software itself. The animations created can be output as a .swf file, or Adobe® Flash® Player file, and are viewable on any computer through a regular internet browser. Captivate software can also track the responses of the students when they interact with the software, thereby assessing their performance. This feature is capable of tracking both correct and incorrect entries. Scores can be recorded directly through a web-based learning environment or saved and emailed to the instructor.

Creation and Implementation of BIM Teaching Modules

Fundamentally, BIM technology should not be used as just a design tool or just a construction management tool, but as an industry-wide tool. To leverage these collaborative capabilities in an educational setting, CSU's Construction Management Department is developing teaching modules that bridge the gap between multiple construction-related educational programs. These modules demonstrate the benefits of BIM technology to students' within their native discipline as well as provide insight regarding the steps and processes required in related disciplines. A specific example is the tandem roles played by structural engineers (SE) and construction managers (CM) in modern design-build projects. In design-build, the design process is iterative and SEs and CMs work in parallel while interacting regularly to share design information related to issues surrounding constructability, scheduling and cost. In order to educate both CM and SE students on this trend, CSU's Construction Management Department has worked directly in conjunction with students and faculty of Structural Engineering in the Civil Engineering Department to develop a teaching module that serves the curriculums of both departments.
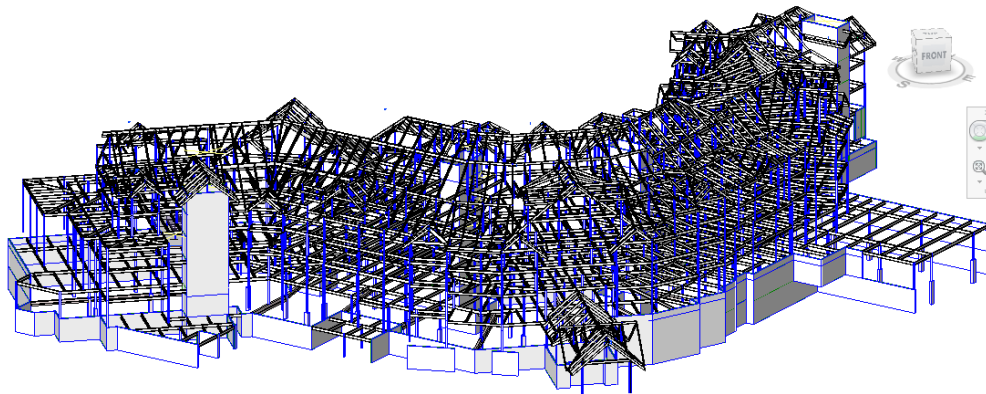

Figure 1: The 3D model that forms the basis for BIM-based teaching demonstration and assessment for both SE and CM students.

A professionally developed BIM provided by KL&A, Inc. forms the basis of this teaching module (Figure 1). Based on this BIM, the teaching module presents a basic overview of BIM software, highlights standard modeling capabilities and information available for both disciplines, and shows the interoperability capabilities between BIM software and analysis programs (Revit Architecture and Robot Structural Analysis).
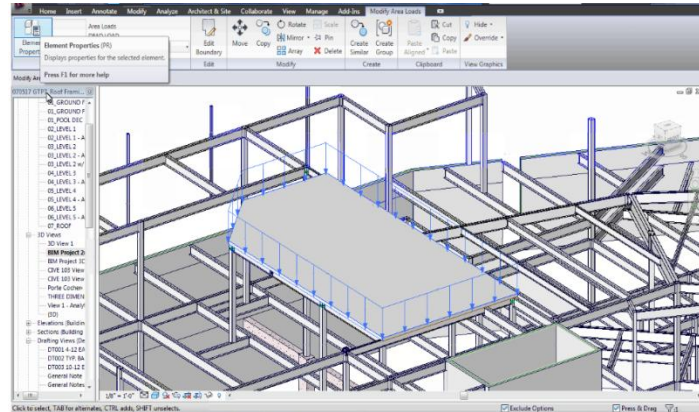
Figure 2: Graphic showing steel beams, columns and floor slab that students work within the demonstration portion of the teaching module for both construction management and structural engineering students.

In total, the teaching module consists of three 3D interactive, narrated animations: one joint demonstration video and two customized assessment videos to meet the needs of both CM and SE students. The demonstration piece of the teaching module explores information relevant to each discipline, such as determining loads, reactions and moments for beams for SE students, and evaluating cost and determining material quantities for CM students. Figure 2 shows a screen capture of what students view in the demonstration portion of the teaching module. Here students are shown how to extract information from the BIM including material properties or take-off quantities.
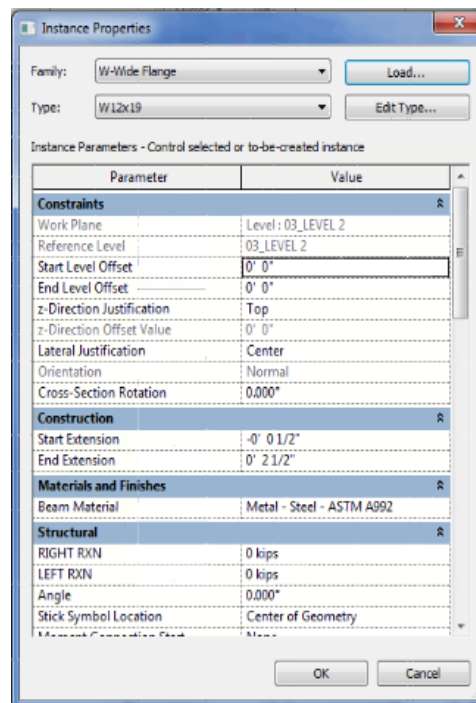

Figure 3: A drop-down menu used by SE students in the assessment module to select the correct beam size.

In addition, two independent assessment pieces are created and tailored to SE or CM students separately. In the assessment for SEs, students demonstrate knowledge by calculating loads, tributary area, reactions, moments, shears, and selection of beam sizes. In contrast, during the assessment piece for CMs, students are asked to demonstrate their knowledge and ability to perform a material takeoff, and determine the costs associated with material and labor. In the example depicted in Figure 3, although both sets of students are shown beam sizing, in this case a W12x19, using BIM during the demonstration video, only the SE students will interact with this menu during the assessment phase. CM students, by contrast, will have a separate related assessment activity. In the SE assessment, students click on individual beams, determine the actual length of the beam, and calculate forces applied to beams based on specific loads and tributary area. The students then enter the calculated information into the

beam's properties dialog box. Students also compute several values regarding particular connections of steel beams to steel girders. In the CM assessment, students create a schedule of the beams selected in a specific area of the model. They are asked questions about the specific construction sequence necessary to construct the structure. They use BIM software to query and filter beam properties as necessary to perform material, cost and constructability analysis. For example, beam sizes, weights, and costs are queried, calculated and totaled. Students then answer several questions regarding the schedule they created and the quantities and costs determined. Figure 4 shows a screen capture from Adobe® Captivate® 5 of the schedule they create within Revit Structure.

Figure 4: Screen capture of material schedule that CM students create during their assessment module as it relates to beam size selection (Figure 3).

Interoperable Learning

In professional practice, SEs primarily focus on specifying loads, designing beams and connections, and the structural performance of the building as a whole. By contrast, CMs generally concentrate on material quantities, cost, constructability, construction sequence and overall construction schedule. The implementation of BIM technology in this teaching module effectively teaches students in both disciplines about the interrelation of information required throughout the building process. Traditional curriculum for SE students does not address issues of constructability or economy of size in either lecture or coursework. Traditional CM classes while more applied with regard to surveying, estimating, scheduling and management, are generally focused on basic concepts and material properties for structures. Neither discipline fully addresses the necessary information exchange between disciplines to construct real-world projects. This omission may leave students confused whether seemingly extraneous pieces of information are actually necessary in the real-world.

A general disconnect exists between knowledge currently obtained within the classroom and the breadth of knowledge students need to support the construction process in its entirety. Traditionally, CM curriculums have tried to bridge this gap through hands-on laboratories or physicals demonstrations. A simple example comes from the teaching of a "pinned" connection. Figure 5A shows the traditional schematic drawing used to show students the structural characteristics of a pinned connection, which is to limit translational motion. Purely schematic, this view does not suggest the size or geometry of the connection. Next if facilities are available, CM students are also shown real-life pin connections using a steel sculpture where they can see and touch the steel used to fabricate such a connection in full scale (Figure 5B). More recently, many programs are now also using 3D models as illustration to help the students more fully understand characteristics of a pinned connection (Figure 5C).

Figure 5: Complementary communication techniques to illustrate the fundamental principles of a pin connection to CM students: A) a line diagram is used to represent a pin connection in calculations and analysis B) an instructional steel sculpture is available to demonstrate the connection materially C) a rotatable computer model makes the connection easily viewable in 3D.

By providing an interactive e-learning environment where students have access to 3D visualization and associated property databases (i.e.; size, material properties, cost etc.), our teaching module provides an enhanced platform for teaching. Here, students have the capability to view a building, beams and connections in the virtual world to develop a greater understanding of the properties of single elements as well as a more complete understanding of how the building systems fit together as a whole. In executing the teaching modules, students gain practice in their respective disciplinary skills, and also develop an understanding of the role and responsibilities of other disciplines. In our example, providing students the capability to visualize a pin connection within the context of an entire building model, improves their understanding of how the connection works as well as how engineers and construction managers need to work together. The educational objective is to have students develop an appreciation and "buy-in" for the importance and relevance of the other disciplines and not just think of their contribution in isolation.

Advantages and Disadvantages of Teaching Modules

A BIM is a useful teaching platform and provides opportunities for students to gain insight into industry practices to better prepare them for work on real projects. The teaching module developed at CSU educates students on information available within a BIM and provides them with a basic feel for navigating through the software and locating certain types of information. The teaching module is software independent and does not require either instructors or students to master the BIM software or have individual licenses.

The benefits of the teaching modules as seen by CSU's Construction Management Department to date include a unique opportunity to link faculty and students across departments and disciplines. Specifically, students learn about the roles and responsibilities of other disciplines in constructing a project. For many students this will be their first exposure to the complexity and variety of information that exists between different disciplines on a single building project. This awareness will increase their interdisciplinary skills and knowledge and better prepare the students to contribute as professionals.

Because both sets of students view the demonstration video, the teaching module provides CM students an opportunity to see how steel buildings are modeled within the BIM, how models are exported to an analysis software package and to understand some of the information structural engineers must input into the model. Likewise, this module shows SE students information construction managers use such as cost, economy of size, and uniformity and how this information affects the constructability of the building. Without this collaboration, students would otherwise not be exposed to these extended applications of BIM since they fall outside the domain of their discipline. Such a collaborative learning approach creates a more holistic understanding of the construction process. In addition, the visualization and animation capabilities of BIM create an opportunity for students of both disciplines to develop a greater understanding of the geometric relationships and sequencing inherent to the construction process particularly within the context of an entire building. Finally, by viewing the teaching modules students gain a brief introduction to BIM software use and its functionalities.

The biggest disadvantage of the teaching module as currently developed is the lack of flexibility to change and manipulate the assessments. Ideally one would be able to create a bank of inputs for loads, member geometries and connections that would allow each student to complete a different assessment to eliminate cheating and provide longevity for the module in the classroom. In the future, Revit Structure and Adobe® Captivate® 5 might integrate

in such a way that it is possible to designate look-up tables to be referenced as necessary. To the authors' knowledge this capability does not currently exist in the interaction between these software packages. An additional disadvantage is the module's inability to track all desired components within the assessment. For example, Captivate is unable to track how many times it takes a student to enter the correct input for a designated fill- in-the-blank answer. Captivate has the capability to set the number of maximum attempts that a student can enter, but if that number is greater than two, it does not report how many of those designated tries the student used before the right answer was achieved.

Conclusion

This overview of the cross-curriculum teaching module developed by the CM faculty for use in both CM and SE courses is only one example of the many opportunities that exists to integrate BIM technology into the teaching curriculum of construction related educational programs. Additional work is being done at CSU to expose students to BIM software and technology including the development of additional modules related to Mechanical, Electrical, Plumbing and Fire Suppression systems as well as Energy Modeling (Clevenger et al., 2010). The authors will continue to expand these modules with the goal of linking additional disciplines within the building process and exposing students to a wider variety of interdisciplinary training opportunities. The knowledge students gain regarding the ideas and concepts of their fellow construction disciplines will make them more well-rounded future employees and capable of comprehending the complexity of the construction industry with greater ease. Future work will include both expanding the capabilities of existing teaching modules as well as creating additional modules.

Acknowledgements

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