Teaching Building Information Modeling at Undergraduate and Graduate Levels

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Abstract. The paper presents our experience and findings of teaching Building Information Modeling (BIM) at both the undergraduate and graduate levels. At the undergraduate level for Environmental Design students, basic BIM concept and modeling were exercised. At the graduate level for Ph.D. and MS students in Architecture, MArch students, and MS students in Construction Science, advanced topics including parametric design, database, Application Programming Interface (API), and building lifecycle applications of BIM were introduced. We suggest an incremental BIM skill development with a course agenda, for example: first year college – modeling; second year and third year – simulation and analysis for building systems; and fourth year and above until graduate level – customization. Detailed description of the courses, strategies, student projects, findings, and discussions are given in the paper.

Keywords. Building Information Modeling; Education; Undergraduate; Graduate.

Introduction

The paper presents our experience and findings of teaching Building Information Modeling (BIM) at both the undergraduate and graduate levels. At the undergraduate level for Environmental Design students, basic BIM concept and modeling were exercised. At the graduate level for Ph.D. and MS students in Architecture, MArch students, and MS students in Construction Science, advanced topics including parametric design, database, Application Programming Interface (API), and building lifecycle applications of BIM were introduced.

Building Information Modeling (BIM) is an emerging technology in Architecture/Engineering/Construction (AEC). As a product, it is a digital representation of physical and functional characteristics of a facility and serves as a shared knowledge resource for information about a facility (NIBS 2008). As a process, it is a digital representation of the building process used to facilitate the exchange and interoperability of information (Eastman et al. 2008).

Despite the rapid adoption of BIM in architectural practice, different views about BIM in architectural education exist in academia (Cheng 2006; Seletsky 2006). Ibrahim (2007) argues that the viewpoints were either underestimating the rapid conversion of the workplace into BIM, or ignoring the fact that learning is a process of adding up knowledge in a layered manner.

We have extensively examined existing BIM courses in construction science (Mulva and Tisdel
Undergraduate Computer Technology Courses

The 3-credit courses (Computer Technology for Design Visualization and Design Communication Foundations) were totally taught five times during 2008 to 2010, with each class linked to a design studio. BIM was one of the major components in these courses and it was focused on the following topics: 3D geometry modeling; modeling building objects; modeling information; domain-specific knowledge; and representation. Basic theories were introduced for each topic, and a select subset of software functionalities was instructed to meet the modeling requirement of design studio projects. The basic BIM applications required in the courses include: building modeling, users’ behavior illustration based on BIM generated images, photorealistic rendering, walkthrough and fly-around animation, and solar analysis.

The learning objectives include: (1) mastering basic BIM methods including geometry modeling and non-geometric building information modeling; (2) acquiring a basic understanding about knowledge embedding in BIM authoring tools. Currently, limited construction knowledge is embedded in BIM tools. For example, the relations between buildings and the sites, the wall layering and joints, window components, etc. BIM become the subjects that students can use to study about buildings interactively; and (3) acquiring skills of visualization as a means of design communication.

In these courses, students, without previous CAD training, followed BIM introduction and tutorials, and created BIM models for studio projects ranging from house to gallery design. Figure 1 demonstrates sample student work. Students soon found the limitations of BIM tools and asked how to model free forms. As in the studio of the Gallery Design project, creativity was emphasized through encouraging non-orthogonal forms. Accordingly, we designed special instructions to facilitate free form modeling by combining CAD and BIM.
Case 1 - Creating BIM Elements through CAD Models: For creating BIM elements with irregular shapes, e.g. slope walls and non-rectangular walls, it is often more convenient to create corresponding geometry in a CAD application such as Autodesk 3ds Max Design®. Import the geometry into a BIM tool such as Autodesk Revit Architecture, and use Revit’ Wall by Face, Roof by Face, etc. commands to create building elements. We also need to add other 3D formats into the exporting/importing pipeline in order for Revit to recognize the faces of the irregular geometry.

Case 2 - Creating a curved form for BIM: similar to student responses in (Sah and Cory 2008), our students found that creating curved surfaces is a big challenge. We created special instructions to help students resolve this problem also by combining the use of CAD and BIM.

Figure 2 shows screenshots of our special instructions for creating irregular and curved BIM elements through the help of CAD. Figure 3 shows that two students’ projects encountered these challenges and the problems were resolved using the taught CAD techniques and other techniques developed by the students themselves.

Findings: Compared to students that used traditional CAD tools for design modeling, students in these courses model buildings faster with BIM for most of their designed buildings, except free form buildings. However, the limitation of the free form modeling capability of current BIM tools can be overcome by combining CAD tools that have more sophisticated solid/surface modeling capability with BIM tools, resulting free form design modeled...
in BIM to satisfy the design requirements and foster students’ creativity. In addition, design visualization with BIM was of better quality. Comments from studio professors about the experiments of linking two courses together were encouraging.

Discussions: Introduction about both BIM concepts and their tools should be provided to students, while ideally the focus should be on the BIM methods. Instructors need to be willing to update their knowledge about the emerging BIM technology quickly as new concepts and applications are developed and disseminated fast. At the same time, instructors have to create a new learning environment that enables the sharing of software operation skills among students as they learn the frequently-upgraded tools often faster than the instructors. The pairing between studios and the computing courses provided problem sets and opportunities for students to learn both.

From our experience, a good understanding of both CAD and BIM by the instructors plays an important role to BIM teaching if CAD is not a prerequisite for BIM courses, and when BIM applications are still at their beginning stages.

**Graduate BIM Courses**

For the graduate level, following a BIM-focused Facility Information Technology course in 2008, we created a new, experimental Building Information Modeling course and taught it in Fall 2009 and Spring 2010. All of these courses are 3 credit hours. The courses introduce BIM principles, methods, and applications in the design process and the building lifecycle. Topics include parametric modeling, databases, computer programming, web technologies, design performance simulation and visualization. The objective of the courses is that students should gain knowledge of architectural computing methods centered at BIM that they can apply in their design studios, thesis work, research, and professional practice. Students should gain knowledge of basic and advanced BIM technologies that can be used to model and retrieve building information in the building lifecycle from design to facility management.

One of the major topics we introduced is BIM-based Parametric Modeling, which becomes the focus of the discussion below (Due to the length limit of this paper, other topics will be discussed in detail in separate publications).

While BIM provides the high integrity central database in the entire building lifecycle, parametric modeling facilitates design changes and design options in a timely manner that is needed in the early design stage. Parametric design as a design method has the potential to foster creative building design. BIM-based parametric modeling combines the creativity of design, embedded architectural
knowledge, and the integrity of project data, which is important to the whole building lifecycle including design, energy analysis, construction, and operation. Therefore BIM-based parametric modeling is promising to be widely adopted by professionals including architects and engineers to transform the AEC industry, and thus it is an emerging topic of architectural education.

An important question we asked was: how to use BIM authoring tools to create customized design, instead of using ‘default’ library objects? The ideal case is that students do “research” and then “design” for everything they create in the projects, ranging from building to furniture. However, the time given for the class is not sufficient for this. Some default objects (e.g. some furniture or some wall types) are therefore allowed in the courses, but a parametric building element design and its model as a case study, are required to be a part of the building modeling projects. For example: a family (or a group of elements related through parameters) of Building Integrated Photovoltaic (BIPV) roof whose angle is driven by the sun path is a possible subject for parametric modeling.

Learning objectives include: (1) understanding how parameters are passed from families to nested families. The actual process and the user interface are application-specific, but the idea of passing values is common in functions of computer programming; (2) creating algorithms that defines the parametric relationships among building elements; and (3) developing an understanding that designing algorithms can be the actual process of design.

Providing examples of existing parametric design will motivate students to study and create their own parametric design. Students looked into existing parametric designs to study the algorithms by modeling the designs. They created their own algorithms to design and model their own building elements.

For example, the physical models in Figure 4 are outcomes of a design project in the linked studio (led by Prof. Rodney Hill at Texas A&M University). The algorithm designed by the student and applied to the design of both the center and outside structures is: at every new level, the element with a given setback value is rotated so that its corner points will touch exactly the corresponding edges of the element at the previous level.

We thought this model was a good example to demonstrate the parametric modeling and therefore built the digital model (though normally the order should be flipped if using CNC fabrication). The parametric models show that (1) how mathematics is used in the design. Quadratic formula solutions and trigonometry functions are used to resolve the mathematical problem for calculating the rotation angle for each level (the angle increment is different at each level); (2) it fosters design changes to be made easily; (3) the apparent differences between the computer models are the results of different parameters following the same algorithm – this helps student comprehend the simple essence of the seemingly complex forms; (4) the precision of the computer model will enable the physical model to be precisely created with CNC machines; and (5) physical materials can be applied to the geometry (e.g. in Figure 5 upper-right), indicating that the structure can potentially be built, which is a significant advantage of BIM-based parametric modeling, over other geometry-based parametric modeling methods.

Figures 6 to 8 present sample student works on BIM applications and parametric modeling, including analysis and parametric modeling of Serpentine Pavilion (designed by Toyo Ito & Associates Architects & Cecil Balmond); modeling of an Alaska cabin and parametric modeling of the cabin’s porch overhang; parametric modeling of a solar-responsive design canopy through Revit’s Application Programming Interface (API).

Findings: BIM’s wide applications enable each graduate student interested in a specific application of BIM to find it useful. Diverse applications or studies of BIM were developed or conducted for historic preservation, cost estimation, parametric design,
solar building design, visualization of form-based urban codes, survey of interoperability with energy analysis tools, and facility management.

The range of applications of BIM is so wide that no single instructor can cover all the topics on the entire building lifecycle in good details. Instructors of a BIM technology course need to introduce the essentials of BIM technology, which include object-oriented modeling, parametric modeling, and database, in order to meet different application requirements and different interests in graduate studies, be it design, construction, operation, or preservation.

Discussions: While some instructors think BIM is intuitive for construction science students (Sacks and Barak 2009; Guidera 2006), architectural educators may think BIM interface didn’t intuitively imply the ability to customize BIM-based applications for architectural design students (e.g. Ibrahim 2007). Streich (1992) discussed several arguments in favor of the computer programming instruction in CAAD education, which may apply to BIM education. Students should not be limited to what the software provides but be capable of molding it according to their needs and take it a step forward to master the analytical skills needed to take BIM technology to the next level (Sah and Cory 2008). Scheer (2005) suggested that our profession needs to be deeply engaged in the development of BIM technology. Thus, for graduate education we suggest that students study the core of the technology beyond merely using the existing functionalities of BIM.

We think getting started with BIM is like playing with Lego City® blocks, which is intuitive using the existing blocks, but to getting the full potential of BIM is like playing with Lego NXT Mindstorms® robotics, for which a good understanding of the block structure and an ability to program the robotics with programming/scripting languages is necessary. Similarly, a good understanding of BIM object structure and its API are useful for exploring the potentials of BIM; therefore our graduate courses introduced basic BIM API programming and scripting (Figure 8 shows a sample result of programming-aided parametric modeling, with C# and Revit API). Students’ final projects are application prototyping. The most important aspect of the final project was for students to see what BIM can do for their design or research projects and find BIM as a technology that facilitates creative applications. In addition, the courses tried to help students develop critical thinking about BIM, e.g. what are missing in the current BIM and how BIM may be improved.

Conclusions and Future Work

Based on BIM capabilities (Eastman et al. 2008), we provide the following information (Table 1) to indicate the coverage of BIM concepts in our
Figure 5
Parametric models created in Revit Architecture 2010 for the lighting appliance. Top: two models of the same geometry but different materials. Note that the upper-right one’s material is of a curtain system. Lower-left: top view of the model. Lower-right: different parameters result in a different design.

Figure 6
undergraduate and graduate BIM courses. It can be seen that we tried to cover most of the subjects gradually from undergraduate to graduate. But we couldn’t cover all the subjects due to the time limit. Some of them may be suitable for BIM integration in other courses, for example, Multi-User Environment will be good to be taught in a studio class that team work is required; and Scalability can be learned in a thesis research project. We suggest an incremental BIM skill development with a course agenda, for example: first year college – modeling; second year and third year – simulation and analysis for building systems; and fourth year and above until graduate level – customization.

We have empirical, encouraging evaluation about our courses through student evaluation for both courses – the courses scores have been consistently high among all technical courses in the department. In addition, the experimental graduate BIM course was evaluated and a new permanent BIM course is approved by the Department of Architecture and the university. However, more data is needed to evaluate the effectiveness of the introduction of BIM in these courses, which will be collected and analyzed in our future work.

Table 1
BIM system capabilities and course coverage.

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<tr>
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<th>Graduate</th>
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<td>Drawing Generation</td>
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<td>Ease of Developing Custom Parametric Objects</td>
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<td>Scalability</td>
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<td>Multi-User Environment</td>
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Figure 7
Parametric modeling and analysis of an Alaska cabin, by Georgina Davis, ARCH689, TAMU, Spring 2010. The porch overhand is a well defined parametric model, which is used to study the solar path and shadow effects on the porch in different seasons. Top: graphical and data analysis of sun angles; Bottom: the overhang and its supporting structure are changed parametrically.
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