The virtual construction simulator - development of an educational simulation game

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**Abstract**

The ability to effectively visualize the construction process and make important decisions about resource utilization, sequencing, site layout, and project-related risks are critical skills for design and construction engineering students. The increase in complexity of projects and shorter schedules pose pressure to develop more efficient construction methods, and also many challenges to educators to prepare students to manage these multifaceted processes. CPM schedules and 2D drawings have been predominantly used for developing construction schedules, but remain rather challenging for construction engineering students who lack the experience required to understand the dynamics of construction processes.

Research at the Pennsylvania State University initiated in 2004 focused on developing a construction schedule simulation application - the Virtual Construction Simulator - as a 4D learning module to visually immerse students in a 3D model allowing them to interactively create a sequence for constructing a building project. The VCS was implemented in an upper level construction management course in 2006 and 2007 and demonstrated benefits for teaching construction scheduling. However, the current VCS application lacks specific project-based constraints that would motivate consideration of the most feasible construction sequence. The feedback exclusively comes from the instructor which can limit the students’ exploration of various decision consequences.

The goal of the current development initiative is to extend the functionality of the existing VCS application into a more comprehensive simulation game with project constraints, rules, variability and system feedback. The goal is to create an experiential simulation environment where students can make decisions about resources, methods, cost/time trade-offs and related risks; and observe the impact of these decisions over time thus actively learning to manage various factors that impact construction projects. The immediate feedback will allow students to track their own progress, while the competition and scoring will introduce fun for more engaged, motivated and deeper learning of complex construction concepts.

**Keywords**: simulation game, construction scheduling, education

1 **Introduction**

Building and infrastructure construction projects are becoming increasingly more complex to match ever more rigid cost, time, quality, safety, and sustainability requirements. This increase in complexity, along with the need to develop more efficient construction processes for reducing negative environmental impacts, poses many challenges to educators to prepare students to manage
these multifaceted processes. Problem solving, decision making, visualization of the built environment, and construction knowledge itself are all important skills for students in the engineering, architecture and construction disciplines. Students are often faced with the enormous challenge of visualizing complex three-dimensional systems and understanding the spatial and temporal relationships required for their construction. Understanding the logic of construction processes and managing inherent project risks is difficult, especially at the undergraduate level with limited practical experience. Traditional educational approaches toward teaching construction processes have typically focused on lecture and class exercises supplemented with field trips to construction sites as critical learning experiences. Although exposure to actual construction settings is very valuable, this approach is often hindered by logistics and lacks the sufficient time for students to see various construction stages and gain deeper understanding of construction complexities.

An evolving area of research and development concerns the use of educational computer simulation games to provide engaging learning experience. Educational simulation games, also referred to as serious games, can effectively simulate real world scenarios to test and aid in the development of student decision making skills and judgment.

2 Simulations in construction engineering education

Several recent research initiatives in engineering education have focused on developing methods to overcome the limitations of traditional methods that use 2D documents for teaching concepts such as scheduling, site congestion, construction trade coordination and other construction project-related issues. One of the challenges construction engineering students frequently encounter lies in understanding the variability underlying complex construction processes and the ability to discern important from less important information. It has been argued that traditional educational methods provide students with theoretical knowledge out of context and that construction processes are taught in a way that does not equip students with knowledge applicable in real life situations (Chinowsky and Vanegas 1996; Dossick et al. 2007; Galarneau 2005).

To address some of these challenges, a small but growing amount of research has shifted toward exploring the value of educational simulations so that students can experience construction issues in environments that closely resemble real construction project situations (Park and Meier 2007; Sawhney et al. 2000). This approach aims to allow learners to build their own knowledge through active participation and reflection instead of simply receiving the information (Galarneau 2004).

A number of simulations developed for teaching construction processes focus on strategic decision making skills by simulating the management processes of the construction company. Such examples include AROUSAL (Lansley 1982); SBID (AbouRizk and Sawhney 1994); CONSTRUCTO (Halpin and Woodhead 1970), and MERIT (Wall and Ahmed 2008). Alternatively, STROBOSCOPE (Martinez and Ioannou 1999) and VITASCOPE (Kamat and Martinez 2004) are developed to visually simulate detailed construction operations and processes such as earthmoving or concrete delivery.

Of particular interest are situational simulations as an opportunity to develop an authentic learning environment in which students can explore “what if” scenarios related to construction processes. Internet-based Construction Management Learning System (ICMLS) is conceived as a discrete event simulation to allow students to test strategies related to construction materials, methods, scheduling, estimating, cost, and resource allocation (Sawhney et al. 2000). Virtual Coach is another example currently being developed as a temporally dynamic environment with system-generating random events, requiring participants to quickly make appropriate decisions (Mukherjee et al. 2005). Since actual construction projects are characterized by constant changes, resource fluctuations, and unexpected delays, these simulations, although not yet fully implemented, aim to teach students the variability of some of these processes and equip them with skills to react to changes and modify strategies accordingly.
Current terminology does not clearly distinguish between simulations, simulation games, and serious games. However, the specific attributes commonly associated with serious games include competition; immediate performance feedback to users’ actions facilitating exploration of problem domain; random or pre-scripted events that impact project outcomes requiring in-depth risk and strategic analysis, and some form of rewards. Aldrich (2003) argues that an ideal learning environment contains elements of both simulations and serious games. While simulation elements facilitate practicing specific skills, game elements create a competitive environment which promotes motivation and engagement, critical aspects of effective learning (Aldrich 2003; Bartles 2003).

3 The Virtual Construction Simulator (VCS)

The Virtual Construction Simulator research project initiated in 2004 sought to address several limitations of traditional methods that use the critical path method (CPM) for teaching construction scheduling. With the increased project complexity, the CPM method can impose a challenge for students to visualize and understand the dynamics of construction processes and easily develop alternative solutions to the construction sequence, method selection, or resource allocation.

The Virtual Construction Simulator (VCS) was developed and implemented in 2006 as an educational module using the Deep Creator game engine for improving knowledge in sequencing (Wang, 2007; Wang and Messner 2007), followed by the improved version developed and implemented in 2007 using Irrlicht open source rendering engine (Jaruhar, 2007). VCS was implemented in an upper level management course and demonstrated an improvement in the scheduling process allowing student teams to directly interact with the 3D model and more easily and effectively create, review and visualize construction schedules, while also engaging in more detailed discussion of alternative solutions with team members (Jaruhar, 2007; Wang, 2007).

3.1 The VCS 3D – Simulation game

Although the Virtual Construction Simulator has demonstrated its value, it does not contain any specific project based constraints that actively seek to motivate students to consider the most feasible set of resources to perform work, or to allow students to revise their initial plan based on progress throughout a project. The primary feedback which students currently receive comes as instructor’ comments and in-class presentations and discussions which tie back into a form of passive learning, and limits, to an extent, student retention of information during planning tasks.

The goal of the current development effort is to extend the functionality of the existing VCS application into a more comprehensive simulation game with project based constraints, rules, variability and system feedback. In this experiential simulation environment students will be able to make decisions for constructing a project and observe the impact of these decisions over time; thus actively learning to manage various factors that impact construction schedules. The immediate feedback will allow students to track their own progress, while the competition and scoring will introduce fun for more engaged, motivated and deeper learning of complex construction concepts.

3.2 Development

Learning objectives guiding the development of the VCS 3D aim to increase knowledge in students about factors affecting the construction schedule such as choosing appropriate construction methods; developing an efficient construction sequence; understanding the resource management needs of the project; and understanding tradeoffs in managing project duration, cost, quality and safety. The simulation game is conceived as a stepped process where students would develop a construction schedule based on a goal defined by the instructor (owner’s satisfaction, budget constraints, or meeting a deadline); observe the daily, or weekly progress of construction for a given project, and
make necessary adjustments to the initial schedule and resource allocation based on the simulation reports. This process would demonstrate the difference between the as-planned and as-built schedule resulting from the impact of factors such as weather, congestion, learning curve, or overtime based on construction project conditions. To simulate these dynamic changes of the construction progress, the calculation of the as-built schedule is approached from a system dynamics model.

3.2.1 System dynamics model
Studies of the CM domain generally agree on the dynamic nature of planning and managing construction projects, involving multiple feedback loops between various resources. Modeling and simulating these processes is thus very complex and challenging due to a high level of unpredictability of factors involved in these processes. A widely accepted approach to simulating construction has been representing processes as discrete events. However, construction projects and processes are too complex and subject to constant changes to be managed in a linear and deterministic way (Toole 2005).

System Dynamics have been considered as a complementary approach to modeling the construction environment due to certain argued advantages to discrete event simulations. These advantages pertain to the ability to model “softer” variables, relating to behavioral and qualitative relationships in the existing system such as morale, fatigue, rework, overtime impact on the productivity, or the learning curve of new workers coming to the construction site (Han et al. 2005; Pena-Mora and Park, 2001). Although the project construction and management feedback loop is quite complex in real world projects; the number of variables in this study is decidedly limited to control for the complexity of the simulation game and avoid information overload to allow for more efficient learning in students.

The metric for satisfactory project construction completion is defined through owner’s satisfaction, as a function of project duration, cost and overall quality. Productivity rate is a variable that will influence the project duration and is directly affected by factors such as learning curve, overtime, overcrowding, and weather conditions. Students have traditionally had very little understanding and awareness of workers’ productivity fluctuation during construction and therefore tend to adopt schedules as a determined sequence of activities with fixed durations. For example, at the start of the construction activity, workers’ productivity may be lower due to a lack of knowledge about the work environment. In situations where the project is under strict time constraints, overtime may be one method to increase the production. Overtime, however, as a psychological effect and resulting in fatigue leads to a reduction of productivity throughout both the normal work period and overtime (Neil, 1982; Pena-Mora and Park, 2001; Thomas and Raynar, 1997). Another method to meet the project deadline would be to hire more workers in which case issues may involve available work space and the possibility of overcrowding, thus affecting the productivity. Resource allocation and resource levelling therefore become very challenging under budget, duration or resource constraints.

Through different scenarios, the VCS 3D simulation game aims to actively involve students in learning to manage daily resource needs and ensure maximum utilization of resources, along with managing trade-offs in minimizing activity delays. At the start of the simulation, students will make initial decisions about construction methods, resources and activity sequence, and subsequently enter the simulation mode where certain factors and events are triggered. Students will observe the daily progress ending with the summary report on the cost, duration, resource utilization and any additional information explaining the changes to the as-planned schedule. Based on the report, students can make necessary adjustments to the initial schedule and run the simulation again repeating the process until the project construction is completed.

3.2.2 Simulation game structure
The VCS 3D is being developed using an open source C# based Microsoft XNA Game Studio™ to support the simulation and 3D visualization; and a Microsoft Access database to store information about construction methods, activities and resources. The modular approach to the VCS 3D
development considers specific function libraries with an option for their reuse in future simulation expansion. Functions currently being developed include construction method selection; resource assignment functions; schedule calculation; cost calculation; 4D simulation; and reporting functions (Figure 1a). Storyboarding, along with students’ feedback and evaluation of the previous two VCS versions, served to define and develop the VCS 3D user interface (Figure 1b).

Figure 1. a) The VCS 3D development structure; b) VCS 3D user interface

3.3 Implementation and assessment

Upon preliminary testing, the VCS 3D simulation game will be implemented in an assignment within a third-year construction engineering and management course. An activity will be structured around a smaller scale project (the construction of a pavilion) with detailed construction methods. The pavilion project is based on a real world project and represents the first phase in developing varying levels of difficulty in the simulation game. Projects of greater complexity along with additional system dynamics variables will be implemented in the subsequent project phases following the implementation and assessment of the first phase.

In the simulation, students will assume the role of the superintendent and observe the daily progress of the as-built schedule. Based on the report, students will make necessary adjustments for the following days and continue to run the simulation until construction is completed. Upon completion, students will justify their decisions, and reflect upon the results of the project performance. To determine the level of learning that occurred as well as the level of motivation during the activity, pre and post-test questionnaires will be administered, while observations will serve to assess any additional information about the group interaction with the simulation, as well as the learning process that may not be otherwise captured through surveys and questionnaires.

4 Conclusion

Simulations and games have been largely stated to be advantageous and beneficial as instructional tools, however, their wide acceptance in educational curriculums has not yet happened due to the lack of convincing data. The reason for such state is because the direct measurement of the effectiveness of games and simulations has proven to be rather difficult. The ongoing research and existing applications being developed demonstrate the need for a complementary approach to traditional ways of teaching complex construction processes. The VCS 3D simulation games aims to address existing challenges in teaching students the dynamic nature of construction through active learning where students can practice to identify problems, make decisions and observe the effect of those decisions.

This paper has discussed the development process of the VCS 3D simulation game and the conceptualization of the application through modular program libraries and system dynamics. The next step is to perform pilot testing of the application followed by its implementation in a construction...
management course. Results will aim to contribute to the existing knowledge on the pedagogical value and effectiveness of simulation games in construction engineering education.

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