A 4D CAD LEARNING MODULE FOR SHORT INTERVAL PRODUCTION SCHEDULING

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ABSTRACT

4D CAD technologies (combining the 3D CAD models and construction time) provide the opportunity for students to more effectively visualize the built environment and gain experience and intuition related to construction method selection, construction sequencing, site planning, and site logistics. This paper focuses on a 4D CAD problem-based learning module that was developed and incorporated into an advanced project management course. The learning activity was modeled from an actual project, the MGM Grand Hotel Renovation in Las Vegas, Nevada. Students develop a Short Interval Production Scheduling (SIPS) for constructing the precast concrete structural system for a typical floor of the hotel. During the last offering of the course, a 3D model of a typical floor of the building and a schedule template were provided to the students so they could link the SIPS they developed with the 3D model in a 4D CAD application. The students could then review their solution and present it to their classmates and the instructor in the Immersive Construction (ICon) Lab on a large display system. A survey was conducted to assess the value of 4D CAD used in the assignment. The survey results show that the students perceive that the 4D CAD modeling portion of the exercise improved their understating of the SIPS process since they were able to communicate with their group members more efficiently, easily review their developed schedule, and present their solutions to the class and the instructor in a more interactive manner. From the research, the authors conclude that 4D CAD can be an effective learning aid for students to better achieve learning outcomes.

KEY WORDS

4D CAD, Engineering Education, Short Interval Production Scheduling (SIPS), Problem Based Learning.

1. INTRODUCTION

4D CAD technology is a powerful tool that combines a 3D CAD model with construction time. There are many studies that have identified benefits of 4D CAD modeling in the Architecture, Engineering and Construction (AEC) Industry (Fischer et al. 2003; Koo and Fischer 2000). 4D CAD modeling allows project teams to visualize construction plans;

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identify construction consequences and space conflicts; identify safety issues; and improve communication of the project team members. For example, the 4D CAD model built for the Walt Disney Concert Hall in Los Angeles helped the construction team find many schedule inconsistencies; resolve access, scaffolding and hoisting issues for the exterior and interior construction in a timely manner; inform more stakeholders of the approach to construction and of the schedule; and engage subcontractors in the scheduling process (Fischer et al. 2003). 4D modeling can also be valuable for production planning and trade sequencing (Riley 2000).

With successful applications of 4D CAD in the industry, it is feasible that 4D CAD may be very beneficial in construction engineering education. It can provide the opportunity to improve construction engineering education by allowing students to experience the dynamic nature of construction. 4D CAD modeling has been implemented in undergraduate Architectural Engineering Department at Penn State. In a previous study, the educational value of having students develop 4D CAD models for a building project was assessed, and it was found that the 4D models can enhance the ability for students to understand typical planning documents (Messner et al. 2003). By using 4D CAD models, students can visualize the built environment and gain experience and intuition related to construction method selection, construction sequencing, site planning, and site logistics.

This paper describes the implementation of 4D CAD technology to aid students' learning about Short Interval Production Scheduling (SIPS). SIPS can be an efficient scheduling method when construction involves repetitive work (Horman et al. 2003). With 4D CAD technology, students are able to not only visualize the schedule better, but also to compare the differences in possible alternative scenarios.

2. LEARNING OBJECTIVES

The original learning objectives of the module included: (1) learning the process for developing a SIPS for a project; (2) gaining experience in the sequencing of activities given resource and time constraints; (3) gaining experience in the impact of temporary equipment and site access on planning; and (4) learning how to effectively communicate a construction plan. To achieve these objectives it is essential for students to be able to visualize the construction site during the project along with the construction process. A 3D model of a building can aid students to understand the building design and the site better. 3D is especially helpful for students with limited design and construction experience.

The implementation of 4D CAD in the learning module can enhance students' understanding of the construction process, and also can facilitate more effective communication of the schedule. By implementing 4D CAD in to the learning module the instructor had the following objectives: (1) improve visualization of 3D design elements, (2) allow more effective review of solutions by group members, (3) encourage alternative solutions and more detailed solution reviews, (4) allow effective communication of developed solution to the class, (5) allow effective presentation and comparison of multiple solutions, and (6) reinforce 4D modeling skills.

3. BACKGROUND

3.1 SHORT INTERVAL PRODUCTION SCHEDULING

SIPS is a scheduling method used to organize construction work. Different from conventional scheduling, which breaks a project into operations, SIPS breaks an operation into detailed repeatable activities. Usually the operation is a critical sequence that is repeated throughout one phase of the project and has a significant impact on the overall duration. Three major attributes that distinguish a SIPS from convention scheduling procedures are (Burkhart 1989):

1. Only one specific operation is analyzed;
2. A much higher level of detail is developed in the SIPS,; and
3. Personnel involvement and commitment of everyone contributing to the operation is built into the process of developing a SIPS.

A SIPS utilizes the personnel involved in the project as part of the plan development, and the results of the SIPS process is a detailed, crew level plan for one specific operation. A SIPS applies the assembly line concept in construction. It provides a productive work sequence for the project and faster learning curve for the crew. It has been used to construct buildings with highly repetitive activities. Projects with a large number of repeatable units, such as hotels, apartments, high rise office towers and prisons, can benefit from the SIPS method. SIPS is a very valuable scheduling method that construction engineering students should learn and has been implemented in an advanced project controls course (AE 473) in the Architectural Engineering Department at Penn State University.

3.2 MGM GRAND HOTEL PROJECT

The learning activity is from an actual project, the MGM Grand Hotel Renovation in Las Vegas, Nevada. The hotel was the largest hotel in the world when it was completed in 1994. The hotel has 5,014 hotel rooms within 30 floors. It has a cross shape with an 88m (290 ft) tall core and four symmetric wings around the core (See Figure 1). The first four floors are cast-in-place reinforced concrete, which supports the other 26 precast concrete floors above. The structure had to be finished within 9 months to meet the owner's requirements.

Figure 1: MGM Grand Hotel Construction Site

Since the precast concrete structure is repetitive for each floor, the construction of the structural system is a viable candidate for the SIPS method. This assignment requires students to develop a SIPS for constructing the precast concrete structural system for a typical floor of the hotel within the time, crew, and equipment constraints.

In previous offering of this assignment, students were given a 2D plan (See Figure 2) of a typical floor, together with some pictures taken from the construction site to visualize the structure system. During the fall 2005 semester, a 4D CAD problem-based learning (PBL) module was incorporated into this assignment as a learning aid for students to learn about SIPS as well as learn potential benefits of 4D CAD.

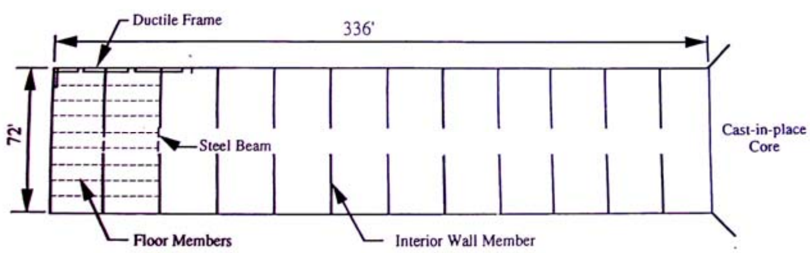

Figure 2: 2D Plan of a Typical Floor

4. THE LEARNING MODULE

4.1 PROBLEM-BASED LEARNING

Problem-Based Learning (PBL) is an instructional method that uses real-world problems to promote the development of critical thinking and problem-solving skills, and the acquisition of key concepts of the knowledge area in question (De Camargo Ribeiro and Mizukami 2005). The emphasis on the active construction of knowledge and on learning in response to and in interaction with real-life problems forms the basis of PBL (Schmidt 1993). The main characteristics of PBL that distinguish it from other types of active, student-centered learning processes is its emphasis in introducing concepts to students by means of challenges in the form of problems relevant to their future practice (Woods 1995). The SIPS for the MGM Grand Hotel assignment inherits these characteristics of PBL. The students are presented with a real life situation from the construction industry that challenges them to develop the most appropriate schedule. Generally, there is no “one” correct answer in PBL, rather there are a number of possible solutions. Each of the solutions could have its potential advantages and disadvantages and students should be aware of them. This characteristic of PBL is well suited for teaching construction scheduling and in particular SIPS, since there could be various solutions to the problem.

Nevertheless, it is also important to note that PBL poses a number of challenges for students and instructors. Many PBL courses rely primarily or exclusively on written or oral problem statements and learning resource material (Hoffmann and Ritchie 1997). It is sometimes difficult for students to visualize the problem. Therefore, students may be confused when confronted with a real life situation. Multimedia, and in the case of this research, 4D CAD visualization technology, can help to address this challenge. Multimedia's ability to increase the richness of the problem also increases the user's ability to interpret and understand the problem through repeated exposures (Hoffmann and Ritchie 1997). Spiro et al. (1992) describe the need for students to repeatedly interact with instructional material in different media forms for better learning.

Engineers are problem-oriented thinkers. Therefore, PBL is likely to be an effective educational tool for engineers (Honebein et al. 1993). The PBL method will allow students to be exposed to challenging, realistic problems, formulate hypotheses, experiment with different scenarios, and test possible solutions. In the process of learning about the solution, students also learn about the topic and learn how to critically think through experience. Problem-based learning is highly suited to developing sound engineering skills, especially for design and construction engineers (Felder and Silverman 1998). The MGM Grand Hotel 4D CAD module, which is based on a real life project, exposes students to the challenges of this environment and develops their problem solving skills.

4.2 MODULE DEVELOPMENT

A 3D model of a typical floor of the hotel (See Figure 3a) was developed using a CAD application. The 3D model was then revised so that all geometry is grouped and arranged according to the construction activities. A schedule template (See Figure 3b) was created using MS Project scheduling software. Both the model and the schedule template were designed in such a way that students can manipulate and experience the model with minimal burden of technical issues.

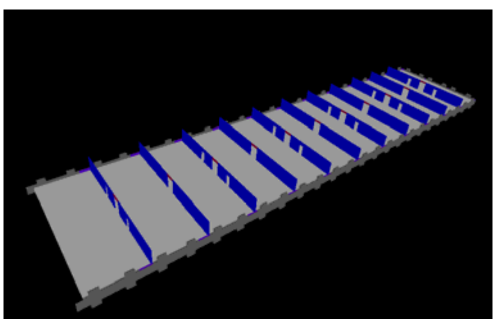

Figure 3a: 3D Model of a typical floor

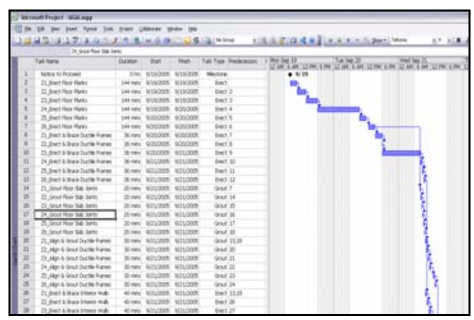

Figure 3b: Schedule template in MS Project

4.3 MODULE INCORPORATION

Students learn how to use the NavisWorks TimeLiner 4D CAD application (NavisWorks, 2006) in one of the classes prior to the SIPS assignment. They start with a simple office model to learn how to import a 3D model and a schedule into the software and link them together. This allows students to become familiar with the software and gain the necessary skills they need to finish the assignment.

After the students are familiar with the 4D CAD software, they start to work on their SIPS assignment. They develop a SIPS in the schedule template, and link their schedule with the given 3D model using the 4D CAD software. The 4D CAD application allows students to review and test their solutions. Final solutions are exported into video files for submission with the assignment. Student groups also present their solutions to their classmates and the instructor in the ICon Lab on a large 3-screen display system (see Figure 4).

Figure 4: Student Group Presenting Solutions on the 3-Screen Display in the ICon Lab

5. ASSESSMENT

The assignment provides an effective learning case study for students to learn the SIPS process, as well as provides an opportunity to assess the impact of 4D CAD in construction engineering education. The impact of the 4D CAD module is assessed by measuring student group performances as defined by their final solution accuracy and presentation effectiveness. Student group communication, student motivation and attitude toward 4D technology were investigated as well by using a survey questionnaire.

5.1 Comparative Assessment

A scoring rubric (Goodrich-Andrade 2000) was designed and used to assess the performance of each student group in 2004 with the same MGM project. The baseline of the group performance is measured using the traditional 2D drawing and CPM schedule. The same rubric was used to evaluate the performance of each group after the module was implemented in the fall 2005 semester. Compared to the previous year, the overall quality of the solutions shows that the student groups are able to develop better solutions than groups in the previous year. For example, 6 out of 9 student groups noticed there are some activities that can be overlapped when using the 4D CAD model, while there were only 3 out of 9 groups that overlapped these activities in the previous year. More groups also noticed there are some activities that can not be conducted during the night shift in 2005. The 4D model of the SIPS allows students to review their solutions and helps them easily identify sequence conflicts, which are difficult to identify in the CPM schedule, so that they can revise their SIPS and determine the most efficient order for each activity. All these factors helped the student groups achieve more logical solutions than the previous year.

5.2 Observation of Presentation and Discussion

Student presentations and discussions were observed when student groups presented their solutions on a large, 3-screen display in the ICon Lab. In the previous year, the instructor reviewed all the solutions from student groups, then discussed with students the most common problems they had in their solutions. With the help of the 4D model, each student group explained their SIPS to other students and the instructor in class in 2005. Since the 4D CAD model graphically presented the SIPS, students could review the SIPS developed by other groups and experience multiple outcomes for the same project. And each group could get immediate feedback on their solution. 4D CAD model makes the learning activity more interactive by allowing students to review and critique different solutions.

From in class discussion, it was noted that the model development improved the planning process by identifying additional issues that were not noted before. For example, the 3D model of one typical floor has two ends, and one end is connected to the core of the building. Some student groups didn't notice this and started constructing the floor from outside toward the core. This was noticed during the review process, and students started discussing issues related to the site planning and site access introduced by this problem. Other topics related to construction methods of grouting exterior wall connections were also discussed when students discovered that the necessary equipment (the crane) would not be available.

5.3 Survey

After students finished the assignment and presented the solutions in the ICon Lab, they were asked to provide feedback on the 4D CAD module by completing a survey. The survey investigated the value of 4D CAD vs. 2D drawings and a CPM schedule; the communication style of the group when they worked on the assignment with the 4D module; the ease of reviewing and revising the schedule they developed; the ease of presenting solutions to the class and the instructor; and to what extent the students understood the SIPS process by using the 4D CAD model. At the same time they were asked to state what challenges they encountered when they worked on the assignment and suggest improvements for the 4D module offered to them. Unstructured student interviews were also conducted with the students and the teaching assistant.

The survey results show that students felt the 4D CAD modeling module improved their understanding of the SIPS process, since they were able to (1) communicate with their group members more efficiently, (2) easily review their developed schedule, and (3) present their solutions to the class and the instructor in a more interactive manner. It also helped them understand other groups' solutions and learn about alternative schedules by graphically stepping through the schedules in the class (see Figure 5). Students provided positive feedback regarding the 4D CAD modeling activity and regarding the assignment design. While the survey showed the value of a 4D CAD model, it also illustrates the difficulties that students had in fully understanding the construction plan by reviewing a traditional CPM schedule.

Unstructured interviews with some students show that students were engaged by the 4D CAD component implemented into this course. They realized the benefits of the 4D technology and would like to use this technology on their other appropriate course projects and future work. The teaching assistant (who took this course in 2003, and acted as teaching assistant in both 2004 and 2005), said the 4D video helped him a lot in identifying which groups more clearly understand the constraints and how to use the resources to schedule the project. He identified the most valuable part of the modules as the in-class discussion, which allowed student groups to get feedback directly from their peers and the instructor.

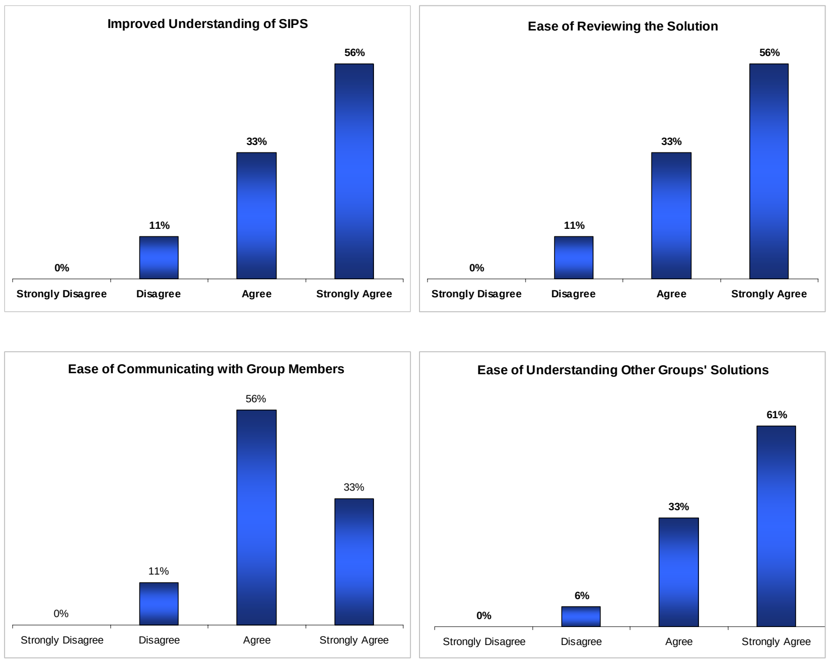

Figure 5: Survey Result

6. LESSONS LEARNED

Though there are a lot of benefits using this 4D CAD learning module, there are some drawbacks that deserve attention. First of all, it was found that the quality of the paper version CPM schedules developed by groups were not as good as the previous year. One group even neglected to submit a paper version. They put more efforts into the 4D CAD development and, in general, decreased their emphasis on the CPM schedule presentation. It is important to emphasize that 4D CAD modeling is a supplement to traditional 2D drawing and CPM schedule, not a substitute. It should be made clear to students that traditional methods are always important. We want to make sure the 4D technology is a good learning aid, which engages students to be more interested in what they are learning instead of them paying more attention to the technology itself. Second, the model should have an appropriate level of details. Students get confused when they found that there are some details, such as grouting joints and connections, which were not displayed in the 4D model. This may reduce the effectiveness of the module by causing confusion and cause students to spend more time in developing the model.

7. CONCLUSION

The use of 4D CAD can make a significant impact on the education of construction engineering students. 4D models are very helpful in classroom discussions. For the case study performed in this research, students tended to discuss more issues related to the SIPS process, such as site planning, construction methods selection and equipment availability.

The 4D model allowed students to visualize both the problem environment and the solutions more effectively. Students could focus on resolving core problems instead of spending time trying to visualize the projects characteristics. This technology can improve group interaction and communication, motivates student learning in an engaging way, and help students achieve effective presentation and better learning outcomes. From this experience, students learn the value of using 4D technology and would like to implement it into their future work

8. FUTURE RESEARCH

In the 2005 offering of the 4D SIPS module, student groups developed the 4D model from the 3D graphical model and a SIPS construction schedule. Then they used a desktop monitor to interact with the virtual model, identify sequence conflicts, and revise their schedule into the most effective sequence. The 3D model and the construction schedule were inputs to this process, and the 4D model was the final product and used as a schedule review tool.

Our next approach will be to develop an interactive module which will allow students to generate a construction schedule directly from the 3D model in an immersive environment, using the large display system in the ICon Lab. The immersive environment should enhance the learning experience by allowing students to enter a virtual space and gain a sense of presence, so that they can visualize the space in more detail and navigate the model to generate an accurate schedule. The output will be a CPM schedule and a 4D CAD model. The impact of the implementation of the immersive environment and the interactive 4D module will be assessed.

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