Use of the 3D Parametric Building Model in Civil and Environmental Engineering Undergraduate Education at WPI

Guillermo F. Salazar, João C. Almeida
Worcester Polytechnic Institute

Introduction
The Architecture/Engineering/Construction (AEC) industry is highly fragmented. To deliver its projects, it depends on the knowledge, skills, and resources of many firms and professionals who are mostly regionally distributed. This fragmentation demands a high level of coordination among the many participants to maintain continuity in the communication of the design as it evolves from a simple idea to a completed physical product. At the same time, it is very difficult for all the participants to develop a consistent and integrated view of the project.

Likewise, the educational process of civil engineers is assembled in a similarly fragmented manner. The various technical disciplines offer courses to teach primarily specialized knowledge and skills to the students, emphasizing certain systems and components of the final product, but integration of disciplines is not stressed enough. This makes it difficult for the students to develop an overall view and understanding of the complete building and the civil engineering activity at large.

The recent introduction of affordable commercial software that supports the innovative concept of the Three-Dimensional Parametric Building Model (3DPBM) is perhaps the most promising mechanism for creating an integrated view of the project within the industry. The 3DPBM software also has tremendous potential for supporting the education of future generations of engineers. The 3DPBM is an object-oriented approach that allows the design team to develop an integrated 3D visualization of the building by creating new ways to reason about the product of design, and by introducing more efficient communication and coordination among multidisciplinary teams who participate through all phases of the project development.

For over three years, a software grant has allowed the authors to experiment with the 3DPBM concept through activities in courses and research at the Department of Civil and Environmental Engineering in the Worcester Polytechnic Institute (WPI) yielding positive and encouraging results. The main objective of this research is to provide students with the educational activities, throughout the civil engineering curriculum, that will allow them to better integrate their understanding of the building, its components, and the design and construction process. This paper describes how the 3DPBM has been introduced in the undergraduate curriculum in the context of the freshmen-sophomore course CE1030 “Civil Engineering and Computer Fundamentals”.
Design-Construction Integration

Over the last decade the area of integration of design and construction has been extensively researched. Four major approaches have been proposed to achieve this integration, these include: (1) Owner’s leadership and involvement during the project execution acting as a link among the various design-build teams, (2) Long term business relationships that help to develop informal bonds that facilitate inter-organizational learning, (3) Leadership provided by integration champions and (4) Professionalism and competence of the project participants and their ability to cooperate throughout the entire project execution.

A higher level of integration can be accomplished through the organizational structure when all members in the project team align their expectations and coordinate their efforts to meet those expectations. A collaborative design-construction team has a very clear definition and understanding of the ultimate project goals and communicates effectively sharing information and knowledge throughout the process to accomplish those goals. This integration is facilitated by creating a contractual relationship among the project parties in which the roles, relations and responsibilities are efficiently and unambiguously defined. Integrated design-build teams in which the two major parties, the designer and the builder, share a single contractual responsibility with the owner naturally lead to a more integrated process.

AEC Industry’s Trends

The AEC industry has been gradually moving towards concurrent engineering, an innovative and integrative work methodology used to reduce construction costs, accelerate design and construction, and to improve the quality of the final product. This approach promotes efficient integration of people, process and technology and relies on improved communication and coordination of simultaneous operation of multi-task teams. In February 1998 a group of researchers established the task Group 33, part of the International Council for Research and Innovation in Building and Construction (CIB) research agenda. Its goal was to further pursue the theory and practice of concurrent engineering in construction. Since then the group organized three international conferences (London, Finland, and Berkeley) and edited several papers and technical reports directly related to concurrent engineering. Research conducted at the Center for Integrated Facility Engineering (CIFE) at Stanford University currently emphasizes the concept of Virtual Design and Construction, i.e., the use of multi-disciplinary performance models of design-construction projects, including the building, work processes, organization of the design - construction - operation team, and economic impact. The core research at CIFE employs models that allow planners to visualize the construction process “as it would be actually built” with usage of graphic images.

The Three-Dimensional Parametric Building Model (3DPBM).

Powerful 3D software, such as CATIA, has been used by large firms like Stone and Webster and by renowned architects (e.g., Frank Gehry) for graphic representation and visualization of the building and its components during and after construction. Nevertheless, those powerful computer applications are extremely expensive requiring substantial investment in software, equipment and training. As a consequence, most of the industry and educational programs, including the civil and environmental engineering program at WPI, still operate with CAD software based on older technologies which creates 3D views as a series of lines and planes and stores information in multiple files, thus making the coordination, communication and
management of information a particularly demanding task. In recent years, however, the AEC industry is gradually moving to affordable 3DPBM software based on object-oriented technology in which the building information is created and defined as a collection of interrelated objects. Academically, some engineering and architectural programs, like the architectural program at Mississippi State University, have also started to use 3DPBM in courses and projects.

Basically, the 3DPBM stores all information related to the building in one central database and it allows any part of the building model - such as dimensions and annotations that document and describe the model - to be linked to and from all other parts of that building model.

In 2000, the Revit Technology Corporation introduced Revit, a software product based on the 3DPBM and developed specifically for the construction industry. In April 2002, Autodesk®, the vendor of AutoCAD and other CAD-related products, acquired Revit Technology. Autodesk Revit® (as the 3DPBM software is now known) may become the long-term platform for the building industry in the future. The specialized press frequently publishes articles related to 3DPBM stressing the innovative capabilities of the application 3, 4, 5, 6

The 3D Parametric Building Model and Integration

It is possible now to integrate the entire process, from design to construction using the 3DPBM. The 3D Parametric Building Model is a tool primarily intended to be used by the project architect who in most cases is the building designer. However, different members of the design team may have access to the model at different stages of design to develop some of its components. In this way a digital three-dimensional model of the final product gradually evolves from preliminary concepts to a detailed product specification in a collaborative fashion. The collaboration of the different members of the design team can be efficiently controlled and coordinated minimizing the potential for errors and omissions.

Due to the object oriented technology and its parametric engine of the 3DPBM, the integrity of the three-dimensional digital model of the design can be maintained at all times. Therefore, any changes made to any aspect of the design in the digital model at any time are systematically propagated to the entire model and consistently accounted for on any of the model representations, that is, plan views, elevations, cross sections, 3D views, etc. (See Figure 1)

Figure 1 Tiled windows showing different visual representations of the 3D digital model
In addition to the geometric integrity of the model, object orientation technology allows the designer to associate components of the building with other components. This association or relationship can be established hierarchically if so desired creating families of objects sharing common characteristics. For example, a door is usually associated with a given wall so when changes are made affecting the wall, the parametric engine checks for immediate impacts that those changes may have on the door. A rich database stores information associated to the technical and commercial attributes of each of the different components of the building (See Figure 2)

![Figure 2 Object Oriented Data Base links graphic objects to its attributes](Source: Richard Taylor, Revit Corporation)

The use of the model is not limited to the designer. Construction firms are starting to exploit some of the phasing characteristics of the model to analyze the constructability of the design prior and during construction and to produce 3D views of the sequence of construction and 4D models (See Figure 3). They also use export information from the model, such as quantities of materials to external databases and application software to produce cost estimates and schedules. Some owners are also extending the use of the digital model for facility planning and management.

![Figure 3 Sequential views of the building during construction](model by A. Elia, J. Lopez and V. Samadad, WPI)

Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition
Copyright © 2004, American Society for Engineering Education
Introduction of the 3DPBM into the Undergraduate Program

The 3DPBM concept was introduced at the undergraduate level through a 1-week module in the context of the freshmen-sophomore course CE1030 “Civil Engineering and Computer Fundamentals. The students had the opportunity to apply this concept later in the course in a subsequent 1-week module involving basic aspects of Fire Safety. The following objectives were identified for this study:

- To develop an integrated view and a better understanding of the building and its components.
- To improve communication, coordination and collaboration when students work in groups.
- To determine how effectively students can get started in the use of the software while developing the two previously stated objectives.

This course introduces students to fundamentals of civil engineering, group dynamics, oral presentation skills, engineering report writing techniques, and uses of the computer. Basics of structural engineering, geotechnical engineering, environmental engineering, surveying, materials, and construction engineering and management are presented in this course through a collaborative group teaching approach. Student groups complete weekly computer laboratory projects and develop oral presentations and written reports. No previous computer use skills are required or assumed.

Background Survey

A background survey addressed students’ past experience in working with design, construction, and management. Also, there were questions about their previous knowledge on software use, including CAD based systems. In general, the results of the background survey showed that the students had limited practical experience in the fields of design, construction, and management, as well as in software applications. The following tables summarize the most important information collected in that survey.

<table>
<thead>
<tr>
<th></th>
<th>Management</th>
<th>Design</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Experience</td>
<td>69%</td>
<td>50%</td>
<td>65%</td>
</tr>
<tr>
<td>Some Experience</td>
<td>27%</td>
<td>42%</td>
<td>23%</td>
</tr>
<tr>
<td>Internship</td>
<td>4%</td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td>Have Worked In</td>
<td>0%</td>
<td>4%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Table 1 – Students were asked about their experience in the fields of management, design, and construction

<table>
<thead>
<tr>
<th></th>
<th>Spreadsheets</th>
<th>AutoCAD</th>
<th>Revit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never Heard</td>
<td>4%</td>
<td>29%</td>
<td>100%</td>
</tr>
<tr>
<td>Some Idea</td>
<td>57%</td>
<td>43%</td>
<td>0%</td>
</tr>
<tr>
<td>Used Sometimes</td>
<td>29%</td>
<td>19%</td>
<td>0%</td>
</tr>
<tr>
<td>Used Frequently</td>
<td>10%</td>
<td>10%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 2 – Students were asked about their expertise on spreadsheets, AutoCAD, and Revit
The background survey represented a valuable source of information for future design and assessment of assignments, as they are shown in the next part.

Assignments
Three assignments were given to the students during the week.

Assignment 1: The first assignment asked the students to work in groups and to issue a request for painting and carpeting services for the classroom where the class was being taught. The objective of the task was to assess their ability to perform measurements of essential building elements, such as walls, windows, doors, and floors, and their ability to represent/communicate their findings. The use of CAD software was optional.

The results of the assignment were satisfactory given the degree of previous knowledge and experience the students. Two-thirds of the class used paper to generate their reports showing drawings with measurements and text. The other third of the class used CAD software to produce their drawings.

Assignment 2: The next assignment (individual) was related to the introduction to the 3DPBM software. The students were asked to complete a tutorial exercise that is included in the software’s “Help” menu. They also were asked to keep track of the time needed to complete the tutorial and to point out any difficulty regarding their exercise.

The results of the assignment 2 were also satisfactory. The students indicated that they were able to finish the task in an average of 2.8 hours. Approximately 40% of the students indicated that the greatest difficulty in getting started learning the software was to place and scale the stairs (a rather advanced feature). Other 20% indicated the most difficult part was in placing elements (walls, windows, or doors) in the model.

Assignment 3: The last assignment involved the measuring and drawing of a three-story house. Each group was asked to measure a part of the house and to generate the corresponding 3D models. The results of assignment 3 were quite adequate considering the level of knowledge they had when the class started.

Learning Styles Survey: An important part of the class related to the assessment of learning styles. The students were asked to complete an on-line survey, part of a model developed by Dr. Felder of the University of North Carolina. That model allowed the students to analyze their own learning styles in connection to the way 3DPBM was introduced to them in CE 1030. Table 3 shows the students’ perception of the value of the 3DPBM as a tool to do the work and to support collaborative effort. The majority of the students indicated that Revit was a helpful tool and facilitated group work.

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
<th>YES/NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Fitted Learning Style</td>
<td>85%</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Revit is a Helpful Tool</td>
<td>88%</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td>Revit Facilitate Group Work</td>
<td>67%</td>
<td>18%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 3 – Summary of Perceived Usage of Revit by CE 1030 Students

Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition
Copyright © 2004, American Society for Engineering Education
Fire Risk Management Plan
At a later week, the students participated in case study project that involved the planning of a risk analysis project for the same house for which the students did the work before. The students were asked to assess the personal and material risks in case of a fire. The task included not only the preventive aspects of fire safety but also to identify an efficient evacuation routing. The use of Revit was a valuable tool for all the groups of students mainly because:

- Students had the option to utilize previously created 3D versions of the house’s plans and therefore save invaluable time in the completion of the task.
- Groups could share their files with partial models of the house and integrate them into a single model for the entire house.
- The task of finding the most effective routing for egress in case of a fire was substantially facilitated because of the flexibility of having several views of the house.
- Finally, the assignment was accomplished in a quite effective way, especially because students could use the software’s “walkthrough” feature to produce a short motion picture of the exits available in the house.

Extending to the use of the 3DPBM to the Curriculum
After the end of the 2003 spring semester, the authors organized a one-hour workshop with seven WPI’s Civil and Environmental Engineering (CEE) department faculty. As a result of this workshop the department has outlined an efficient strategy for licensing the software and to create systematic educational activities in the future. Several specific actions have been identified for immediate implementation in other graduate and other undergraduate courses as well as in student projects and thesis. The most direct is related to the AutoCAD class in which assignment 2 of the CE1030 class has been incorporated in the course syllabus in the final week of the term.

Conclusions
The results of the use of the 3DPBM show that the 3DPBM model facilitates the progress of effective learning mainly because it involves sharing, communicating, and group problem solving. It also helps students to actively engage in the process of planning, designing, and interpreting construction related data. Moreover, the model represents an invaluable tool to teach students the notion of cooperative work, which is in line with the advancements of the construction industry. The experiment demonstrated that starting the use of the 3DPBM – based primarily on project outcomes - requires neither previous work-related experience nor high level of computer skills.

Another important aspect of the introduction of the 3DPBM within the CEE curriculum refers to future career opportunities created for WPI graduates in the AEC industry. The students not only gain a competitive advantage in the job market but they will also become agents of change impacting the way the industry works today.
Bibliographic Information


Biographical Information

GUILLERMO F. SALAZAR is an Associate Professor in Civil and Environmental Engineering at the Worcester Polytechnic Institute in Massachusetts. He received his doctoral degree from the Massachusetts Institute of Technology in 1983 in the area of construction engineering and project management. He has 30 years of national and international experience as a consultant, contractor, researcher and educator in the construction industry.

JOAO C. ALMEIDA is a Ph. D. candidate at the Civil and Environmental Engineering department, Worcester Polytechnic Institute (WPI). He holds an MBA from University of North Florida as well as a Master of Science degree from WPI in construction project management. He has more than 15 years experience in the construction industry (residential buildings) and management.