The Pennsylvania State University

The Graduate School

Department of Architectural Engineering

EVALUATING A SIMULATION GAME IN CONSTRUCTION ENGINEERING EDUCATION: THE VIRTUAL CONSTRUCTION SIMULATOR 3

A Dissertation in

Architectural Engineering

by

Dragana Nikolić

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2011

The dissertation of Dragana Nikolić was reviewed and approved* by the following:

John I. Messner
Associate Professor of Architectural Engineering
Dissertation Advisor
Chair of Committee

Jelena Srebrić
Associate Professor of Architectural Engineering
Adjunct Professor of Mechanical and Nuclear Engineering

Loukas Kalisperis
Professor of Architecture

Chimay J. Anumba
Professor of Architectural Engineering
Head of the Department of Architectural Engineering

*Signatures are on file in the Graduate School

ABSTRACT

Building construction processes are dynamic, complex, and subject to constant and unanticipated changes and delays. Learning to manage inherent construction process variability and its associated risks is challenging, especially at the undergraduate level when students typically have only limited practical construction management experience. The advances in computing technology have afforded novel approaches to teaching dynamic construction management concepts that could transform undergraduate learning. One such advance – educational *simulation games* – has shown great promise in teaching students construction process variability, allowing learners to react and respond to unanticipated construction events in a safe, simulated construction environment. To date, construction engineering undergraduate programs have not yet fully embraced the potential of simulation games and have fallen short when integrating this potentially transformative teaching approach into the classroom. In addition, a literature review yields a paucity of research on the simulation game development process and its effectiveness in construction engineering and management education.

To address these gaps, the present study explores simulation game applicability for construction engineering education and provides guidelines for the development of the next generation of simulation game learning tools. This study begins by explicating the simulation game attributes conducive to learning and motivation, and details the development process of the Virtual Construction Simulator 3 (VCS3) game to teach students the dynamic nature of construction project planning and management. The VCS3 incorporates project constraints and real-time feedback, and allows students to optimize for varying construction process strategies and observe results in real time. The underlying system dynamics model encapsulates the feedback loop between varying construction factors to simulate industry conditions and add to the content realism.

The pedagogical value of the VCS3 simulation game is estimated through a pre- and post-testing of 97 students in a third-year introductory course to building construction at Penn State. Findings indicate the value and the potential of the VCS3 simulation game to help students form a more holistic view of construction scheduling, and increase student interest and motivation in learning about construction processes; cost and time tradeoffs; and inherent management challenges. The VCS3 simulation also helped students to discern the differences between the as-planned and as-built construction schedules resulting from varying factors such as resource availability, weather and labor productivity. Goal-driven exploration and immediate feedback confirmed the value of the VCS3 simulation game to shift the student's role from passive to active learner complementing instructor feedback and creating opportunities to raise more questions and more robust in-class discussions.

The development of the computational simulation game model, along with the documented process and implementation findings further an understanding of the role of simulation games for construction engineering education; address the changing mode of learning for the current generation; and provide a basis for the promotion of the next generation of effective learning tools based on simulation games.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I am very grateful to my dissertation committee for their encouragement and support throughout my research work. I am indebted to my advisor, Dr. John Messner for his continuous support, tremendous patience, and excellent mentorship. I thank him deeply for his belief in me and encouragement to embark on this long and exciting academic journey. His visionary and caring personality, dedication to work, enthusiasm, and passion were inspirational.

I thank Dr. Chimay Anumba for his always thought-provoking questions and his expertise that provided direction when needed. His kind personality and sense of humor made the research environment all the more exciting and stimulating.

I was privileged to have Dr. Loukas Kalisperis continue to challenge my thinking with new ideas and I have enjoyed our spirited discussions about both the academy and life.

I extend special thanks to Dr. Jelena Srebric for her sharp mind, support, and invaluable friendship throughout my studies. She has taught me how to believe in myself and has shared valuable life and career lessons.

I thank Dr. Sanghoon Lee for his tremendous help and work in programming the simulation game for this study – he was a true pleasure to work with.

I am very grateful for the support from the Visualization Group for this study. In particular, I thank George Otto for his invaluable and continuous support, and Lorne Leonard for helping with the programming at critical times.

I extend my sincere thanks to Dr. Sarah Zappe for her selfless support and feedback during implementation and data analysis.

I am deeply thankful to my dearest friends and CIC members for their help and feedback at all times: Elena, Craig, Steve, Ralph, Sonali, Atefeh, Rob, Chitwan and Andreas – I cherish you all.

Above all, I thank my family for providing me with strength and motivation to persist on this quest for knowledge – my fiancé Seth for his love, optimism, and selfless support throughout my graduate studies, and my mom for her endless patience, encouragement, and unconditional love from miles away.

Chapter 1

Introduction

The education and training of young engineers in construction involves many challenges. Building construction projects are becoming increasingly more complex to match ever more strict cost, time, quality, safety, and sustainability requirements. This increase in building complexity necessitates more efficient construction processes and cost-effective management of available resources. Planning and managing a construction project is a dynamic process subject to changes and unanticipated events, and involves intricate relationships of various factors that affect construction progress and project performance. The multifaceted nature of construction planning and management processes is becoming more difficult for inexperienced students to grasp. While on the job training has been traditionally a major portion of experiential learning, construction industry progressively more demands graduates with sufficient domain knowledge and adequate problem solving skills to enter the job force as productive employees. Traditional lecture-based approach still focuses on memorization of facts and limits students to explore different options and experience various situations found in real world projects. To address some of the challenges, an evolving area of research is the use of educational computer simulations to enhance the learning experience. These educational simulations, sometimes also referred to as serious games, can be developed to simulate real world scenarios which test and aid in the development of decision making skills for students. Computer simulations can capture complex and dynamic relationships between various factors and add to the content richness and realism complementing the lecture format of instruction. Grounded in theories of situated cognition and constructivist framework, simulations and serious games offer a more active approach to learning, one where students can test various options, explore consequences, and through constant feedback develop their own understanding of the processes.

Background

Problem solving, visualization of the built environment, decision making, and construction knowledge itself are all important skills necessary for students in the engineering disciplines. Students are often faced with the enormous challenge of visualizing complex three-dimensional structures and understanding the spatial and temporal relationships required for their construction. Furthermore, understanding the logic of construction processes and managing inherent project risks is difficult, especially at the undergraduate level with limited practical experience. Anecdotally speaking, superintendents or project managers frequently comment that while newly-hired engineering graduates often excel in computer skills and the use of scheduling applications, they often lack an understanding of underlying schedule logics. This is not surprising since the current generation of learners with information age mind set represents the most technically savvy population in recent decades. However, current teaching methods face challenge to address this change in learners' characteristics and equip students with necessary knowledge and problem solving abilities applicable in the industry and practice. Traditional educational approaches toward teaching construction processes have typically focused on lectures and class exercises focusing on memorization of facts and presenting students with problems that are mostly well structured and detached from the context. Field trips to construction sites as a supplement to classroom teaching represent a critical learning experience. However, exposure to actual construction sites is often hindered by logistics and lacks the sufficient time for students to see various construction stages and gain deeper understanding of construction complexities.

To bridge the gap between the theoretical knowledge and knowledge applicable in real life settings, new approaches to teaching construction concepts concern the use of computer simulation games to enhance the learning experience. Grounded in theory of situated cognition and constructivist framework, simulation games are explored as instructional settings where students can practice decision-making and solving of ill-defined problems commonly found in design and construction domains. Through immediate feedback students can start testing different scenarios and track and observe the impact of their decisions in an environment that closely resembles reality. Simulated game environments can increase the sense of engagement and motivation identified as critical aspects of learning. Advanced development of computer and media technology has made simulation games highly interactive and engaging bringing various opportunities for educators to promote active learning through exploration.

Educational simulation games are associated with scenario based and discovery learning and allow users to practice problem solving by viewing it from different perspectives (Warren 2001). Thus, the problem-solving and decision-making environment of simulation games promotes them as potentially effective interactive instructional tools. Capturing complex relationships between various variables, simulation games promote learning through processes of identifying the relationships and making corresponding decisions which may resemble real life situations. In this sense, simulation games are also valued to promote skill transfer and knowledge applicable in real world situations (Warren 2001). However, from the pedagogical perspective, the design and the development of simulation games face challenges in achieving the balance between the realism of the modeled reality and the level of complexity that is not overwhelming to the students.

Research initiated at the Pennsylvania State University in 2004 focused on developing a 4D learning module – the Virtual Construction Simulator – to immerse students in a 3D model to interactively create a building construction sequence. The main objective of this research was to address the limitations of existing construction teaching methods that used the critical path method (CPM) and 2D drawings as their primary educational tools. Wang (2007) and Jaruhar (2007) developed the Virtual Construction Simulator (VCS) – a 4D learning module to visually immerse students in a 3D model as they interactively create a sequence of construction for a building project. In its two versions, the VCS 4D learning module sought to integrate schedule creation and 3D information review processes for developing 4D models allowing students to create groups of individual objects, attach activities to these groups, and generate sequences between these activities. To generate the construction sequence, students must identify appropriate work packages; develop activities with appropriate durations for each work package, and design an effective sequence for the construction activities. After developing their process, they can then visualize their solution as a 4D model.

Implementation of the VCS 1 in 2006, and VCS 2 in 2007 in an upper-level construction management course demonstrated its value in helping students to more easily and effectively create, review and visualize complex construction schedules (Nikolic et al. 2009; Wang and Messner 2007). However, the VCS 4D module was envisioned as only the first step in this research, and does not contain any specific project-based constraints to motivate students to consider the most feasible resource parameters or allow students to revise or modify initial plans based on project progress. The lack of real-time performance feedback limits exploration of alternatives as students receive their schedule evaluations exclusively from the instructor during in-class reviews. While this format allows for a compelling learning experience, the exploratory nature of the planning experience is limited since the instructor is leading the exploration and evaluation.

Embedding substantive interactive feedback mechanisms and extending the VCS from a *simulation* into a *simulation game* platform would encourage an active learning and allow students to track and observe the impact of changes on their developed construction plan. The development of VCS game enables students to explore various tradeoffs when choosing construction methods or allocating resources to manage cost, duration, quality and safety. Through the VCS simulation game application, students can observe the differences between as-planned and as-built schedules resulting from actors such as weather or labor productivity. Thus, the VCS game affords incentives for students to examine project sequencing logic or optimize efficiency of all available project resources through immediate feedback of project management decisions.

The purpose of the study

The changes in learners' characteristics of today's generation, and the existing discord with the one-way passive instruction of dynamic construction management problems necessitate innovative teaching methods to address these changes for enhanced learning. The increased pressure on instructors to equip students with necessary knowledge, decision-making and problem-solving skills; along with the increased acceptance of *situated learning* to promote active learning and complement traditional instruction, all create an environment which promotes the use of interactive simulation technologies.

The goal of this dissertation is to address existing challenges in teaching students dynamic construction processes, and understand how a simulation game affects learning of construction planning and management concepts. This study explores the elements of simulation games that are conducive to enhanced learning and increased level of motivation. In particular, this study focuses on the effects of attributes of simulations and games such as immediate feedback, factor variability, and challenge on learning of construction concepts. The overview of current research reveals the lack of a systematic and detailed documentation of the development process for the simulation games for construction engineering and management. In addition to evaluating the effects of the simulation game on learning of construction scheduling concepts, this research aims to provide complete project documentation including the development process, user's guide, and implementation procedures for broader adoption and future improvement. This research aims to provide a theoretical understanding of a simulation game concept and identify practical and methodological implications for developing simulation games for construction education.

To leverage the current research and address some of the above mentioned challenges, the focus of this research is to *develop, implement, and evaluate a simulation game to engage construction engineering students in active learning experiences that improve their construction planning knowledge and decision-making skills*. To achieve this goal, the following objectives include:

- Designing and developing an educational simulation game to allow for scenarios where a student or student team plans and manages the construction of a construction project;
- Testing and refinement of the application through preliminary evaluation with students and faculty members;
- Implementing and evaluating the effectiveness of the educational simulation experience in achieving the learning objectives for given educational scenarios in an undergraduate construction engineering course; and

- Documenting the development process, implementation materials and guidelines to disseminate the application and the results.

Research scope

The research focus is to explore the benefits and the pedagogical value of the simulation game environment in teaching construction scheduling and management processes in construction engineering education. To evaluate the effectiveness of simulation game environment on learning and decision making, the VCS3 simulation game development centers on planning, creating, reviewing, and modifying the construction schedule with respect to decisions made about resources such as labor, equipment, cost, and embedded variability. Through the implementation and assessment of the VCS3 simulation game application, the goal is to evaluate the effect this type of environment has on meeting learning objectives, as well on engagement and motivation and their effect on learning. The aim is to add to the current research on the pedagogical value of simulation games as teaching tools.

Method of inquiry

Digital and virtual technologies are gaining momentum changing the way and speed with which information is processed. The effort to introduce computer simulation technologies into traditional learning environments is the subject of an ongoing debate among the learning theorists and the educators. The overview of existing challenges and current teaching practices in the construction engineering and management education along with the recognized potential of interactive simulation tools served as a basis for formulating the research question in this study. Table 1 outlines the research steps taken in conducting the study along with tasks involved in each step.

Table 1: Research steps

Research steps:	Tasks involved:	**Description**
1. Literature review	1.1 Review of the current state; 1.2 Define terms / simulation game; 1.3 Identify simulation game attributes and their relationships to learning; 1.4 Identify gaps in the current application in construction education.	Identifies important research trends and knowledge gaps in the area of educational simulation games for construction.
2. VCS simulation game development	2.1 Clarify learning objectives 2.2 Develop the VCS concept model 2.3 Develop system dynamics model 2.4 Graphics user interface design 2.5 Develop system architecture and data flow 2.6 Programming and development 2.7 Validation and verification of the application functionality 2.8 Preliminary testing	Addresses the identified gaps and evaluate the effectiveness of simulation games for construction planning and management through the Virtual Construction Simulator 3 game development.
3. Implementation and evaluation	3.1 Research design (one group pre- and post-test) 3.2 Select the setting (third-year undergraduate course in AE 3.3 Develop instruments, assessment material, surveys, and procedures 3.4 Implement	Focuses on measuring the change in the level of students' learning and motivation as an effect of the VCS game.
4. Data collection	4.1 Pre- and post-test surveys 4.2 Schedule /database solutions	Provides raw data to be analyzed.
5. Data analysis	5.1 Statistical procedures for quantitative data 5.2 Content analysis of the qualitative data	Employs appropriate procedures to identify trends and potential effects of simulation games on learning and motivation.
6. Findings and conclusions	6.1 Interpret and discuss findings 6.2 Implications 6.3 Limitations 6.4 Recommendations 6.5 Conclusions	Evaluates and explains findings, and discusses possible reasons for given outcomes. Summarizes the limitations of the study and provides directions for future research.
7. Documentation	7.1 Document design and development process, and materials 7.2 Document lessons learned and recommendations 7.3 Future research	Establishes reproducibility of the study by carefully documenting the development and implementation processes, instruments, and materials.

Research step 1: Literature review and research question

Literature review as the first step provides a critical overview of the current state of research in the area of simulation technologies in education and their relation to critical thinking and problem solving. The summary of existing learning theories provides the basis for analyzing current instructional practices within the construction engineering domain, and their effectiveness in supporting the development of problem-solving strategies. The synthesis of the current research efforts to advance the construction education through the use of simulation technologies identifies trends and existing challenges, and also establishes the context and the purpose of this study. In the process of recognizing the potential and applicability of simulation games within the construction planning and management education, the literature review also serves to consolidate existing definitions of simulation technologies for instruction. The operationalization of the simulation game definition refines the scope for further analysis of its current use for teaching construction planning and management concepts; assists in identifying current knowledge gaps, and establishes the research question.

Research step 2: VCS simulation game development

The research question resulting from the overview of the current state focuses on addressing the limitations of existing instructional approaches in teaching construction planning and management concepts. The recognized potential of simulation games on learning and scarce evidence about their effectiveness for learning construction concepts direct this research to contribute to the present discourse on the applicability of simulation games for instruction and inherent challenges in their development. To test the concept of using simulation technologies for construction engineering education and document the development process, the second step involves developing the Virtual Construction Simulator (VCS3) simulation game for teaching construction planning and management concepts, and its subsequent implementation in the undergraduate construction course.

To test the effectiveness of the simulation game-based approach to teaching construction planning and management, the second step involves the development of a construction method-based approach to planning and managing a schedule as opposed to a typical sequence-based approach inherent in commercial 4D simulation technologies. Placed in the context of undergraduate construction engineering and management education, the development process involves the following subtasks.

- Identifying the learning objectives and the list of assumptions which guide the development of the simulation game conceptual model;
- Developing the VCS3 concept model to correspond to the identified learning objectives. In this stage, storyboarding is used to conceptualize the user interface, application behavior, functions, and the information flow;
- Developing the system dynamics model to identify content factors such as labor productivity, weather, or learning curve; and their relationships to represent the dynamic nature of construction processes and add to the realism of planning and managing construction schedules. This step is continuously refined through consultations with the faculty members and the corresponding literature;
- Developing the graphics user interface (GUI) based on the conceptualized design;
- Developing the system architecture through establishing object classes and attributes; and structuring the data flow between the application, database, and the game engine;
- Programming and development of the functional prototype with enlisting detailed application specifications;
- Validation and verification of the application functionality and reliability to check the model complies with the initial list of assumptions; and
- Preliminary testing prior the implementation phase.

Research step 3: Implementation and evaluation

To measure the level of change in learning and motivation as the result of the VCS3 simulation game, the next step is to define the appropriate research design, identify research setting and subjects; and develop the appropriate measurement instruments. Chapter 5 describes in detail the research design and the implementation procedures. The measurement instruments, surveys and questionnaires, as well as additional material such as handouts and consent forms are included in the appendix section.

Research step 4: Data collection

Online questionnaires and handouts were developed and refined throughout the process of the VCS3 simulation game development and are included in the appendices. Construction schedules in the form of Microsoft Project files, which students generated during the assignment, were also collected for additional insights into the thinking process related to grouping of objects and sequencing activities; and also for debugging purposes and easier tracking of any problems should they arise.

In addition to pre- and post-test questionnaires, focus group interviews were scheduled to provide an additional insight into the learning processes; debrief students on the experiences in using the simulation game tool, and clarify any questions or challenges students may have encountered during the simulation. However, due to scheduling conflicts and the low response rate from the students, focus group interviews were not conducted.

Research step 5: Data analysis

Collected data was analyzed using qualitative approach and content analysis for all open-ended questions and word/image type of data. Close-ended questions and numerical data were statistically analyzed. Both Chapter 5 – discussing the implementation procedures and data collection, and Chapter 6 – reporting the results; discuss in detail specific analysis methods used for each type of data.

Research step 6: Findings and conclusions

The data analysis serves to establish relationships between the study findings and existing theories and practices. This section explains the findings through identified trends and patterns, and discusses how the evidences relate to the research question. The discussion section addresses existing limitations of the study, summarizes lessons learned and provides future research recommendations.

Research step 7: Documentation

Careful and systematic documentation of the simulation game development process, the research methodology, implementation, and all accompanying materials will allow the study to be scrutinized for future improvement. The documentation of both development and implementation processes ensure the reproducibility of the study and helps advancement of the knowledge in the field.

Contributions

In the emerging field of educational simulation games, this thesis makes the following contributions:

- Development of the *simulation game computational model* that provides a basis for the promotion of construction simulation games for education. Specifically, the contributions include the development of the system dynamics model in the form of a feedback loop between construction factors and variables for calculating the as-built simulation results. The factors and relationships were identified to support the development of customized learning scenario and allow for a focused learning of complex information. To implement this computational model, the systems architecture was outlined to define the application structure, the relationships between its components and their properties, and the data exchange processes. The overall simulation game model encompasses broad research in simulation games for construction engineering education, and also identifies variables and attributes of both simulations and serious games that lend themselves to teaching construction scheduling and management concepts.

- Documentation of the simulation game development process, along with the reported and documented implementation material will allow for the model and the simulation game to be further analyzed, scrutinized, replicated, or implemented by future researchers and interested users. The simulation game developed and tested in this research is also available for free download at *www.engr.psu.edu/vcs.* To support further development and customization of the VCS simulation game, a substantial amount of work has been devoted to carefully documenting and commenting the code; documenting the development process through flow-chart and UML (Unified Modeling Language) diagrams, and also providing detailed user guidelines. In addition to the application uploaded on the above stated website, the supplementary documentation, including the manual, class handouts, and procedures, is included in the appendix section of the thesis.
- The implementation findings also contribute to the existing body of knowledge on the pedagogical value of simulation games in construction engineering education. One of the objectives of this research was to explore and advance the theoretical and formal understanding of the learning process promoted by simulation games, and also explain the applicability of the simulation games as instructional tools from the methodological and practical perspectives. For that reason, significant effort has been invested in developing an evaluation procedure to provide a better understanding of how to measure learning as well as the level of engagement as its contributing component.

The thesis structure

The dissertation is organized as follows. Chapter 2 discusses simulation games as instructional tools through the lenses of the constructivist framework and the theory of situated learning, and explores the problem-solving and learning mechanism as a function of different instructional approaches. The scope of the study and the research question are further refined by examining the current status of simulation games for construction planning and management education, and by identifying development trends and existing gaps. As groundwork for this study, the Virtual Construction Simulator project and its background are explained. Chapter 3 presents the point of departure and in response to the research problem, details the development process of the current VCS3 simulation game. Specifically, the VCS3 simulation game conceptual model, the system dynamics model, systems architecture, and the user interface, are explicated. Chapter 4 outlines research methods and procedures employed to evaluate the effects of the VCS simulation game on students' learning and motivation. Chapter 5 reports the implementation findings; and Chapter 6 discusses the results, implications and limitations; and concludes with recommendations and the directions for future research.

Chapter 2

Review of Literature and a Research Problem

Problem solving and decision-making skills are essential for construction engineering students. Experience is a critical learning component and the level of experience builds expertise for construction engineers and greatly influences problem solving strategies (Jonassen et al. 2006; Konradt 1995; Mukherjee et al. 2005). Students lacking experience face many challenges in learning the concepts of planning and managing construction schedules. In essence, a construction schedule represents a timetable of construction activities needed to complete a building project and serves to establish project goals, communicate the construction plan, monitor and control the progress, and manage changes. Developing a construction schedule involves the recognition of tasks and resources needed to complete each of the tasks. However, there are complex interactions between factors such as resources, labor productivity, budget and various changes that occur almost inevitably, which impose difficulties in managing construction processes. Labor productivity alone represents a key factor to a project cost and is influenced by competing factors ranging from workers' experience and fatigue to resource management strategies (El-Rayes and Jun 2009; Fulenwider et al. 2004). Unexpected changes and delays require continuous adjustments to the plan and management of resources, time, and cost. Students at the undergraduate level struggle to understand concepts of critical activities and their relationships, while at the same time they need to acquire skills to manage inherent project risks, safety, or quality, and respond to schedule changes and delays.

Teaching students to solve problems related to construction scheduling requires an understanding of the nature of those problems followed by adopting appropriate instructional strategies. Construction scheduling represents an ill-defined problem solving activity with no immediate solution to the problem but rather many possible solutions. The process of achieving the most optimal solution consists of numerous iterations and frequent solution evaluations. Construction scheduling typically begins by identifying constraints, project goals, appropriate construction activities and durations, in order to compute the overall project timeline. As this is an iterative design process, the first schedule iteration is rarely viable and the construction schedule is subject to constant revisions and adjustments.

Traditional methods in teaching construction scheduling are criticized for presenting students with problems that are inconsistent with problems encountered in the industry. Complex and dynamic construction problems and scenarios are presented in a well-structured and fragmented way in a classroom setting which does not adequately prepare students with necessary decision making skills for the industry (Lattuca et al. 2006; Mukherjee et al. 2005). Students are generally presented with problems that are solved in a linear fashion with typically one correct solution. Instead, students should be trained to engage in a problem solving activities in which they learn to identify problems and test and evaluate multiple solution alternatives. Classroom problems generally fail to capture the ill-structured nature of real construction problems characterized by differing goals, multiple solutions, unexpected problems, various constraints and human factors (Jonassen et al. 2006). Solving ill-defined problems requires the ability to identify goals, determine constraints, generate possible solutions, evaluate and adopt the most optimum solution (Eastman 1969; Jonassen 2000). To learn to solve practical problems, students need to develop conceptual frameworks and subsequently learn to apply those frameworks when solving ill-structured problems (Jonassen et al. 2006; Jonassen 2000).

The nature of problem solving activity

A problem solving activity has two critical attributes - mental representation of the problem and active manipulation of the problem space represented either internally or externally (Jonassen 2000). More specifically, in addition to learners' individual differences, the problem type and the way it is represented influence problem-solving skills (Figure 1).

Problem Solving Skills		
Problem Type	**Representation**	**Individual Differences**
Ill-structuredness	Context	Domain knowledge
Complexity	Modality	Conceptual knowledge
Abstract/Situated	Cues/Clues	Procedural knowledge
		Experience
		Domain-specific reasoning
		Self-confidence
		Motivation / perseverance

Figure 1: Problem solving skills. Adapted from (Jonassen 2000)

Well-structured and ill-structured problems

Cognitive psychology classifies problem types into two categories – well-structured and ill-structured problems:

- *Well-structured problems,* also well-defined problems, have a clear goal and a finite number of possible procedures leading to a correct solution. Examples include mathematical operations, or solving equations.
- *Ill-structured problems* or ill-defined problems have multiple, competing or conflicting goals; may involve ambiguities or lack sufficient information for solving the problem, and have more possible solutions rather than one correct solution. Ill-structured problems, such as design or planning, require consideration of different knowledge domains, and often rely more on creative thinking than standard problem solving methods (Roberts 2000).

Experts are good problem solvers because experience allows them to recognize problem types and apply familiar strategies (Swellller 1988). Conversely, novices rely on general problem solving strategies which are weak when solving ill-defined problems (Mayer 1992). Problems in construction engineering are dynamic with factors that change over time. However, problems students learn to solve and which are typically found in exams are well defined and organized in a prescriptive way and mostly rely on learned concepts and procedures. Existing research in education argues that problem solving activities are situated within the context and therefore, domain-specific strategies are stronger than general problem solving strategies (Brown et al. 1989; Herrington and Oliver 1995; Mayer 1992).

Visualization

A second critical component to problem solving is the way the problem is represented. The connection between visualization ability and problem solving has been widely discussed and it is argued that visualization can greatly support creative thinking and problem-solving (Alias et al. 2002; Kosslyn 1994). Rice (2003) argues that the medium of representation can have a significant impact on spatial ability and the creative process. Information can be visualized in one's mind until it becomes too complex and difficult to *imagine*, in which case the external display serves as an aid in analyzing the information. In this manner, it is possible to mentally test different solutions using externally presented information. Thus, if the information is displayed in a way that is easily perceived, it will facilitate problem-solving (Ware 2003).

Problem solving in construction domain

Construction projects and concepts are inherently spatial in nature and place great emphasis on adequate visualization skills in construction engineering education. Engineering, among math, science, and computer-aided design has been identified as an area where spatial ability and visualization are critical in helping students understand complex concepts by establishing relationships between reality and the abstracted model of that reality (Alias et al. 2002; Trindade et al. 2002). Visualization has been recognized as a powerful problem-solving tool (Finke 1990; Finke et al. 1996; Rieber 1994) and yet remains underutilized as such in teaching construction scheduling concepts.

In construction engineering and management education, teaching construction scheduling still mainly relies on critical path method (CPM) schedules, Gantt charts, and network diagrams which require a high level of technical competency (Shah and Haque 2006). The level of abstraction in the CPM schedules does not allow for easy implementation of changes that can affect the progress of a project and its cost

(AbouRizk 2010). Because scheduling entails not only identifying construction activities and their sequence, but also management of resources such as labor, equipment, and materials, these forms of representation may limit student ability to visualize and make appropriate decisions related to factors affecting the schedule. Supporting the problem solving process becomes critical and greatly affected by the medium. According to Johnson (1997), poor external representations can affect internal representations by forcing the user to extrapolate and filter information, resulting in an inferior mental performance. For this reason, enhancing visualization skills and allowing for creative thinking greatly depends on the use of appropriate representation medium. Multimedia has gained a significant role in helping learners visualize and understand information verbally described by instruction. Highly visual computer-based learning environments suggest great opportunity to tackle complex ideas and concepts in a visual and intuitive way (Rieber 1994). The growing trend of coupling 3D models with temporal schedules to create and simulate a construction sequence begins to address the difficulty in visualizing construction processes. Construction sequence simulations and 4D models provide spatial, sequential and temporal project construction data and are therefore valued as effective tools for construction process and problem analysis visualization (Haque 2007).

Innovative teaching approaches attempt to include more active, hands-on and problem-based learning opportunities for students to synthesize and test acquired knowledge aligned with real-life scenarios (Williams and Pender 2002). Interactive environments such as simulations and games offer opportunities to actively involve learners to practice decision making and problem solving through direct interaction with the knowledge domain. The shift in focus from traditional methods of teaching to simulated environments and games is supported by the shift in the view of learning from a passive to an active process where engagement and motivation have a critical role.

Learning theories

Learning is the focus of educational and cognitive psychology and represents a multidimensional construct that comprises of *cognitive*, *metacognitive*, and a *motivational* component (Mayer 1998). Cognitive aspect involves two types of knowledge – declarative, defined as the ability to memorize and recall information; and procedural knowledge defined as the ability to apply acquired knowledge in new situations (Gagné 1985). Metacognitive aspect is context based, and refers to one's knowledge about how, when and which skills to use when solving a problem (Ke 2009; Mayer 1998). Instructional implications of the metacognitive aspect involve providing realistic problem based situations for learning and the acquisition of meta-skills. Knowledge constructed through context based activities is at the core of constructivist view and the theory of *situated cognition* or situated learning (Brown et al. 1989; Van Eck 2006). Based in Piaget's (1970) theory of cognitive development in which individuals construct their knowledge from experience, constructivist view and the theory of situated learning have made a significant impact on educational thinking by placing emphasis not on memory, but process and perception (Herrington and Oliver 1995). Research confirms that the information retention is affected by the level of learner's involvement (Figure 2).

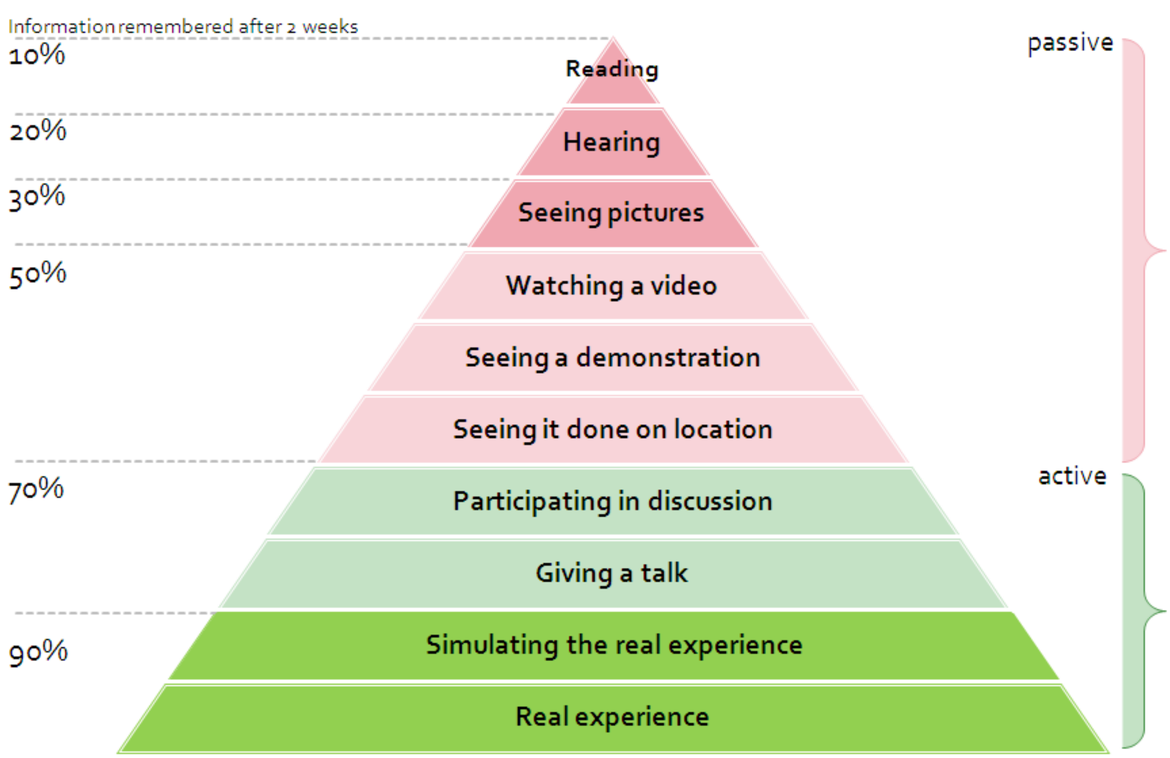


Figure 2: Forms of active and passive learning methods. Adapted from:(Dale 1954)

Traditional view of learning is based in the information processing theory which places the content at the core of instruction with the goal of adopting a pre-defined set of concepts, rules, and procedures (Swelller 1988). Alternatively, constructivist framework takes learning as an active process of constructing and transforming knowledge through experience. Kolb (1984) describes this learning, also termed experiential, as a four-stage process in which each experience through reflection is abstracted into a more general concept and continuously tested through new experiences (Figure 3).

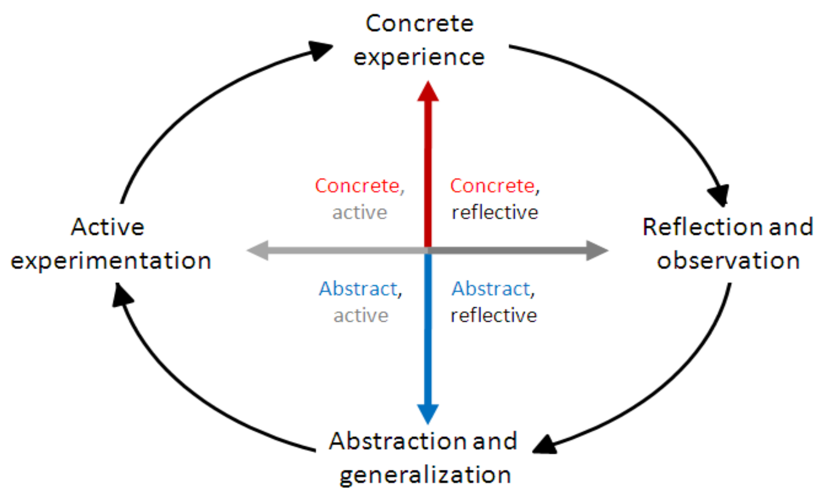


Figure 3: Kolb's cycle of experiential learning (Kolb 1984)

The shift from *learning through listening* model of instruction towards *learning by doing,* places emphasis on the set of skills and ability to find and use the information as needed as opposed to ability to recall the information (Garris et al. 2002; Simon 1996). The outcome of the former approach is the set of generalizable skills that can be applied across domains, while the latter focuses on the development of context-dependent and expert problem-solving skills within a specific domain.

The third component of learning is *motivation*. Motivation is a multidimensional construct comprising of components such as learner's perceived competence, learner's beliefs in importance of the task, and learner's emotional reactions to the task (Ke 2009; Mayer 1998; Pintrich and Groot 1990). Motivation is influenced both by external factors such as rewards, and by internal factors such as individual interest, effort, values and self-confidence (Ainley 2004). Research has confirmed a strong correlation between high motivation and engagement, and learning and student success (Becker 2007; Dev 1997; Gee 2007; Prensky 2001a; Squire 2006). Intrinsically motivated students retain information longer and are more likely to engage in a lifelong learning outside the classroom (Dev 1997). However, motivation in general instruction is still subject to an ongoing debate about the relationship between fun and learning. While some educators still consider fun as trivial and unimportant in education, Prensky (2001b) argues that fun brings relaxation and motivation for the learner to put forth effort without resentment, resulting in a better learning.

Computer simulations and games are being increasingly explored for their ability to support situated learning by providing a close to realistic environment for problem solving through visualization, exploration, and immediate feedback (Gee 2007; Ke 2009). Games and simulations have been introduced in education in 1950s, however their application has been mostly reserved for business, military and medical fields (Gredler 1996). Some empirical evidence confirms that simulation games can be effective learning tools and help understanding of complex concepts (Cordova and Lepper 1996). Although strong evidence still lacks, recent research increasingly explores the relationship between simulation games, motivation and learning outcomes. Two major themes promoting the use of simulation games as learning tools are their motivational power to engage the learner, and an active process of learning by doing (Gee 2007; Kirriemuir and McFarlane 2004; Squire 2006).

Simulation technologies for learning

Pervasive presence of technology and the information age has brought a generation of learners who learn differently than generations who grew up without technology (Blunt 2007; Kirkley and Kirkley 2005; Prensky 2001a). Generation born after 1982, called “Millennials”, is a digital generation heavily influenced by information technology (Frand 2000; Jonas-Dwyer and Pospisil 2004; Nguyen et al. 2010; Oblinger 2003; Prensky 2001a). Millennials demonstrate different learning characteristics compared to earlier generations; they are collaborators and goal oriented, with strong preference for teamwork, experiential activities and the use of technology (Jonas-Dwyer and Pospisil 2004; Oblinger 2003). As information-age generation they are most technology savvy – they spend more time on the computer than watching TV; they multitask; prefer typing to writing; expect instant feedback and have little to no tolerance for delays (Frand 2000; Nguyen et al. 2010; Oblinger 2003). Learning for the new generation results from trial and error approach where actions and results are preferred over knowledge and facts. For the new generation of learners, engagement becomes the critical part of the learning experience (Prensky 2001a).

While the ability to learn dynamically is growing in its importance, there is also a growing need for educational methods and tools which are capable of capturing and teaching highly complex systems in a way that is also easy to understand. Designing contextual learning experiences to engage students in a more active process of learning and problem solving is the subject of continuous research in construction education. Traditional educational methods have become insufficient to equip students with required problem solving skills and knowledge applicable in real life situations (Brown et al. 1989; Chinowsky and Vanegas 1996; Dossick et al. 2007; Galarneau 2005; Howard et al. 2010). In-class lectures and case studies are valuable learning tools, but learning that occurs through instructor's review and feedback remains mainly passive. Bridging the gap between theoretical and abstract knowledge qualified as inert, and knowledge that is applicable in practice has long been a primary concern in education (Brown et al. 1989; Galarneau 2005).

Grounded in a constructivist framework and the theory of situated cognition, simulated environments as an instructional method share assumptions with views known as the "learner-centered", "problem-based", "discovery" or "experiential" learning (Norman and Spohrer 1996). The overarching idea behind these views is that learners learn most when engaged in problem-solving activity reflecting real life situations and problems; and actively explore, seek and construct their knowledge. Simulations and games have thus become increasingly considered for their potential to support strategic thinking, planning, communicating, negotiating, and decision making (Kirriemuir and McFarlane 2004).

An overview of literature reveals that current terminology blurs the distinction between simulations and serious games. Simulation and game characteristics identified to potentially enhance the learning process often overlap and frequently these two terms are used interchangeably. The following is an overview of definitions and main characteristics of games and simulations.

Games

Games in general, as well as *serious games* developed for education, are broadly defined as goal-directed contests under certain set of rules and constraints (Dempsey et al. 1995; Gredler 2003; Hays 2005). Contests can be either between individuals or between an individual and the system, and may involve elements of chance or fantasy (Hogle 1996; Randel et al. 1992). In essence, whether instructional, computer-based or not, games are fun and intrinsically motivating (Dempsey et al. 1995; Gibson et al. 2007; Hogle 1996; Lepper and Malone 1987). As Prensky (2001b) explains, games are engaging since the primary goal of games is to keep the user engaged. Key game elements include:

- *Rules and Goals.* The rules define actions and moves players are allowed to make in order to win the game. Rules depend on a game type and may not be entirely included in the game instructions (Bartles 2003; Blunt 2007). The goal defines rules and establishes the criteria for winning.
- *Interaction and feedback.* Immediate response to decisions made places the player firmly within the learning environment and decisions can affect the course of the game (Prensky 2001a). Depending on a goal, players take an active role in testing different responses to a specific problem and start viewing the situation from various perspectives (Blunt 2007; Kirkley and Kirkley 2005).
- *Challenge/Strategies.* Success in a game depends on the strategies players take. Players need to consider factors and variables as well as likely consequences and manage their thinking and actions accordingly (Gredler 1996). During that process, players' knowledge of phenomena is challenged and mistakes become more educational than success (Aldrich 2003). Failure is a critical precondition for learning forcing students to

cycle through play and resolve conflicts and gaps in their current understandings (Squire 2005).

- *Motivation/Fun.* Fun is essential to games to make them interesting and engaging. Increased interest leads to increased engagement and thus invested time in the game. From the pedagogical perspective, the more players are engaged in a game they are more willing to invest in the learning process and more likely to remember the experience (Blunt 2007).

Other characteristics pertaining to games include control, sensory stimuli and a scoring mechanism (Garris et al. 2002; Jacobs and Dempsey 1993). Within games, there are different genres such as action, puzzle, sports, or adventure, each emphasizing different attributes. For example, puzzles and board games require skill, card games are games of chance, while chess is a game of strategy. The broad range of game types further complicates an agreed upon, comprehensive definition of games that would include properties common to all types of games.

Simulations

A simulation is defined as a simplified model of reality or set of abstract concepts that may be developed for teaching purposes, predicting behavior or testing models and processes, and for entertainment (Dede and Lewis 1995; Prensky 2004; Rieber 1994; Rieber 1996; Sawhney et al. 2001). Simulations for teaching are developed around learning situations that contain contextual information students master through reflection and interaction with the environment (Dede et al. 1999). Simulations and games are similar in that they are both interactive exercises in which learners observe the change in output based on their input and almost instantly observe the consequences as the result of their actions (Gredler 1996; Gredler 2003). The key distinction of simulations is they generally represent a real world model, system, or a concept, while games necessarily do not (Garris et al. 2002; Hays 2005). Simulations further differ from games in that they do not contain key game attributes such as fun, goals, risks, or competition. While games are competitive exercises with the goal of winning, simulation games can simulate real life experiences and focus on role-play. Gredler (1996) defines simulations as experiential interactive exercise, in which participants assume roles with serious decision-making responsibilities. This engages player to investigate the scenario from a specific role view and allows freedom to explore and experiment (Howard et al. 2010).

At the core of simulations are computational models which include factors, their relationships, and assumptions about their importance (Prensky 2004). According to Prensky (2004), simulations can be further categorized by whether they simulate “things”, “systems”, or “people”. Simulating “things” is the most straightforward input-output type of simulations with a fully predictable set of behaviors. Systems may involve factor variability and can significantly vary in complexity, while simulating “people” would be the most complex and difficult set of behaviors to predict with accuracy.

In general, simulations are designed as a training environment where skill is acquired through repetition of a certain activity (e.g., a flight simulator) while the concept of serious games incorporates additional features, such as goal-driven activities, competition, uncertainty, risks, a scoring mechanism, or rewards. Nevertheless, simulations can include any of the game characteristics, such as a scoring mechanism, and thus become game-like. This has led researchers to use the term gaming simulations or *simulation games* as an attempt to reconcile the multiple perspectives on each. A simulation game for instruction is thus defined as:

- a simplified model of reality in which students compete for a certain outcome based on the set of rules and constraints (Szczurek 1982; Van Eck and Dempsey 2002).

With simulation games, students have the ability to examine, experiment, and reinforce theories learned in a classroom in a close to realistic setting (Nassar 2002). Figure 4 shows key characteristics pertinent to games, simulations and simulation games.

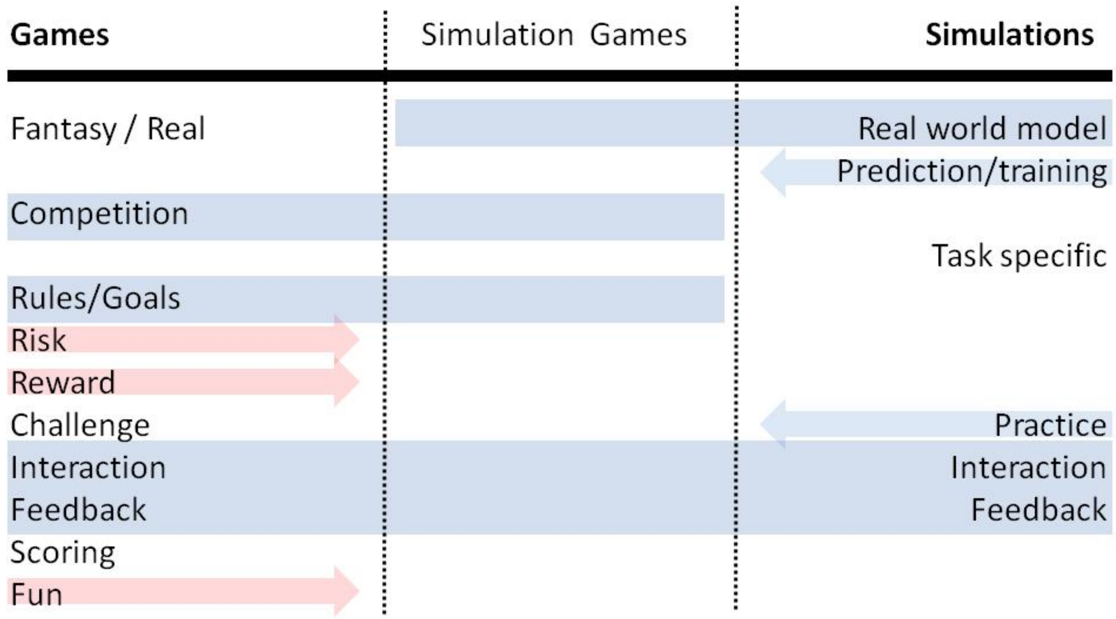


Figure 4: Key characteristics of games and simulations

A further distinction is made between simulation games which clearly determine the state of winning and losing, and simulation games which focus more on open exploration of the system through modifying variables and observing the effects. Warren (2001) indicates that the inclination towards the *closure* is greater among the commercial simulation game developers, while instructors generally prefer open exploration format.

Educational games and simulations are however, only as valuable as the pedagogical approach taken in their design (Galarneau 2005). Aldrich (2003) argues that an ideal learning environment contains elements of both simulations and serious games. While simulation elements facilitate practicing skills, game elements add familiar and entertaining interactions to the activity that can increase enjoyment of and time spent on an experience, ultimately increasing learning (Aldrich 2003; Aldrich 2004). Similarly, Bartles (2003) argues that game elements create a competitive environment that promotes motivation and engagement, critical aspects of effective learning. Ultimately, simulation games can provide realistic tasks and environment and challenge student's critical thinking and problem solving by testing alternative strategies and scenarios at no real-life risks. The non-linear learning process characteristic of simulation games is reflected in the shifting of the control of information from the instructor onto the learner. Warren (2001) explains:

> *"Simulation/games allow learners to construct understanding by immersing themselves in a complex situation, making choices and sequencing information in a way that is personally meaningful—while not deferring to the authority of a knowledge 'expert'. This type of learning is non-linear because a teacher cannot identify a linear, hierarchical structure of knowledge presentation that will be optimal for each learner. Rather, the learner is expected to socially construct knowledge in a manner that is optimal for them."*(pg.11)

Implications for design of instructional simulation games

Situated learning as a framework faced certain challenges in its implementation in classrooms. Computer-based simulations can complement traditional teaching methods and have the potential to bring situated learning into the classroom. Although the criticism that computer simulated environments represent another courseware learning environment rather than authentic situation (Hummel 1993), researchers have generally accepted the idea of simulated environments as a suitable and viable alternative to real life settings (Herrington and Oliver 1995). Specific characteristics that promote simulation games as effective learning tools relate to their ability to:

- Challenge the existing mental models through constant testing of the knowledge and ideas and resolving of occurring conflicts;
- Help establish a big picture of the subject matter through a more holistic approach to representing complex systems and interrelated components;
- Accelerate the learning process by allowing learners to experience the outcomes of their decisions and actions within a short time frame; and
- Provide a close to realistic, risk-free experiential environment where learning occurs through both success and failures without real world consequences.

Although the value and the potential have been largely identified, the greatest criticism of the constructivist approach targets the lack of detailed and systematic development of instructional design guidelines and translation of the constructivist views inside classrooms. While this type of learning environment enables students to construct the knowledge in an active manner, current research identifies the potential problems that may arise in designing these environments, as well as strategies that should be employed to ensure an effective learning. Designing game-based simulated environments should specifically consider challenges related to a discovery-based and unguided learning; learner types and preferences; structuring of the learning environment; and assessment methods.

- *Guidance:* The core idea of the learner-centered, discovery-based, or problem-based learning in which the learner is responsible for constructing own knowledge, have come under criticism with the argument that self-guided learning lacking instructed guidance can cause frustration and cognitive overload in the novice learner who is exploring the problem space for relevant information (Kirschner 2006). de Jong and van Joolingen (1998) discuss the explorative and discovery learning – often referred to as strong points of instructional games and simulations – and argue that learners often have difficulties with forming and testing hypotheses in these environments. Similarly, Sweller (2002) explains that effective problem solving in the simulated environments can place a large cognitive load if there are too many elements to be learned. Related to this, Kirschner (2006) argues that the learner needs to have a prior knowledge to be effective in a problem-based learning environment. For this reason, guidance becomes a critical part in implementing these types of learning experiences. Implication for the design of simulation games is the incorporation of appropriate assistance tools, help content and additional scaffolding that will be available to learners at critical times.

- *Learner types.* Gagne's (1985) theory of learning conditions has few implications for the design of instructional technology, including simulation games. Among five major categories of human capabilities, cognitive strategies refer to inductive and deductive reasoning and represent a skill to manage one's thinking and learning (Gagné 1985; Gredler 1996). These cognitive strategies however can vary greatly among students. Several theorists argue that novices and students who lack prior knowledge about the domain should not interact with ill-structured learning environments (Jonassen 1997; Moreno and Mayer 1999; Mousavi et al. 1995). Jonassen (1997) explains that while ill-structured learning environment rely on the learner's ability to *discover* solutions, this may impose a significant cognitive load for novices due to lack of sufficient domain knowledge. For this reason, novices should be taught in a well-structured environment. Simulation games are a particular kind of experience that may not appeal to everyone. While failure is almost a starting state when playing games and identified as critical aspect of learning, failure may stimulate some learners and equally frustrate others. Squire (2005) reports findings on implementing historical and geographical simulation game *Civilization III* in the classroom for learning about planning, building, and managing civilizations. While more confident students saw failure as a learning opportunity, others identified failure with their value as students, or found the game not interesting or too difficult, dismissing the entire learning experience (Squire 2005). Different learner types may show preferences for different teaching methods. Kolb (1984) identified four main learning types of students:

- *Reflector:* Ponders experiences and observes, seeks data and considers thoroughly, postpones decision making until all information is collected, watches and listens before offering an opinion.
- *Theorist:* Approaches problems using vertical, step by step approach; pulls together disparate fact into coherent theories; seeks perfection; dislikes flippancy and uninformed decision making.
- *Pragmatist*: displays practical problem solving and decision making skills; sees problems as opportunities; acts quickly and confidently to implement ideas; dislikes ruminating and open-ended discussions.
- *Activist*: acts first and considers the consequences later; focuses on the present; thrives on challenges.

The differences in learner types are likely to result in different approaches to solving problems with simulation games. A study by McGuire and Babbott (1967) observed problem-solving styles in simulations with 186 fourth year medical students, and recognized two patterns where one group of students would make fewer and deliberate choices, while another group of students made more random choices resulting in a higher level of error.

- *Structure.* The challenges inherent in the new approach relate to appropriate structuring of learning activities to ensure that students are meeting the learning objectives. Theorists and proponents of situated learning recommend that design of the learning environment should aim to provide:
  - Authentic setting with realistic tasks reflecting the knowledge that will be used in real settings;
  - Multiple roles and perspectives of the situation and problem;
  - Support and scaffolding during the learning process;
  - Reflection to reinforce an understanding of new concepts;

  More specifically when designing simulation games for learning, Prensky (2001) and Gee (2007) agree that a good learning environment that supports practice is the one where the learner invests a lot of time on a task and engages. For that reason, additional elements that have been identified as critical in developing instructional strategies to support effective and active learning include:
  - Clear goal;
  - Immediate feedback (during the play);
  - Uncertain outcome (increases curiosity);
  - Competition (against another player or oneself);
  - Elements if randomness and variability; and
  - Reflection.

Reflective learning is stated as the most critical component to ensure the learning process and resolve conflicts students may encounter. Though the general assertion of the active learning approach is that learners learn through experience, debriefing has been included as a critical part for players to highlight and generalize lessons learned in order to be able to apply it later in different situations (2007; Prensky 2001c).

- *Assessment.* Research in using simulation and game technology in education has traditionally focused on qualitative methods to determine the effectiveness of these types of instructional tools. In the large pool of research, only few studies have used quantitative approach but have come under scrutiny for the lack of rigor and confounding results. Although simulations and games have been largely stated to be advantageous and beneficial as instructional tools, their wide acceptance in the 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 comparison of traditional teaching methods and those that involve games and simulations have long been the focus of great number of studies that aimed to determine the advantages of the latter. Although comparison of simulation games to a regular classroom instruction in most cases seeks to quantify clear benefits of one method over the other, the difference in nature of instructional objectives of both methods may vary greatly. More recent studies however, question the validity of comparing the two teaching methods different in nature due to the content, involved activities, and abilities they are intended to support. The evaluation of simulation games yielded outcomes such as attitude changes or tolerance for ambiguity, which remain mostly irrelevant in the traditional assessment (Warren 2001). Conversely, traditional learning evaluation and measurement methods mainly utilize test scores which measure the ability to recall information and not necessarily the ability to apply it (Norman and Spohrer 1996). An interactive simulation game exercise and a regular lecture instruction are very different in nature and thus their comparison based on the traditional achievement test is not well suited to yield definitive information on the effectiveness of one over the other method (Gredler 1996). Another major challenge in the assessment methods identified is the lack of consideration of students' characteristics. Gredler (1996) argues that studies about games and simulations fail to document the level of interaction among students with the subject. To conduct a usable research and evaluate the problem solving gains from using simulation games, Gredler (1996) recommends a three-step approach in which:

- The first step is to ensure that the simulation model is reflective of the knowledge domain and demonstrative of the variable processes and relationships excluding chance or random strategies as means for success;
- The second step is to verify that the game or a simulation promotes intended skills, and to determine students' behavior and attitudes toward the simulation game;
- The third step is to conduct a follow-up study and identify types of students' abilities, attitudes and thinking strategies. This component of research may use both quantitative and qualitative data where pretests of domain knowledge may be compared to problem solving strategies following the simulation.

However, for teaching and learning there is still a general agreement that one method is not superior to the other. Traditional teaching is still quite useful in situations when presenting a wide spectrum of information. Rote learning and memorization may be weak in motivating the learner, but still have place in situations when new knowledge or skill need to be automated and applied in new situation without requiring significant conscious effort (Norman and Spohrer 1996). Active, learner-centered approach is on the other hand more engaging, motivating and can provide a better conceptual understanding (Norman and Spohrer 1996).

Simulation games for teaching construction

In construction engineering education, simulations are becoming an accepted concept for instruction for their ability to expose students to realistic experiences without real costs or risks. Simulations mirroring the reality start to prepare students with skills that can be applied in real world situations (Scott et al. 2010).

Case studies and site visits are generally employed as a means to introduce students to the practical issues surrounding construction projects. However, hands-on experience and site visits, while valuable, are difficult to implement extensively in courses due to the limitations of cost, safety, and availability. Several current research initiatives in engineering education focus on surmounting the limitations of employing traditional 2D documents in teaching concepts such as scheduling, site congestion, trades coordination and other project-related construction issues. Recent research, such as CALVisual (Bouchlaghem et al. 2002), has demonstrated innovative attempts aimed at bringing real construction site experience into the classroom. This initiative brings the experience of a construction site into the classroom by employing multimedia technologies to build a construction image database (ibid, 2002).

Construction simulation and 4D models

The growing trend of combining 3D models with construction schedules to create 4D models begins to address the problem of construction process visualization. Because 4D models provide spatial, sequential and temporal information, they are valued as tools for effective visualization of construction processes and problem analysis among project participants (Haque 2007). Main components in developing a 4D model are the 3D model and a CPM schedule (Figure 5). Typically, the development of a 4D model is a four-step process starting with acquiring of the 3D model; developing a construction schedule based on knowledge and experience; grouping 3D objects into construction elements or assemblies; and lastly, linking the 3D components to corresponding activities in the construction (CPM) schedule (Wang 2007).

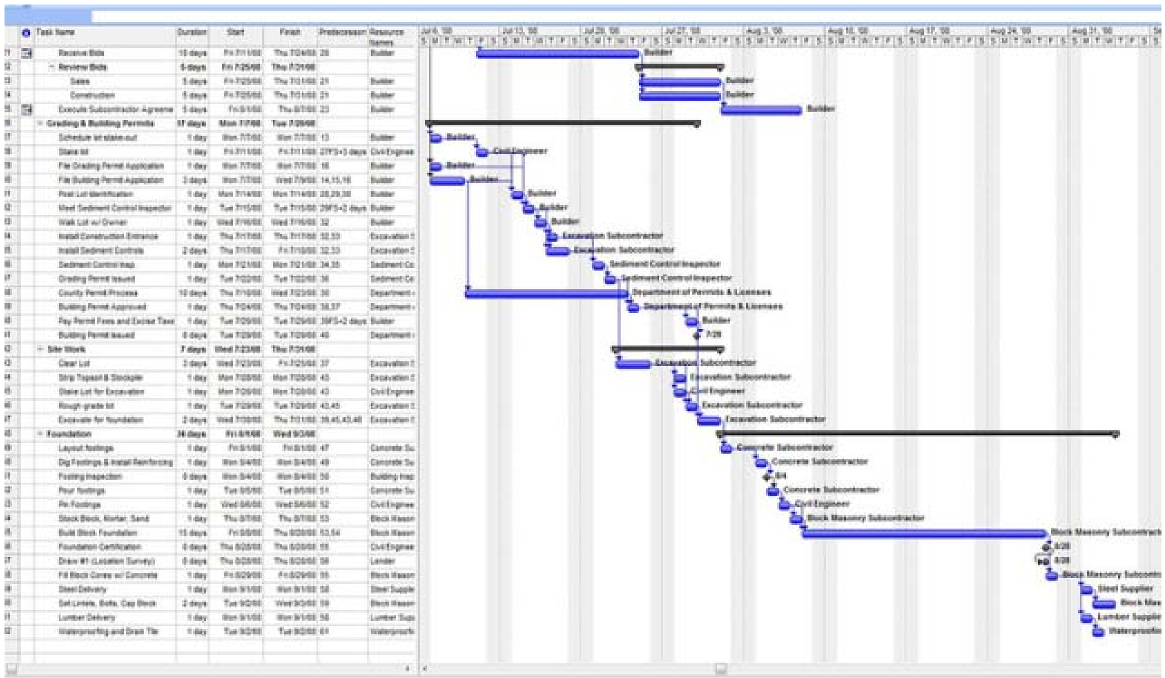


Figure 5: Critical Path Method (CPM) Schedule Example

4D modeling technology has become widely implemented in the architecture, engineering, and construction fields for its ability to facilitate communication between project teams related to visualization of construction documents, identification of potential conflicts, safety issues and other potential challenges (Koo and Fischer 2000). In addition to easier detection of schedule inconsistencies and conflict resolution, 4D models can significantly decrease construction costs through better coordination of trades, and through critical design feedback help reduce construction interferences in the field (Messner et al. 2002). The construction industry increasingly employs 4D CAD (Figure 6) models for detailed schedule reviews, but commercial applications currently used for creating these 4D models are often inadequate for construction engineering education due to their inability to concurrently create and review schedules.

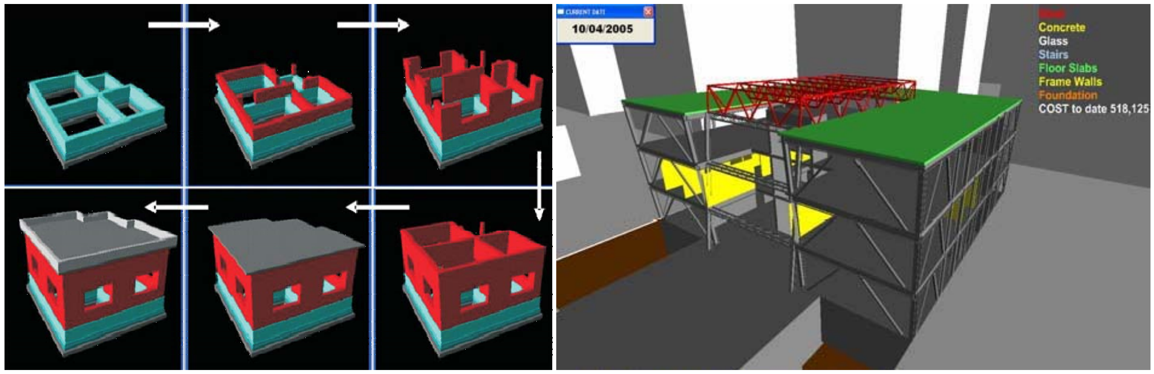


Figure 6: Construction sequence simulation combines 3D information with a construction schedule (*Source*: http://www.exponent.com/virtual_design/)

Commercial 4D models as schedule review tools remain limited in their ability to teach students the logic of activity sequences and dynamic nature of construction schedules. The inherent limitation in the process of using commercial 4D application is the preceding development of the CPM schedule and subsequent linking to 3D objects. Critical path method and the sequencing oriented approach has traditionally been used as the primary visualization technique for teaching construction scheduling; however, as project complexity increases, this method, represented as network diagrams or bar charts, can contain an unwieldy amount of information. This can be daunting for students learning to visualize and understand construction processes and the interdependence of activities embedded within these processes. This challenge further impedes students' ability to visually understand the logic of construction and develop alternative solutions to construction project issues, such as construction method selection, activity sequencing, activity durations, and temporary facility locations.

Educational simulations for construction planning and management

A small but growing amount of research explores the value of educational simulations as opportunities to experience simulated construction scenarios that closely resemble actual construction processes (Park and Meier 2007; Sawhney et al. 2001). Simulations developed for teaching construction processes include bidding, planning, schedule review, productivity analysis, resource allocation, risk analysis and site planning. Al-Jibouri et al. (2005) developed a simulation to plan construction, monitor progress and manage contingencies for the construction of rock and clay dams, and initial results of classroom implementation indicated the simulation was a valuable supplement to traditional teaching methods. Martin (2000) developed the Project Management Simulation Engine for generating customized simulations for project management education. A particular implementation called Contract and Construct for teaching contract management was deemed useful not only in the classroom but also to commercial project engineers and managers (ibid, 2000). Chen & Levinson (2006) used a network growth simulator program called SONG for teaching transportation-engineering students about traffic planning. Similarly, Rojas and Mukherjee (2005) developed Virtual Coach, a web-based general purpose situational simulation environment conceived as a temporally dynamic environment with system-generating random events which challenged participants to make quick decisions. Although not yet fully developed to a level of implementation and assessment, this project demonstrates the possibilities for developing contextually rich construction education environments by investigating general-purpose situational simulations for effective student training.

Visual computer-based learning environments also suggest opportunities to tackle complex ideas and concepts in a visual and intuitive way (Rieber 1994). Jaffari et al. (2001) argue that in construction planning, the mental framework to visualize construction processes and determine the feasibility of decisions made is acquired through practice and years of experience on actual projects. For that reason, contrary to experienced professionals, students generally have insufficient mental references to visualize the physical component and the magnitude of tasks involved on the construction site (Jaafari et al. 2001). Construction planning due to its complexities thus lends itself to the use of tools that can help understanding and visualizing plans and processes.

The Virtual Construction Simulator Project

Ongoing research at Penn State initiated in 2004 has sought to address challenges in visualizing construction processes. The development of the Virtual Construction Simulator (VCS) application focused on the challenges students encounter when visualizing and understanding complex construction schedule processes. The main objective was to address the limitations of existing teaching methods for construction concepts that employed critical path method (CPM) method and 2D drawings as their primary educational tools.

In 2005, Penn State graduate student Grace Wang developed the Virtual Construction Simulator (VCS) as an educational module for improving knowledge in sequencing using the Deep Creator game engine (Wang 2007; Wang and Messner 2007). In 2007, the second version of the VCS was developed using the Irrlicht[1] open source rendering engine with an improved user interface and functionality (Jaruhar 2007). This VCS project focused on investigating an interactive 4D educational simulation application for construction schedule creation and allows for expansion of its functionality to other construction concepts. At the time of the VCS project inception, commercially available 4D applications functioned primarily as schedule review tools in which visualizing a 3D model and creating the schedule were separate processes carried out in discrete applications. One major limitation of this process was that the schedule and the 3D model were seen as separate inputs subsequently linked to create a 4D model output (Figure 7a). This approach involves the development of the CPM schedule independently of the 3D model that is subsequently linked to the 3D model in order to create and simulate the 4D model. Conversely, the VCS approach makes both creating schedules and reviewing 3D information integral parts of developing 4D models (Figure 7b). The VCS application allowed students to interact with a 3D model by creating groups of individual objects, attaching activities to these groups, and generating sequences between these activities. Thus, the VCS approach generated a construction schedule directly from a 3D model, eliminating the need for a separate schedule.

[1] http://irrlicht.sourceforge.net/downloads.html

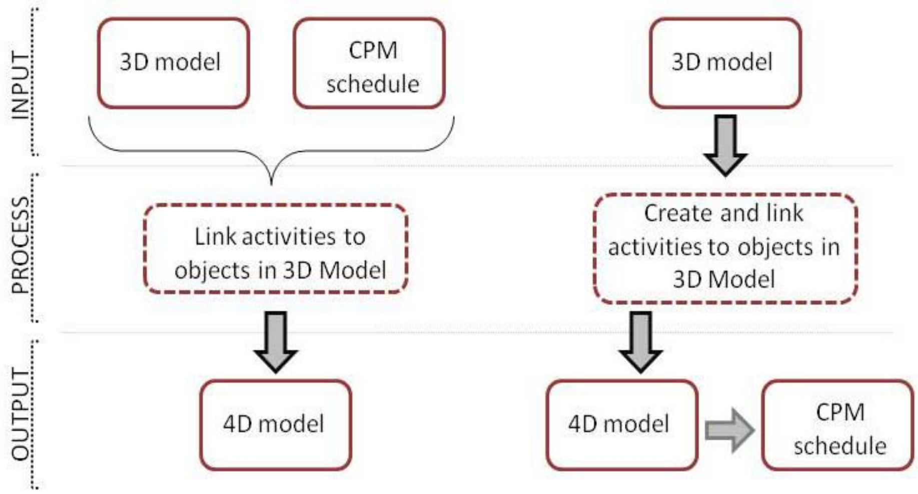


Figure 7: (a) Traditional approach to 4D modeling with a CPM schedule as an input; **(b)** VCS approach to 4D modeling with a CPM schedule as an output

The Virtual Construction Simulator was implemented in 2006 and 2007 in an upper-level construction management course at Penn State. The Virtual Construction Simulator has demonstrated an improvement on the process of creating, reviewing and visualizing construction schedules (Nikolic et al. 2009; Wang and Messner 2007). The visual aspect of the application provided a common language for helping students to better communicate and focus on tasks. The 4D modeling process confirmed its value in its ability to aid students in the problem solving process and support schedule development learning.

Nevertheless, a major limitation of the VCS is that no specific project-based constraints exist that would motivate consideration of the most feasible construction sequence. For all groups in both implementation years, the comparison of initial schedules developed during the lab session and the final schedules reviewed in class revealed that although student groups went back to make corrections to obvious and logical errors in the sequence after developing an initial schedule, they rarely revised and significantly altered their sequences to test for alternative solutions. Possible reasons for this may have been the time consuming nature involved in developing the initial sequence as well as the lack of any intermediate feedback or performance metrics against which to compare the generated schedule. In the future, reviews of solutions and the feedback on the quality of the developed sequence could be included in the application to guide and motivate students to develop and test more than one option. The quality of schedule solutions did not vary significantly between groups, possibly because of the relatively small project scope.

The VCS 4D module was envisioned as only the first step in this research, and does not contain any specific project-based constraints to motivate students to consider the most feasible resource parameters or allow students to revise or modify initial plans based on project progress. The lack of real-time performance feedback limits exploration of alternatives as students receive their schedule evaluations exclusively from the instructor during in-class reviews.

Research problem

This literature review provided an overview of simulation technologies and their role in learning and problem solving viewed through the lenses of situated learning theory and the constructivist framework. Challenges inherent in constructivist approach and simulation games for learning, such as design process and assessment have also been discussed. Although extensive research exists on simulation technologies for instruction, detailed documentation of the design process and their effectiveness remains fragmented and inconclusive. This research aims to address these issues in the context of construction engineering education.

The goal of this research is to explore the effects of a simulation game in engaging construction engineering students in active learning experiences to improve their construction method knowledge, planning and decision making skills. This research focuses on exploring the pedagogical benefits and value of a simulation game environment in the specific context of teaching construction processes in construction engineering education. The development of the next step – VCS3 simulation game focuses on planning, creating, reviewing, and modifying construction schedules with respect to decisions made regarding resources such as labor, equipment, cost, and embedded variability.

Chapter 3

The VCS Simulation Game

Construction planning typically begins by identifying project goals and appropriate construction activities and durations in order to compute the overall project timeline. This is an iterative design process, and the first schedule iteration is rarely viable and typically subject to constant revisions and adjustments. The main reason for this schedule variability is that interconnections between labor, equipment, and other factors such weather or work hours are in constant flux, which is rather difficult for inexperienced students to grasp. The Virtual Construction Simulator as a 4D learning module has demonstrated its value in allowing student teams to more easily and effectively create, review and visualize complex construction schedules. However, both VCS 1 and the VCS 2 do 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. To evaluate the schedule quality, the primary source of feedback students receive comes as instructor's comments. Although valuable, this delayed feedback limits the exploration of different schedule solutions and their immediate outcomes. In addition, the manual calculation of activity durations still being a part of the schedule planning process also hinders an extensive analysis and comparison of different solutions. Along with fewer solution iterations, the lack of dynamic factors and project based constraints limit students' understanding of factors that could impact the construction progress.

Building upon the initial VCS 4D learning module, the current VCS3 development phase takes a more active approach to learning by incorporating additional learning content and integrating simulation and serious games attributes for richer feedback and scenario-based learning. To explore the VCS3 simulation game effectiveness on learning of construction planning and management concepts, the following sections explain the development process and implementation steps.

The VCS3 Simulation Game Concept

The main concept for the VCS3 simulation game is based on demonstrating the dynamic nature of construction schedules and the changes that frequently occur to the construction progress. The VCS3 simulation game focuses on planning and managing of construction schedules and demonstrates the difference between the as-planned and the as-built schedule. On one level, the VCS3 simulation game targets the acquisition of basic knowledge in construction scheduling; and on the other, the development of higher level management skills related to making decisions about resources, cost / time tradeoffs, risks, varying productivity, safety, and quality. The objective is for students to:

Understand:

- *Project goals and conditions*
- *Construction methods*
- *Resources*
- *Activities*
- *Construction sequence*
- *Project reports*

As planned

vs.

Manage:

- *Resources needs*
- *Cost/Time trade-offs*
- *Risk factors*
- *Productivity fluctuations*
- *Safety, quality*

As built

On a broader level, the VCS simulation game is developed to:

- Improve the learning process through active and interactive engagement;
- Provide students with an opportunity to test their ideas and decisions;
- Demonstrate the inherent uncertainty on projects and how to manage, and
- Provide an enjoyable and stimulating learning experience.

Specific learning objectives guiding the development of the VCS simulation game 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.

To achieve these objectives, the simulation game is conceived as a stepped decision process where students would develop a construction schedule based on a defined goal such as budget constraints, meeting a deadline, or owner's satisfaction. The planned schedule would be subsequently simulated with additional factors being triggered and thus affecting the schedule progress. Students, assuming the role of superintendents, would 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 (Figure 8). 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.

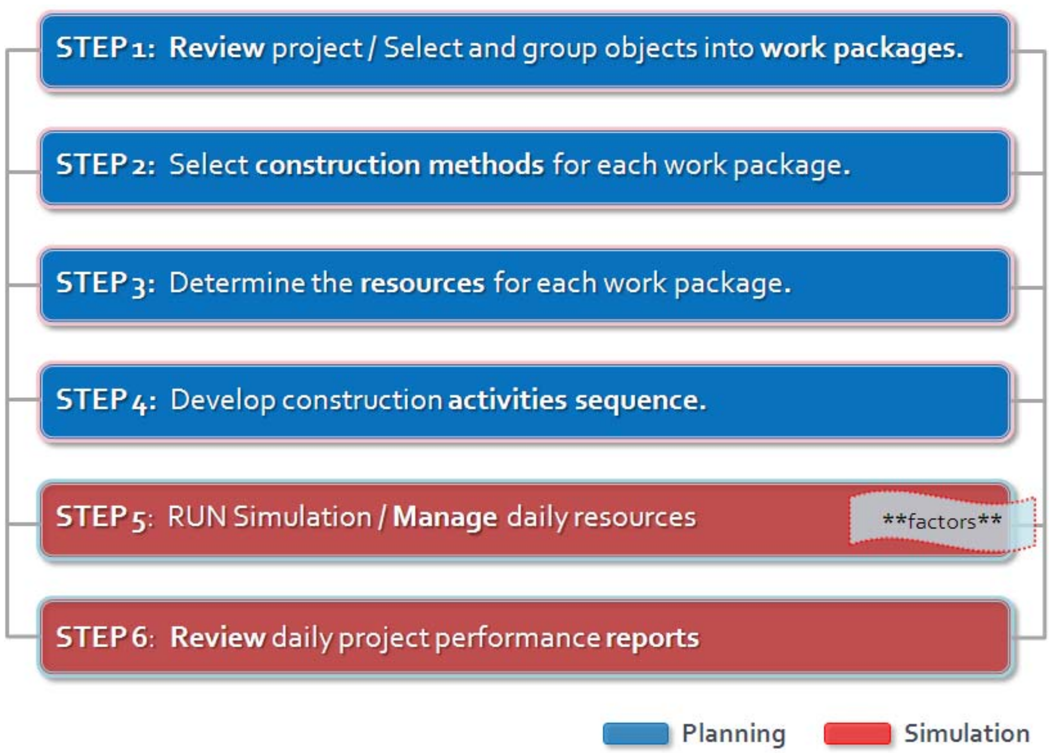


Figure 8: The planning and simulation steps in the VCS simulation game

The planning phase would thus involve schedule planning activities such as reviewing the project information and goals, analyzing work packages, choosing construction methods, deciding on the resources needs, and creating the construction sequence. The simulation side of the game places students on the virtual construction site where in the role of superintendents they start making decisions related to resource management and the dynamic changes affecting the schedule progress. By monitoring cost, time, and the productivity, students learn to maintain the project timeline and respond to any delays that may occur due to various factors. In this manner, the difference between the plan and the *actual* construction offers incentives for students to examine project sequencing logic or optimize efficiency of all available project resources. In summary, specific competencies promoted by the VCS3 simulation game include:

Fundamental engineering and management competencies critical for effective construction process planning. These include the development of intuitive skills to primarily understand the relationships between activity sequence; resource leveling and utilization; construction method selection and cost control; as well as construction site layout planning; temporary structure planning; safety assessment and planning; and risk assessment.

Problem-solving competencies ranging from problem identification and clarification to information gathering, solution generation, testing, and solution optimization. These skills will be encouraged by a guided step-based decision making process embedded in the simulation game that directs and encourages students to test variety of solutions, evaluate the performance of these solutions, and explore alternative methods.

To provide an engaging and realistic construction learning environment, the next VCS3 step integrates the learning content with attributes of both simulations and serious games identified as mechanisms to support active learning. Figure 9 illustrates the general approach to developing the VCS3 simulation game and identifies attributes of simulations and serious games to be incorporated together with the learning content.

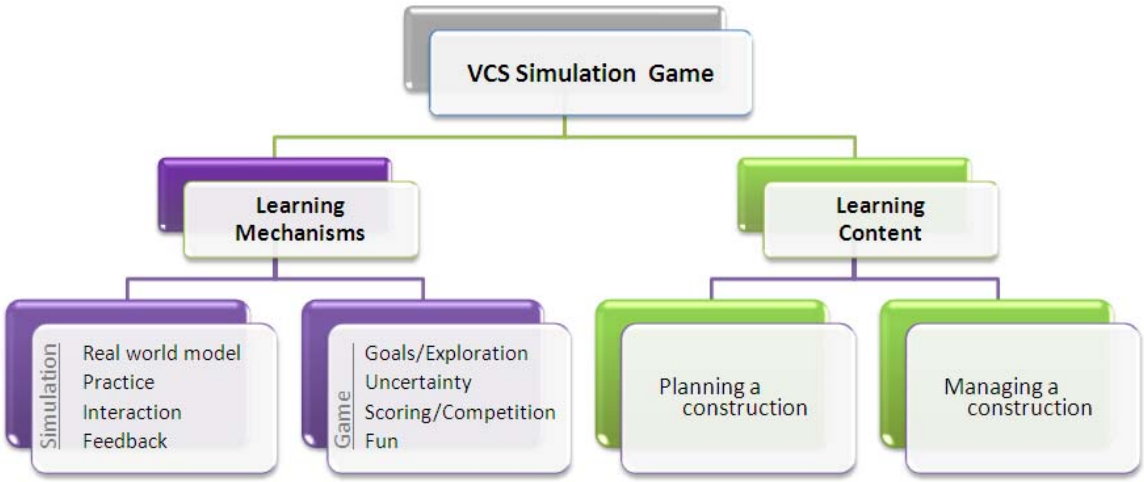


Figure 9: The VCS3 simulation game learning structure

Simulation game attributes – the learning mechanisms

Studies in educational simulations and serious games have recognized attributes which can potentially enhance learning and information retention. The critical attributes identified as beneficial for learning include:

- *Interactivity and immediate feedback* – Students actively build knowledge by manipulating input variables, testing assumptions, and through system feedback, see the outcomes of their solutions and deepen their understanding of concepts. The interactive nature of games and simulations enhances hand-eye coordination, the ability to visualize 3D space through representations, and the skills of rule-discovery through trial and error (Prensky 2001a). Interactivity supports active learning by engaging students with the material which is responsive to students' actions instead of passively receiving the information (Thomas 2001).

- *Realism* – When testing options and assumptions, realistic representation of environments or processes is important to allow for realistic feedback. In a construction project simulation game environment, the absence of any constraints in the 4D simulation environment significantly limits the realism of a simulated project (Rojas and Mukherjee 2006). It is important, then, that students not only understand the 3D representation of a project, but that they also visualize planned construction sequence in four dimensions with respect to time. Realism depending on the context can be defined as either representational or functional isomorphism (Otto 2002). While representational isomorphism refers to photorealistic representation of the virtual world, functional isomorphism refers to how closely the virtual world behaves comparably to a real world experience. In the context of the VCS3 simulation game development, realism refers to the representation of the processes involved in planning and managing of the project construction; factors impacting progress; associated decision-making, and the feedback.

- *Repeatability* – Repetition has been identified as an essential part of play where repeating processes and operations serve as a means of exploring possibilities (Coyne 2003). Students can easily practice processes, adopt and modify different strategies, test outcomes and repeat activities as needed at their own pace. This allows for internalization of processes and concepts as opposed to rote memorization (Graven and MacKinnon 2005).

Serious game attributes that have been identified to contribute and support active learning include:

- *Goal-driven exploration* – developing construction project scenarios with specific goals enable students to explore different strategies to meet the project goal and observe decision outcomes. For example, while the goal may be completing the project under the minimum costs or in the shortest time frame, students can test different options when choosing construction methods or developing activity sequence to meet the set goal. This goal-driven exploration allows students to build their own understanding of various tradeoffs and learn to identify sub goals and prioritize relevant information.

- *Uncertainty* – studies in educational psychology recognize uncertainty to both engage in and stimulate effective learning through mechanism employed to resolve a cognitive conflict resulting from the uncertainty (Piaget 1970). Uncertainty in construction processes is reflected in factors that often fluctuate in real life projects such as weather, labor productivity, congestion, or overtime. Incorporating these factors and their variance provides students with a more realistic picture of the dynamic and variable nature of constructions processes. The variability raises awareness of the factors and their intricate relationships and forces students to consider measurements to respond to changes. Variability in games stimulates the development and testing of different strategies and strategic thinking.
- *Competition* – the competitive aspect of simulation games is identified as a motivational and engaging attribute that can enhance learning experience (Aldrich 2005; Shih and Gamon 2001; Van Eck and Dempsey 2002). Competition against other players or one own score can promote both extrinsic and intrinsic motivation respectively, and thus learning through perseverance (Van Eck and Dempsey 2002). Competition is closely related to the Lepper and Malone's (1987) concept of challenge that contributes to the intrinsic motivation. The competition can be structured within the game against the predefined performance metrics, or externally against other players.
- *Engagement and motivation* – Motivation is a driving force behind learning and "learning by doing" raises interest and investment in time spent on an experience (Gee 2007; Squire 2006). The above mentioned factors work together to promote and stimulate curiosity, exploration through trial-and-error approach, questioning, sustained attention, and intrinsic motivation and engagement.

These attributes support active learning by allowing students to test construction options and observe progress over time. By actively testing different approaches to manage factors that impact construction schedules, students start to develop personal understanding of processes.

Learning content

Integrated with the simulation game attributes as the learning mechanisms, the learning content is the second component in the VCS3 simulation game learning structure. The learning content focuses on the information and decision processes involved in planning and managing a building construction. Typically, when students develop a construction plan, they do not necessarily foresee changes that may affect the schedule, and furthermore, do not have opportunities to observe changes and make necessary decisions. Planning and managing construction schedules involve dynamic processes and impact of various factors such as labor productivity, or weather on the project progress and cost. Students with little experience struggle to understand that construction schedules are subject to constant changes and the process of achieving the most optimal solution consists of numerous iterations and frequent solution evaluations. Typically, when students schedule resources they tend to assume both maximum efficiency and minimal changes to their initial schedule. The learning intent of the VCS3 simulation game is to demonstrate the difference between the as-planned and the as-built schedules, and engage students in making decisions involved in both planning and managing of the construction processes. For those reasons, critical content elements the VCS simulation game introduces include:

- **Project-based constraints** – represent an umbrella of factors to influence the development of the construction schedule, such as resource types, methods, and cost; as well as additional project goals set by the given scenario. In addition to general project constraints, additional building element and activity constraints are incorporated to ensure the logics of a construction sequence. Physical constraints prevent, for example, the column to be installed before its corresponding footing is in place. Similarly, activity constraints ensure that that pouring of concrete can start only after the excavation has been completed.
- **Construction methods, activities, and resources** – in VCS3 simulation game, planning a construction schedule is primarily a

function of choosing construction methods and resources. For each assembly type listed for a given project, students choose between possible construction methods by comparing data such as resources types, daily output, and costs. Choosing one construction method over the other may have a different effect on activity's duration and cost, and will depend on the project goal. Selecting construction methods and respective crew sizes creates a pre-defined list of construction activities attached to student-created assembly groups. Based on selected methods and crew sizes, activity's as-planned duration is automatically calculated. With the list of auto-generated activities, students decide on the activity sequence as the last step in planning a schedule. The automated calculation and a pre-defined activity list eliminate the laborious manual calculation of activity durations and serve to motivate students to more efficiently explore alternatives for the most optimum solution. The process of planning a schedule is explained in more detail in the user interface section of this chapter.

- **Costs** – by comparing costs and daily outputs of different construction methods and resources, students can start thinking about various cost-time tradeoffs depending on the project goal. When managing the project construction, cost reports enable students to track and understand resources costs and how they correlate to efficient resource utilization.
- **Dynamic factors** – factors that impact the construction progress appear to be the most challenging for students to grasp in traditional educational settings. Learning to respond to any changes and delays to the construction schedules that occur due to weather, fluctuating labor productivity, congestion or other unanticipated events is difficult when using CPM schedules or listening to a lecture. The VCS3 simulation game incorporates productivity factors that can vary depending specific project conditions. Labor productivity for example

fluctuates depending on the weather conditions, congestion, working overtime for extended period, or laborers' project experience. Understanding the effect of these factors and their intricate relationships can improve the decision-making process to manage construction efficiently. To simulate these dynamic changes of the construction progress, the calculation of the as-built schedule is approached from a system dynamics model.

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). Discrete event simulation has been predominantly employed in construction simulations that focus on measurable and observable processes such as excavation or earthmoving. However, while discrete event approach understands the complex system in terms of its components through a Work Breakdown Structure (Han et al. 2005), system dynamics considers the system as a whole through capturing feedback effects, managerial actions, and behavioral relationships.

System dynamics is thus considered as a complementary approach to modeling the construction environment due to its 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). The relationships between the schedule progress, productivity, cost, and labor utilization are dynamic and multidirectional forming a complex and a non-linear system, thus lending itself to the system dynamics approach (Pena-Mora and Park 2001). For example, in practice when construction schedule faces the pressure to meet the deadline, few actions typically employed include increasing the work hours, hiring more laborers, or working overtime. Simple calculation would mean increase in the production and accelerated construction. However, a certain amount of overtime work causes fatigue resulting in a lower quality of performed work and decreased productivity, ultimately increasing the overall cost. The productivity of workers also fluctuates depending on the time spent on the site and their project experience level. The dynamics in this process is reflected in the constant change of the required work level, based on the amount of work that needs to be completed. The challenge in this however, would be to quantify the human behavior and achieve the necessary precision in the factors and valid outcomes.

In the VCS3 simulation game, to 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, the calculation of the as-built schedule is approached from a system dynamics model. 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.

Figure 10 shows the system dynamics model underlying the VCS3 development with factors identified as the most common to affect the project schedule and cost. Construction factors and their relationships have been identified and adapted from the construction productivity studies (Fulenwider et al. 2004; Neil 1982; Thomas and Raynar 1997; Thomas and Sakarcan 1994) and scoped to the level which allows for scenario based and focused learning. 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*, *congestion*, and *weather* conditions.

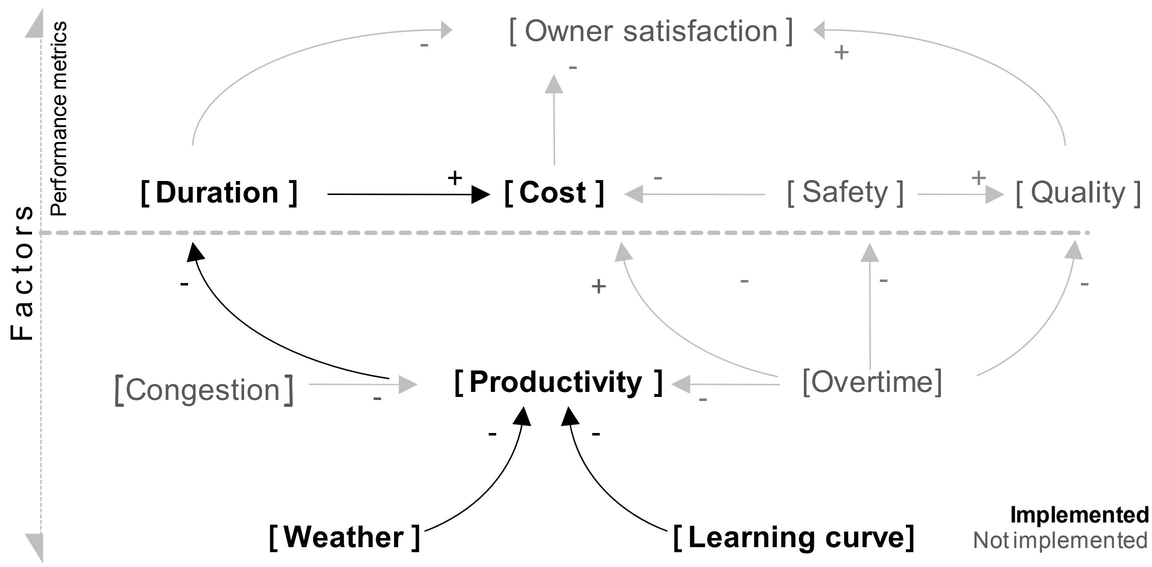


Figure 10: The VCS system dynamics model

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. The productivity may start below average when new resources are brought to the site but slowly increase as workers become more familiar with the construction environment.

Learning curve

The learning curve is an exponential curve with more rapid growth in the beginning followed by a more steady growth with time. For the VCS3 purpose, this curve has been transformed into a series of multipliers as a function of time spent on a project (Figure 11). Worker's productivity thus starts at 75% efficiency in the first hour and increases from 90% in the first four hours to 100% between four and 24 hours. To account for the project experience, the productivity for the subsequent hours increases to 110%.

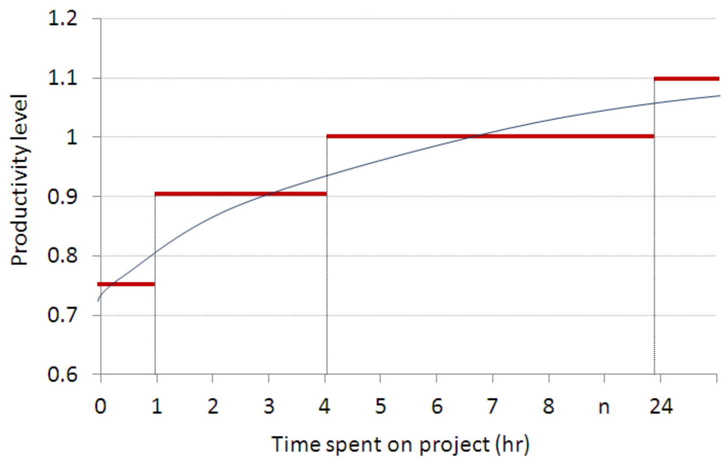


Figure 11: The learning curve factors graph

Weather

The weather is a common factor which can affect the productivity and cause major schedule delays. In conditions such as extreme cold or very hot and humid summer days, the productivity can degrade significantly. To demonstrate the concept of the weather effects on the construction progress, two major weather states are defined – the *ideal* weather conditions which do not affect the productivity, and the *rainy* state which reduces the productivity to 90% efficiency (Figure 12). Also, at this stage of the VCS3 development, the weather change is not random but programmed to change on a four-day cycle. At later development stages, a wider range of weather conditions can be introduced with random changes, which may be appropriate for advanced levels of difficulty.

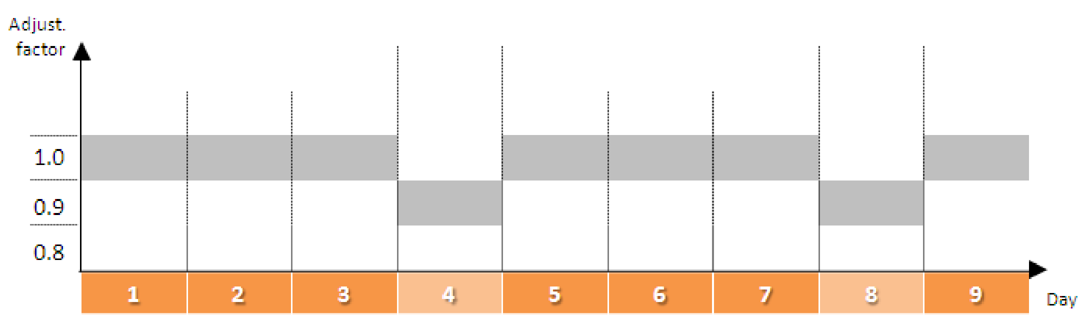


Figure 12: Weather adjustment factors in the VCS 3

Overtime

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). Thus, work beyond a standard five day week and eight hour day period will cause an overall reduction in productivity. In the VCS3 system dynamics model, overtime affects the project cost both directly through higher labor cost for overtime hours, and indirectly through reduced productivity and longer activity durations. Figure 13 shows the productivity adjustment factors as a function of the number of work days and work hours.

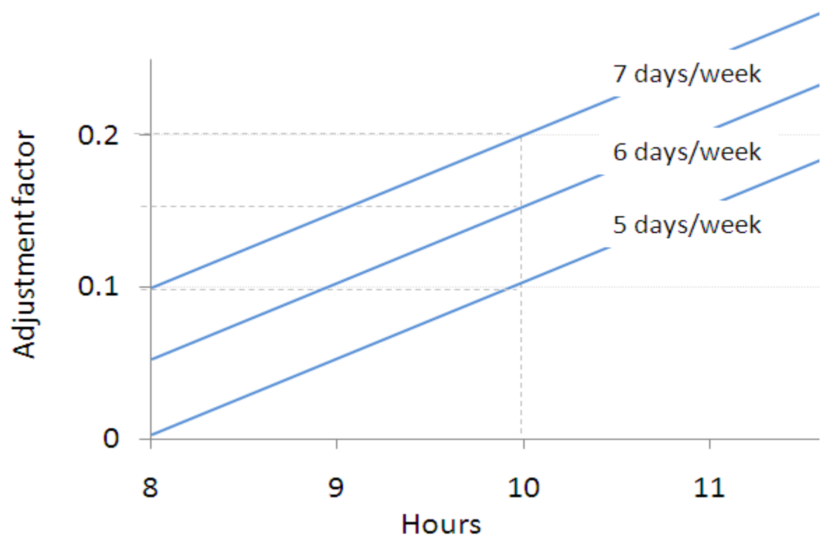


Figure 13: Overtime adjustment factors, adapted from (Neil 1982)

Congestion

Another method to increase the production and meet the project deadline would be to hire more workers in which case issues may involve the availability of work space. In this situation, people, equipment and materials need to share the same space which can lead to overcrowding and reduced productivity. Resource allocation and resource leveling therefore become very challenging under budget, duration or resource constraints. Figure 14 shows the general approach to adjusting the productivity depending on the amount of available space.

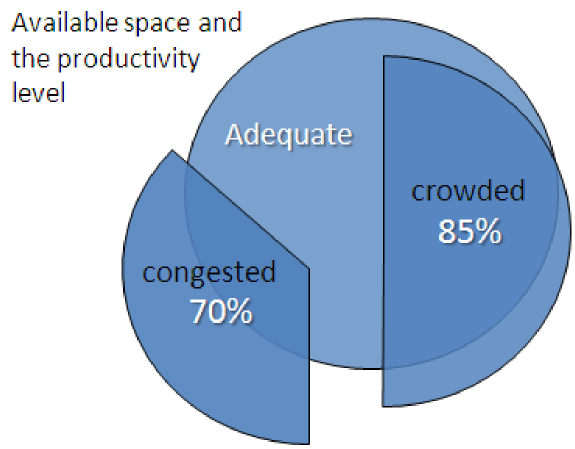


Figure 14: Site congestion adjustment factors, adapted from (Neil 1982)

For educational purposes and to have a more focused and guided learning, the system dynamics model for the VCS3 as mentioned previously is a simplified feedback loop compared to those typically found on real construction projects. The as-built schedule calculations thus, are not intended to make accurate predictions but to demonstrate more clearly the dynamic concepts and the nature of decisions made on a construction project. To test the VCS3 model concept, the scenario for the first stage of the VCS3 implementation focuses on the varying labor productivity as a function of the learning curve and the weather factor, and their overall impact on project cost and duration. The reason for limiting the number of factors is to control for the task complexity and information overload. From the educational perspective, the intention is to have a more guided learning experience and focus students' attention to specific schedule factors and available measures to manage changes to the schedule. From the methodological perspective, this would allow for further validation of the concept and whether the application user interface supports the learning of the incorporated factors. Identifying the challenges in the learning process would provide guidance in implementing additional factors and developing additional learning scenarios.

The case study project - Pavilion

To demonstrate the dynamic nature and the greater level of complexity in managing construction processes, a relatively small-scope pavilion project was deemed as the most appropriate to avoid information overload. This pavilion project adapted from a real world project comprises of work packages such as cast in place foundations, a slab, wood columns, beams, trusses, sheathing, and shingles (Figure 15). For each work package, a minimum of one and maximum of two possible construction methods are offered for students to choose depending on the scenario and project goals. Construction methods differ sufficiently in parameters such as daily production output, cost, and crew types to allow for analysis of advantages of each.

To construct the pavilion, students step through the planning phase and develop the schedule by selecting the construction methods for each building element; plan crew sizes, and develop the sequence of activities. Based on the as-planned schedule, students run the construction simulation and in the role of superintendents make day-to-day decisions regarding resource allocation and observe the progress of their planned as-built schedule.

Figure 15: The pavilion project used for VCS simulation game

A significant difference between previous VCS1 and VCS2 4D learning modules and the current VCS3 simulation game iteration is that students do not directly create activities or calculate their own activity durations when developing a construction schedule. Instead, activities are automatically created from the selected construction methods attached to building element groups, while the activity duration is calculated using the crew's daily output for the chosen method and the appropriate building element quantities embedded in the model. This enables students to test different scenarios in which construction method selection and resource allocation directly affect activity durations and schedule productivity.

Systems Architecture

Based on the concept of demonstrating the difference between the as-planned and as-built schedule, the user interface and the VCS3 application are structured around a planning and a simulation mode. Figure 16 charts the VCS3 system architecture, major VCS3 game components, and the data flow path between the components.

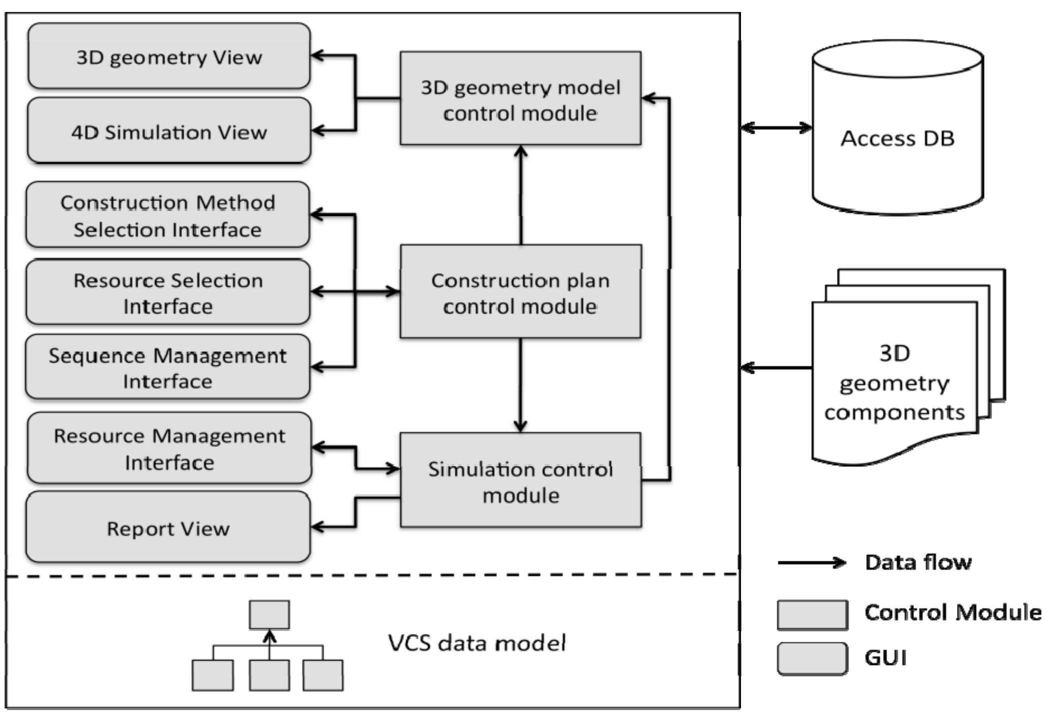


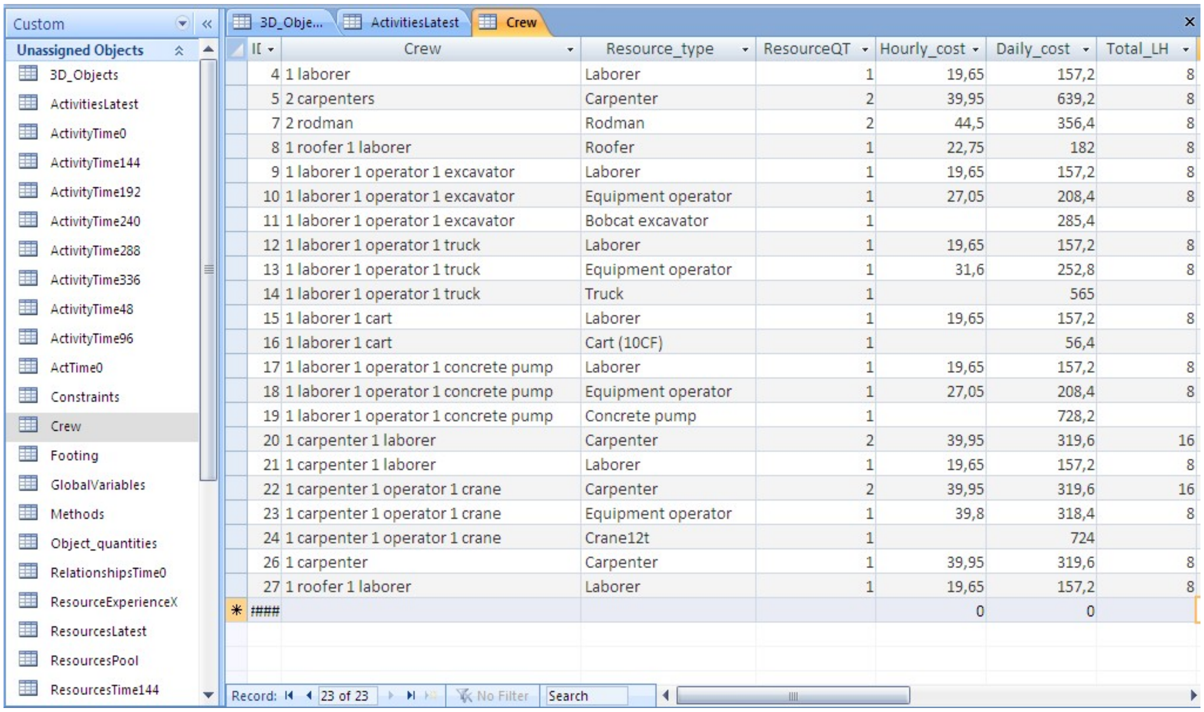
Figure 16: The System Architecture of VCS3 simulation game

The three major system architecture components include the VCS3 application, the game engine, and the database.

- **The VCS3 application** – consisting of the series of graphical user interfaces, the VCS3 application is the interactive part of the system accessible to the user and is supported by the other two elements. The VCS3 application itself is comprised of three core control modules:
    1. The three-dimensional geometry module supports viewing and navigating the 3D model and the 4D simulation. Supported by the Microsoft XNA game engine, the 3D geometry module loads and displays the binary 3D model of the pavilion project and visually simulates the construction progress by using each building element's color and texture properties.
    2. The construction planning module enables the user to develop the as-planned schedule by choosing construction methods, allocating resources to each activity and developing sequences for construction activities attached to each building element group.
    3. The simulation module calculates the as-built schedule and visually simulates the construction progress. The simulation module starts new activities based on user-allocated resources, calculates the progress of ongoing activities, updates the resources utilization and status, and generates the report at the end of the simulation run. The module continues the process until the construction project is completed.

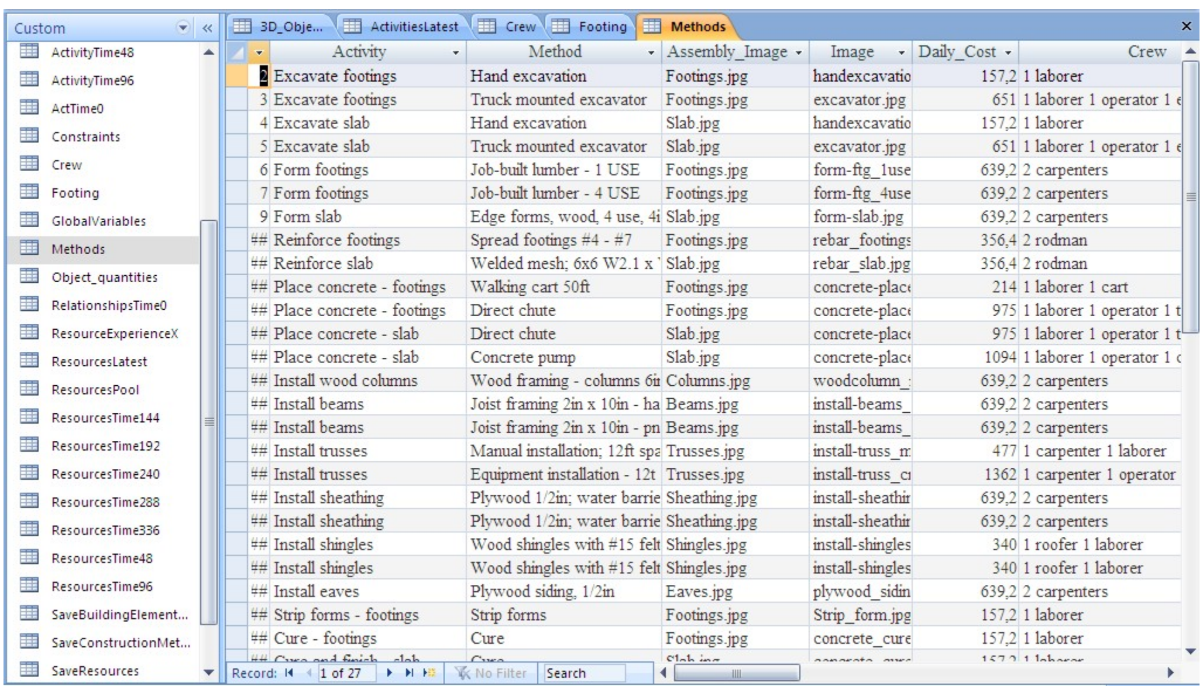
- **3D game engine -** The Microsoft XNA game engine supports the visual display of the three-dimensional geometric models of the pavilion building elements, as well as the 4D simulation side. XNA Game Studio incorporates the XNA Framework, an extensive set of class libraries designed to support cross-platform computer game development based on Microsoft .NET Framework 2.0. The XNA Framework enables game portability between compatible platforms allowing greater focus on the content development and gaming experience. The Microsoft XNA game engine was chosen for its performance and 3D rendering quality being based on DirectX technology. In addition, XNA game engine is based on the .NET framework which is advantageous to the C++ alternative for allowing more rapid and efficient game development.

- **Access database** – the Microsoft Access relational database in a series of tables stores detailed project information data about building elements and their properties, quantities, construction methods, resources, and cost (Figure 17 and Figure 18); as well as global variables such as visibility attributes, camera views, and factors variability. The construction methods, crew, cost, and productivity data are adapted from a common construction data source such as RS Means database. During planning and simulation, the VCS3 application simultaneously retrieves data from the database and stores users' input.



ID	Crew	Resource_type	ResourceQT	Hourly_cost	Daily_cost	Total_LH
4	1 laborer	Laborer	1	19,65	157,2	8
5	2 carpenters	Carpenter	2	39,95	639,2	8
7	2 rodman	Rodman	2	44,5	356,4	8
8	1 roofer 1 laborer	Roofer	1	22,75	182	8
9	1 laborer 1 operator 1 excavator	Laborer	1	19,65	157,2	8
10	1 laborer 1 operator 1 excavator	Equipment operator	1	27,05	208,4	8
11	1 laborer 1 operator 1 excavator	Bobcat excavator	1		285,4	
12	1 laborer 1 operator 1 truck	Laborer	1	19,65	157,2	8
13	1 laborer 1 operator 1 truck	Equipment operator	1	31,6	252,8	8
14	1 laborer 1 operator 1 truck	Truck	1		565	
15	1 laborer 1 cart	Laborer	1	19,65	157,2	8
16	1 laborer 1 cart	Cart (10CF)	1		56,4	
17	1 laborer 1 operator 1 concrete pump	Laborer	1	19,65	157,2	8
18	1 laborer 1 operator 1 concrete pump	Equipment operator	1	27,05	208,4	8
19	1 laborer 1 operator 1 concrete pump	Concrete pump	1		728,2	
20	1 carpenter 1 laborer	Carpenter	2	39,95	319,6	16
21	1 carpenter 1 laborer	Laborer	1	19,65	157,2	8
22	1 carpenter 1 operator 1 crane	Carpenter	2	39,95	319,6	16
23	1 carpenter 1 operator 1 crane	Equipment operator	1	39,8	318,4	8
24	1 carpenter 1 operator 1 crane	Crane12t	1		724	
26	1 carpenter	Carpenter	1	39,95	319,6	8
27	1 roofer 1 laborer	Laborer	1	19,65	157,2	8
####				0	0	

Figure 17: Access database tables storing information about resources



ID	Activity	Method	Assembly_Image	Image	Daily_Cost	Crew
2	Excavate footings	Hand excavation	Footings.jpg	handexcavatio	157,2	1 laborer
3	Excavate footings	Truck mounted excavator	Footings.jpg	excavator.jpg	651	1 laborer 1 operator 1 e
4	Excavate slab	Hand excavation	Slab.jpg	handexcavatio	157,2	1 laborer
5	Excavate slab	Truck mounted excavator	Slab.jpg	excavator.jpg	651	1 laborer 1 operator 1 e
6	Form footings	Job-built lumber - 1 USE	Footings.jpg	form-ftg_1use	639,2	2 carpenters
7	Form footings	Job-built lumber - 4 USE	Footings.jpg	form-ftg_4use	639,2	2 carpenters
9	Form slab	Edge forms, wood, 4 use, 4i	Slab.jpg	form-slab.jpg	639,2	2 carpenters
##	Reinforce footings	Spread footings #4 - #7	Footings.jpg	rebar_footings	356,4	2 rodman
##	Reinforce slab	Welded mesh; 6x6 W2.1 x	Slab.jpg	rebar_slab.jpg	356,4	2 rodman
##	Place concrete - footings	Walking cart 50ft	Footings.jpg	concrete-place	214	1 laborer 1 cart
##	Place concrete - footings	Direct chute	Footings.jpg	concrete-place	975	1 laborer 1 operator 1 t
##	Place concrete - slab	Direct chute	Slab.jpg	concrete-place	975	1 laborer 1 operator 1 t
##	Place concrete - slab	Concrete pump	Slab.jpg	concrete-place	1094	1 laborer 1 operator 1 c
##	Install wood columns	Wood framing - columns 6i	Columns.jpg	woodcolumn_	639,2	2 carpenters
##	Install beams	Joist framing 2in x 10in - ha	Beams.jpg	install-beams_	639,2	2 carpenters
##	Install beams	Joist framing 2in x 10in - pn	Beams.jpg	install-beams_	639,2	2 carpenters
##	Install trusses	Manual installation; 12ft spa	Trusses.jpg	install-truss_m	477	1 carpenter 1 laborer
##	Install trusses	Equipment installation - 12t	Trusses.jpg	install-truss_c	1362	1 carpenter 1 operator
##	Install sheathing	Plywood 1/2in; water barrie	Sheathing.jpg	install-sheathir	639,2	2 carpenters
##	Install sheathing	Plywood 1/2in; water barrie	Sheathing.jpg	install-sheathir	639,2	2 carpenters
##	Install shingles	Wood shingles with #15 felt	Shingles.jpg	install-shingles	340	1 roofer 1 laborer
##	Install shingles	Wood shingles with #15 felt	Shingles.jpg	install-shingles	340	1 roofer 1 laborer
##	Install eaves	Plywood siding, 1/2in	Eaves.jpg	plywood_sidin	639,2	2 carpenters
##	Strip forms - footings	Strip forms	Footings.jpg	Strip_form.jpg	157,2	1 laborer
##	Cure - footings	Cure	Footings.jpg	concrete_cure	157,2	1 laborer

Figure 18: Access database tables storing information about construction methods

Project 3D Modeling

The pavilion project was modeled in 3D Studio Max with applied image textures. To load the model into the VCS application, each individual 3D object was exported as a separate **.fbx** file. The total of 57 pavilion objects were exported including the background, 8 footings, one slab, 8 columns, 6 pairs of beams, 13 trusses, 12 sheets of sheathing, 6 blocks of shingles, and 2 roof closures. Due to initial slow loading of the **.fbx** files into the VCS application, all FBX files and associated texture images were further converted into an **.xnb** format using a template windows game. Initially intended to be loaded from the database, all the building elements are loaded from the content folder associated with the VCS application. Figure 19 shows the pavilion model before and after it is exported into the VCS3 application.

Figure 19: The pavilion project in 3D Studio Max (left) and VCS3 (right)

The VCS3 object data model

An object-oriented programming paradigm is used to represent objects such as building elements, construction methods, resources, and functions needed for communicating with the database and for calculating construction simulation progress. Figure 20 shows the VCS3 class diagram in the Unified Modeling Language (UML) describing the system structure and object classes, their attributes, and class relationships. This class diagram underlies the programming code of the VCS3 simulation game.

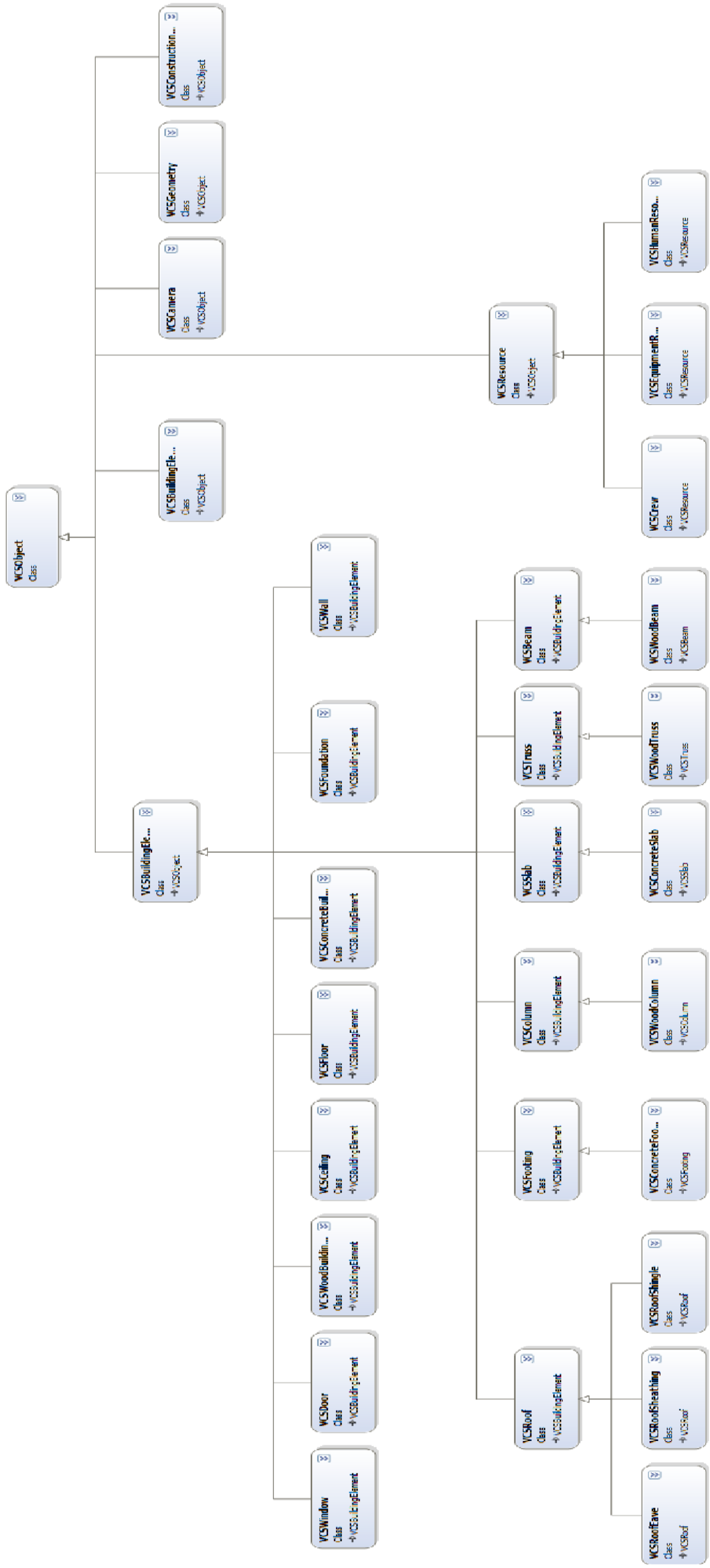


Figure 20: VCS Class Diagram

The VCS3 simulation game object data model has four general classes:

i. VCSBuildingElement class defines project building elements including footings, slab, columns, beams, roof, and trusses. The attributes of this class include geometry representation, associated construction activities, physical constraints, and construction status (Figure 21a).

ii. VCSResource class defines resource types associated with construction activities. The resource class further defines human resources, equipment, and crew classes as child classes (Figure 21b). A construction crew represents a unit required to perform a given construction activity, and consists of either laborers only, or both laborers and equipment. Therefore, the Crew class has a list of HumanResource class instances and a list of EquipmentResource class instances to form a construction team unit that performs a specific construction activity. Human resources have an additional attribute of project experience measured in hours worked on the project, which affects the learning curve factor activated in the simulation.

iii. VCSConstructionActivity class defines construction activities. The class attributes include associated building element group, construction method, assigned human and equipment resource lists, crew size, duration, total and remaining workload quantity, activity status, and the predecessor and successor activity lists (Figure 21d).

iv. VCSGeometry class defines building elements geometries. Associated attributes include color, transparency, and GeometricModel (Figure 21c). In addition, for programming convenience, static functions are also used to perform specific functions independent from the object classes, such as SQL (Structured Query Language) functions.

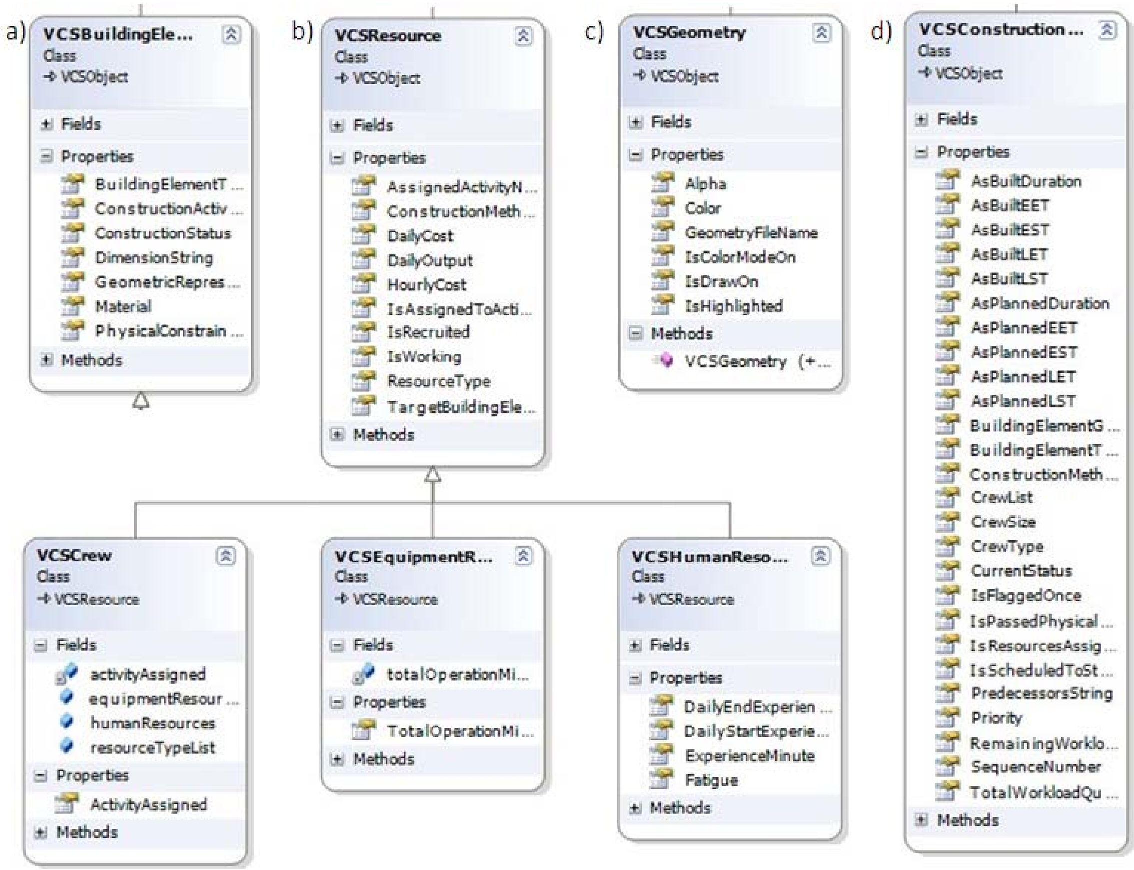


Figure 21: VCS object model classes a) building element class; b) resource class; c) construction activity class, and d) geometry class

Activity duration and cost data is automatically generated within the simulation using information from the RS Means Database, a commonly accepted cost and production data source. The process of semi-automated schedule development process is described in more detail in the following section.

User interface

The system of graphical user interfaces is developed to support the stages in decision making process involved in planning a schedule, and subsequently managing the construction based on the as-planned schedule. The main window opened upon application startup, consists of a 3D model view and the building element tree view listing all the objects and their properties (Figure 22).

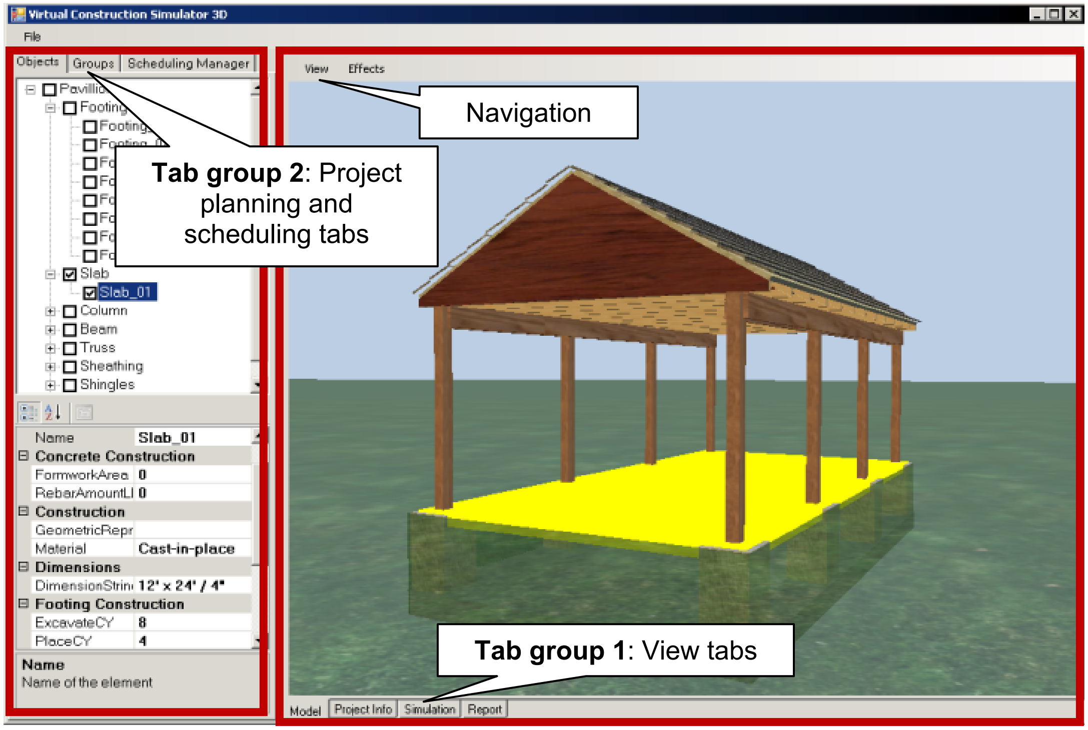


Figure 22: The VCS main window

The main window is organized into a two set of tabs. The first set of four tabs below the 3D view switches between views:

- *Model* view tab – for displaying and navigating the model;
- *Project description* tab – displays project specific information;
- *Simulation* view tab – activates when the simulation starts to show the construction progress; and
- *Report* tab – showing the report summary of the construction progress, generated at the end of the each simulation cycle.

The second set of three tabs left to the 3D view contains functions organized into:

- *Objects* tab listing all the building elements; selecting and highlighting objects in the model view window; and displaying each element's properties upon selection,

- *Grouping* tab in which the first step is breaking the project into construction zones and grouping objects into work packages. In the process of grouping, only objects of the same type can be grouped, for example footings to footings, but not footings to columns. The reason is the construction methods are provided for assembly types and respective activities.
- *Scheduling manager* tab in which the majority of activity takes place is organized into a **planning** phase and a **simulation** phase (Figure 23). Each phase becomes active once the preceding steps have been completed.

Mode 1: Planning the schedule

The **planning** part of the scheduling manager comprises of three sequential steps to plan a project construction schedule including (1) choosing construction methods; (2) deciding on the crew sizes and work hours, and (3) creating a sequence (Figure 23).

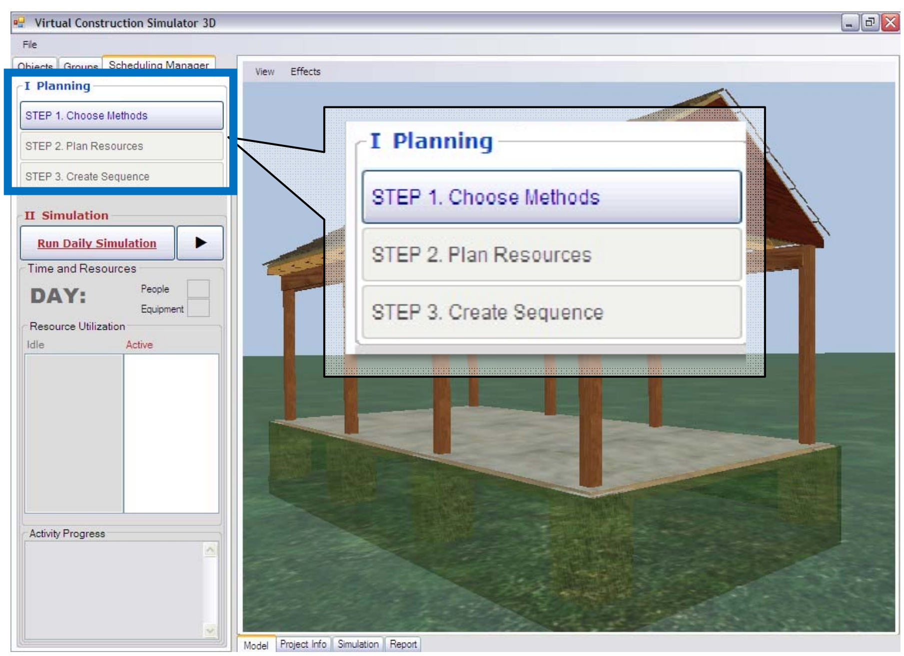


Figure 23: The Scheduling manager tab - *Planning* mode

A series of corresponding graphical user interfaces (GUI) in the construction plan control module allows the user to make informed decisions for each of the three steps. The first step after all the objects are in a grouped status is to choose construction methods for each of the assembly types and their corresponding construction activities. Each assembly depending on the type has the list of embedded activities. For example, a cast-in-place concrete footing assembly involves *excavation*, *formwork* placement, *reinforcement*, *concrete placement*, and *formwork removal* activity. Each activity can be performed by different methods (Figure 24). The automated calculation of as-planned durations is thus a function of assembly's material quantity, chosen construction method, and its associated crew size.

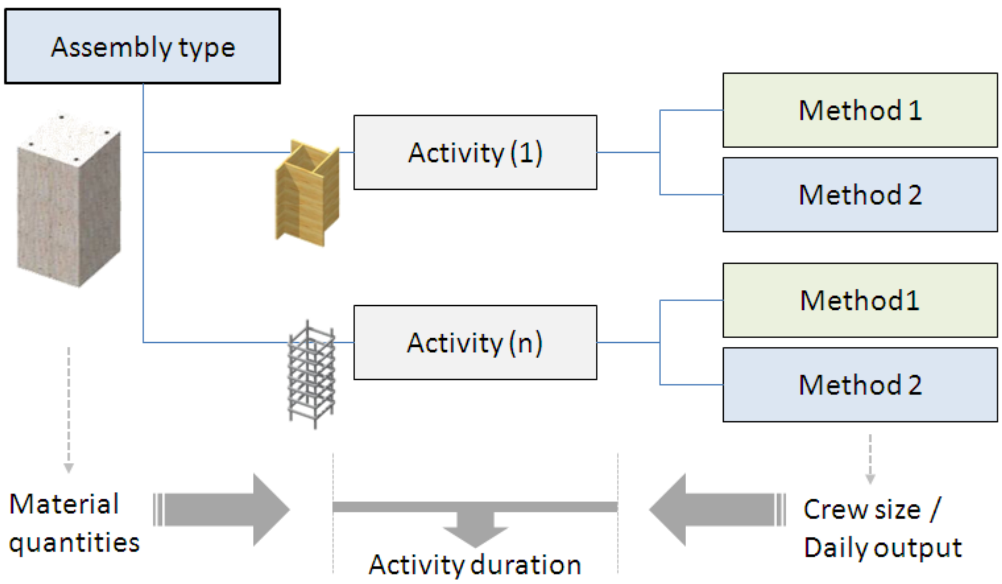
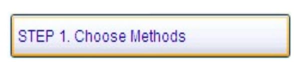


Figure 24: Schematic representation of the relationships between assembly, construction activities, and construction methods

1. **STEP 1 - Choose Methods**:



The *construction method selection* GUI displays available methods for each activity with corresponding crew types and daily costs so students can readily understand and compare construction methods (Figure 25).

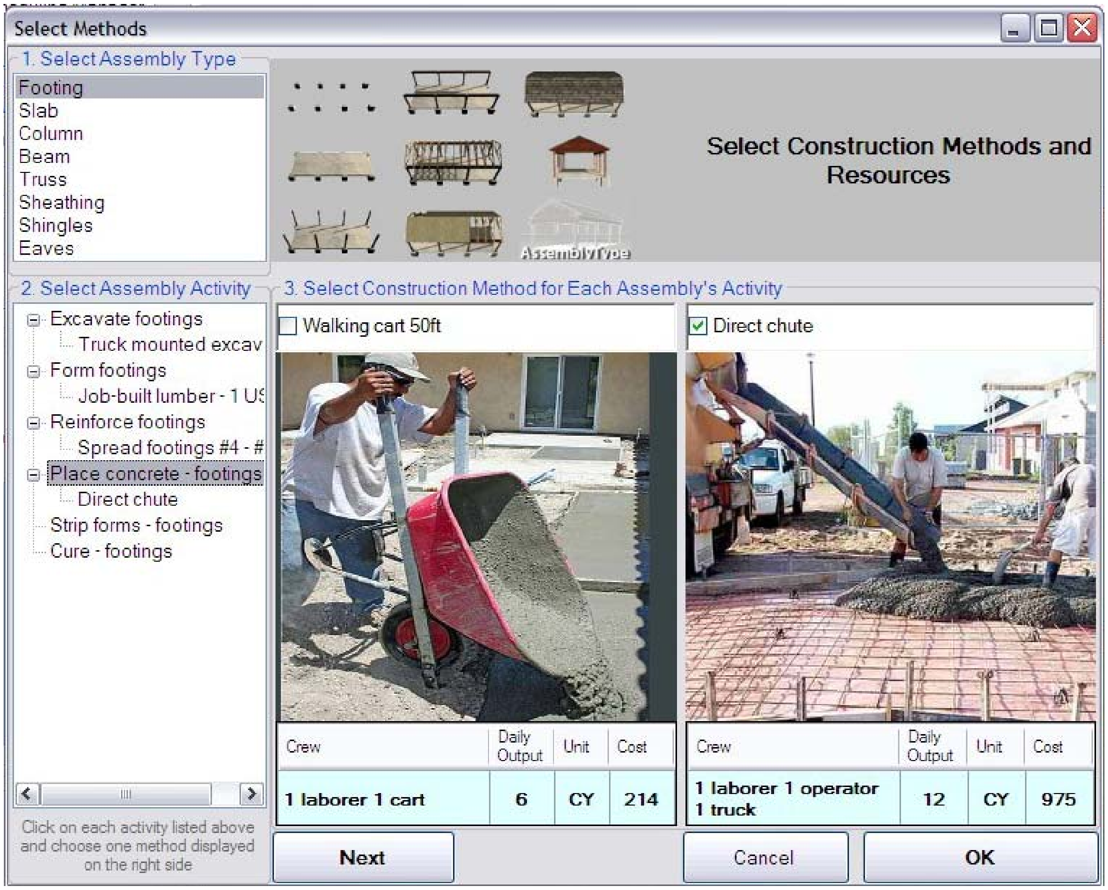


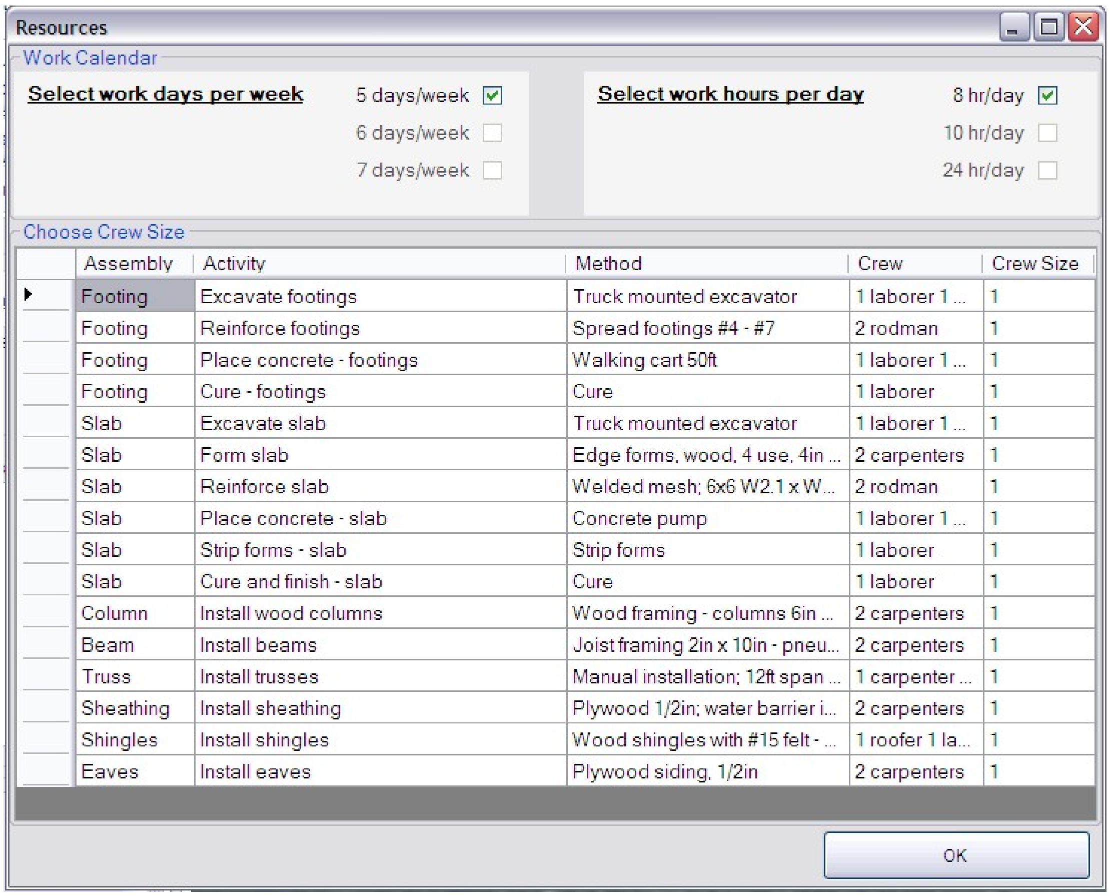
Figure 25: Construction methods selection (GUI)

For the cast-in-place concrete footings assembly only, an additional decision step is introduced. Before selecting construction methods for each of the associated activities, students are asked to decide whether they would like to have formed or ground-formed footings. A brief description of each method explaining their differences in cost due to additional labor for formwork or material waste is provided. Thus, depending on the choice, the list of subsequently displayed activities for cast in place footings will include, or exclude the formwork placement and formwork removal activities.

In addition, concrete curing is the only activity that is implemented as a continuous activity in a manner that it will take between 10 and 12 hours to complete after the concrete is poured, and is independent of crew size.

2. **STEP 2 - Plan Resources**:

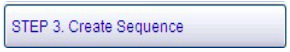
The *resource allocation* GUI allows users to select crew sizes for each construction method and calculates as-planned durations (Figure 26). Although not implemented at this stage, this step will also allow changing the work week and the number of work hours with the inclusion of the overtime factor.



Assembly	Activity	Method	Crew	Crew Size
Footing	Excavate footings	Truck mounted excavator	1 laborer 1 ...	1
Footing	Reinforce footings	Spread footings #4 - #7	2 rodman	1
Footing	Place concrete - footings	Walking cart 50ft	1 laborer 1 ...	1
Footing	Cure - footings	Cure	1 laborer	1
Slab	Excavate slab	Truck mounted excavator	1 laborer 1 ...	1
Slab	Form slab	Edge forms, wood, 4 use, 4in ...	2 carpenters	1
Slab	Reinforce slab	Welded mesh; 6x6 W2.1 x W...	2 rodman	1
Slab	Place concrete - slab	Concrete pump	1 laborer 1 ...	1
Slab	Strip forms - slab	Strip forms	1 laborer	1
Slab	Cure and finish - slab	Cure	1 laborer	1
Column	Install wood columns	Wood framing - columns 6in ...	2 carpenters	1
Beam	Install beams	Joist framing 2in x 10in - pneu...	2 carpenters	1
Truss	Install trusses	Manual installation; 12ft span ...	1 carpenter ...	1
Sheathing	Install sheathing	Plywood 1/2in; water barrier i...	2 carpenters	1
Shingles	Install shingles	Wood shingles with #15 felt - ...	1 roofer 1 la...	1
Eaves	Install eaves	Plywood siding, 1/2in	2 carpenters	1

Figure 26: Resource allocation GUI

3. **STEP 3 – Create Sequence**:



The *activity sequence* GUI displays the list of auto-generated construction activities and their calculated durations based on the chosen method and crew size (Figure 27). The sequencing GUI allows users to develop activity sequences either by typing in the activity predecessor's number manually or loading Microsoft Project activity list and duration information. The integration with the MS Project allows the list of activities to be imported from the VCS3 into the MS Project by clicking the "View in MS Project" button (Figure 27). After developing the sequence, the predecessors' data and the sequence can then be updated from the MS Project inside the VCS3 application. The integration with the MS Project allows students to use either environment depending on their comfort level, and provides an option to save each schedule in a standard format.

The activity list in the sequencing window is sorted by their physical precedence and constraints starting with footings, slab, columns, and continuing until the roof closure. Currently implemented constraints include both the building element and activity order which may not be violated. Thus, if the constraints are not met (e.g. sequencing column before footing, or concrete placement before excavation), the VCS3 will display the error message and will not continue with the visual simulation of the sequence.

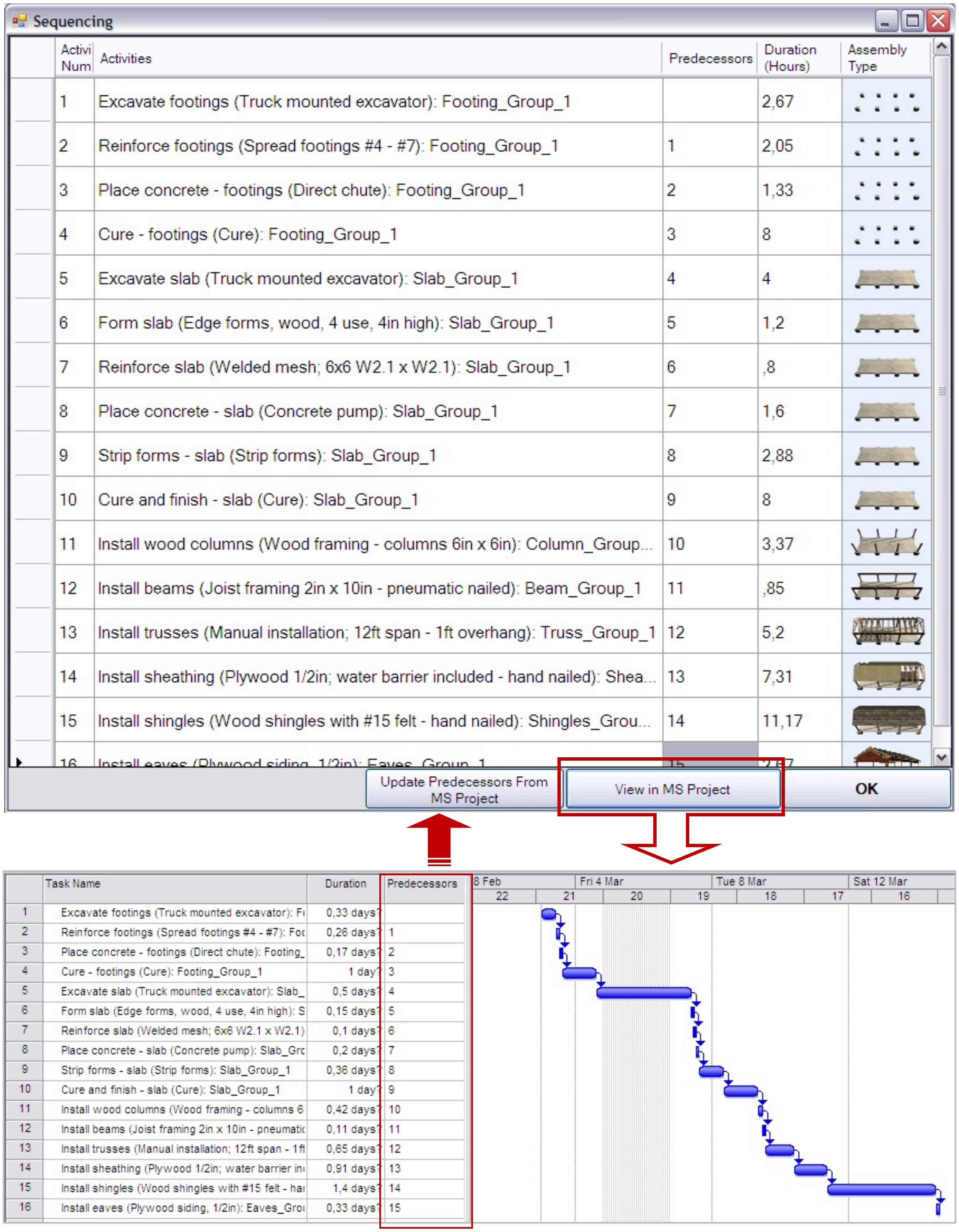


Figure 27: The sequencing interface (GUI) and the integration with the MS Project

As mentioned earlier, instead of the user deciding on the construction activities, the list of construction activities is generated within the application. Once the user chooses construction methods, each of the assembly's embedded activities becomes attached to the user created groups (Figure 28). This streamlines the process of developing the construction schedule and ensures the comparability of the schedules developed between simulation runs and between different players. With the automated activity creation, the idea is for students to get a more holistic overview of the scheduling process. In this way, students can focus more on the types of decisions involved in the process rather than investing time in searching for data and manually developing and calculating the schedule. The predetermined set of activities can be both limiting and advantageous, however, this allows for customized project scenarios and focus on specific issues depending the learning objectives.

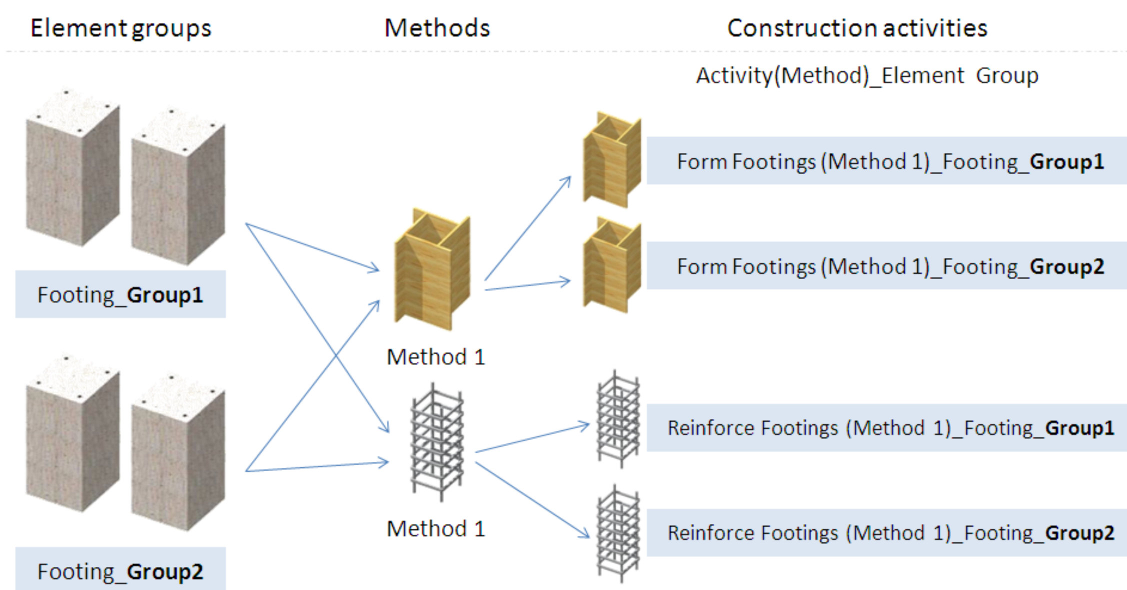


Figure 28: The process of automated construction activity generation in VCS

Mode 2: Simulating the construction

Upon developing the as-planned schedule, the next step is to start the project construction and manage its daily progress. The *simulation control module* calculates daily schedule progress based on scheduled construction activities and the type and number of human resources and equipment allocated for each activity. Figure 29 shows the simulation mode user interface consisting of "Run Daily Simulation" and *play* buttons, and the "Time and Resources" information summary panel below, displaying the following:

- The simulation day counter – displaying which day of the construction is currently being simulated;
- The number of resources (human and equipment) on site that day;
- Active and idle resources – during the construction simulation process the utilization of resources is tracked by updating at ten-minute intervals the resources who have been assigned to an activity and those who are waiting to be assigned to the next activity;

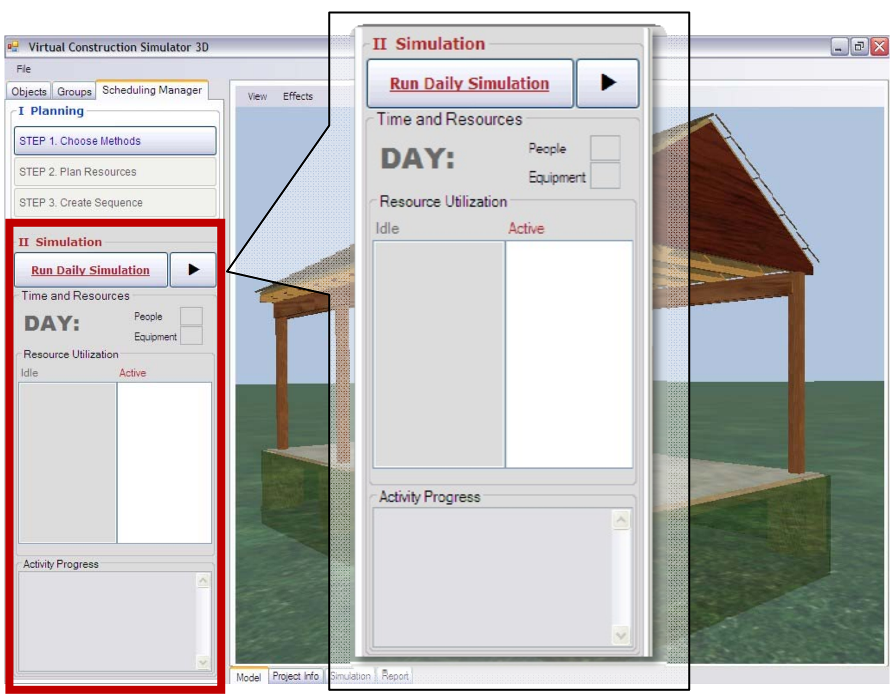


Figure 29: The Scheduling manager tab - *Simulation* mode

- Activity progress – real time reporting of the ongoing activities along with the amount of work completed and work remaining, also updated on a ten-minute interval.

In the simulation mode, the user assumes the role of a superintendent and makes decisions related to managing daily resources needs. The following are the steps:

1. Run Daily Simulation

Clicking on the button activates the simulation mode and opens the new window for choosing the resources to be on the site that day (Figure 30). Each day before the construction starts, the user “hires” resources to be on the site that day based on the as-planned schedule and the list of activities planned to start on the same day. Resources consist of both *laborers* and *equipment*. In addition, human resources have a property of project experience directly related to their productivity rate. The level of each laborer’s experience is displayed in the properties window in the form of time spent on the project.

The user interface for choosing daily resources displays the list of activities with the planned start day and the resources needed. However, each activity can be accelerated by hiring multiple crews if necessary. In this manner, the planned schedule can be altered and updated based on the progress.

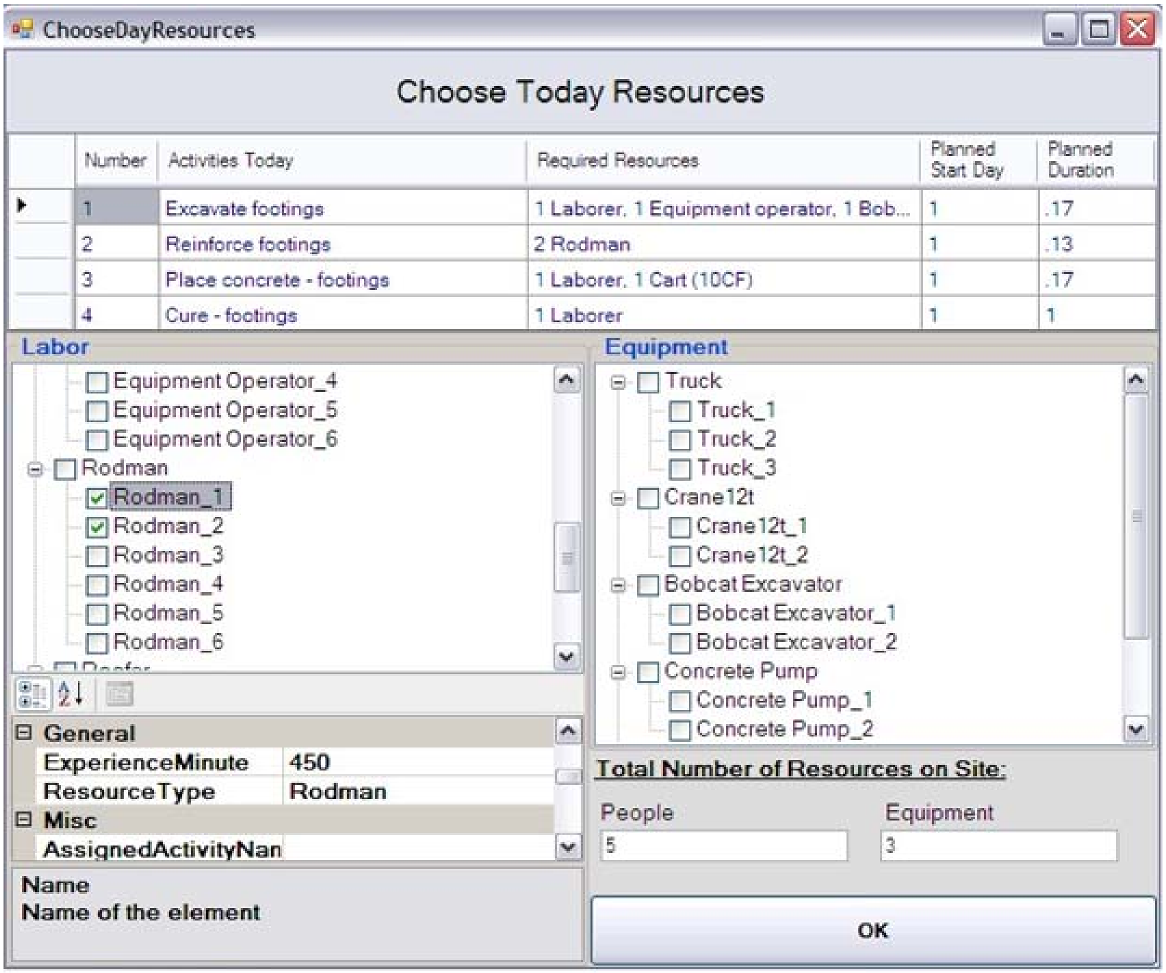


Figure 30: Choosing daily resources GUI in the simulation mode

2. Start the construction simulation

Once the labor and equipment has been selected for the day, the "play" button starts the actual construction simulation, both the visualization part and the as-built calculation with the weather and learning curve factors taking effects. The daily counter and the list of resources hired for the day are now displayed in the simulation panel.

When the simulation begins, the user is prompted to allocate available resources each time new activity is scheduled to start (Figure 31).

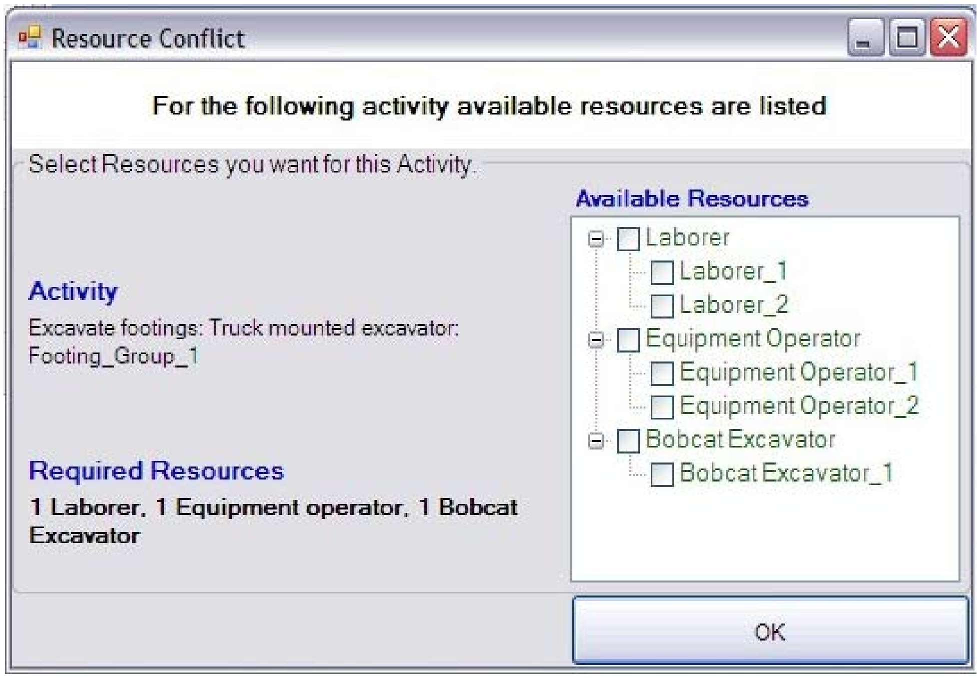


Figure 31: Resource allocation GUI

In instances where there are more than a required number of available resources listed, the user can choose to allocate multiple crews for a starting activity. However, if the activity is scheduled to start and there are no available resources, the user is notified and required to wait until necessary resources become available. The simulation progress is updated at a ten-minute interval, each showing resources that are assigned to ongoing activities (*active resources*) and resources that are on the site but not assigned to any activities (*idle resources*).

After completing the daily simulation, the user can review daily and cumulative construction progress on the *reporting* GUI. The report shows the information about the weather and its effect on the overall productivity; the construction progress and the status of each activity; resource utilization, and daily and cumulative labor and equipment costs (Figure 32). After reviewing the report, the user repeats the simulation process by clicking “Run Daily Simulation” button again, and hiring resources for the next day until the project construction is complete.

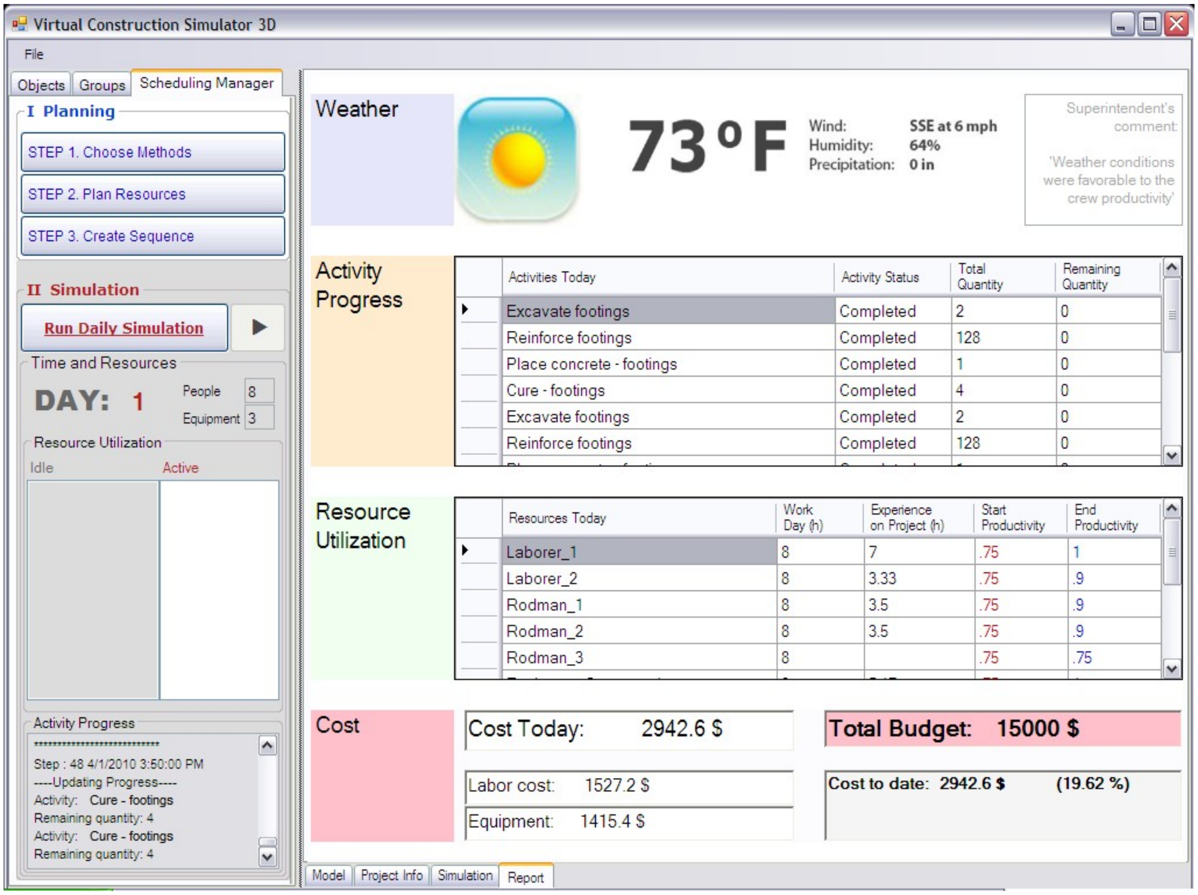


Figure 32: The report generated at the end of a daily simulation cycle

Although the simulated sequence is based on the as-planned schedule, additional factors are triggered to demonstrate the schedule variability and the need to manage and update the as-built schedule. The factors such as weather or labor productivity fluctuate affecting the construction progress. Calculating the new as-built activity duration takes into consideration new factors that were triggered in the simulation mode.

Program verification and validation

Following the conversion of the system dynamics model into a computational simulation model, the simulation model underwent a verification process in which the simulation was checked for both its internal and external representational validity.

Internal validity refers to the simulation game functionality and whether the running model complies with the initial list of assumptions. The validation process sought to ensure that specified information in a learning scenario was included in the computational model. For consistent and reliable application performance, each simulation step output was manually calculated to check the simulation model for accuracy; and in repeated simulation runs all outputs were checked for consistency.

External representational validity refers to how closely the simulation model behaves and corresponds to its relevant real world experience. External validity thus refers to appropriate inclusion of identified construction factors and decision processes found on real construction projects. The simulation model external validity was confirmed through reviews by several faculty members and two industry practitioners.

User Interface Testing

To further assess the usability of the application from a student perspective, a group of 10 graduate students were asked to voluntarily complete the assignment using the VCS3 application. Only students who were not involved in the actual VCS3 implementation were selected. The obtained feedback was used to further improve the user interface, application performance, and correct any application errors. Application parameters such as the length of the simulation and the number of cycles to complete the VCS 3 activities were also tested prior to full scale classroom implementation.

To summarize, through different scenarios, the VCS3 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. Students will learn to make initial decisions about construction methods, resources and activity sequence, and subsequently 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.

Chapter 4

The VCS3 Simulation Game Evaluation

The VCS3 simulation game is evaluated on two main levels – for its representational validity and effectiveness as a teaching tool. Representational validity, described in the previous section, is part of the program verification and precedes the educational evaluation. Representational validity as a required basis for educational evaluation ensures the consistent and reliable application performance and relevant content.

The second evaluation level examines the educational value and effectiveness of the simulation game for achieving specific learning outcomes. Measuring the educational effectiveness focuses on the extent to which the learners' knowledge has changed or improved as effect of the simulation game, as well as whether students' motivation to learn has improved. Additional evaluation questions may focus on the relevance of skills and knowledge gained to the real world scenarios.

Table 2 summarizes main categories of evaluation questions and respective feedback sources to evaluate the VCS3 simulation game on both levels. While application performance and content validity are evaluated before implementation, the remaining categories focus on measuring learning, motivation and experience from students' participation. In the implementation stage, students and other potential users evaluate the VCS3 effectiveness as an instructional tool for meeting learning objectives; its usability, and the realism of the experience through ratings of engagement and satisfaction.

To evaluate the effects of a simulation game for learning construction planning and management concepts, the VCS3 simulation game was implemented and tested in an undergraduate construction engineering course at Penn State. The following section describes in detail the research design, procedures, and instruments used to evaluate the VCS3 simulation game as a teaching tool for construction planning and management concepts.

Table 2: Evaluation categories and questions for the VCS3 simulation game

	The Evaluation Questions	Data / Method	Source
Application Performance	Is the simulation game reliable?	Crashes, bugs, error messages	Beta-testing
	Is the simulation consistent in its performance?	Same output in each run	Beta-testing
Content	Is the content accurate?	Review with faculty and industry members if applicable	Faculty / experts
	Is the content appropriate?	Review with faculty members	Faculty / experts
Usability	Is the simulation game easy to learn to use?	Survey	Students
	Does the simulation game account for learner's experience?	Survey	Students
Learning	What are the learning objectives?	Review with faculty	Faculty
	How well do students meet the learning objectives?	Tests/questionnaires	Students
Realism	Is the simulation game compelling/engaging for the students?	Survey	Students

Research Question

Given that a computer simulation game for construction can capture dynamic spatial and temporal relationships, the explorative and interactive nature of this virtual construction environment makes it a powerful visualization tool supportive of the learning process. Simulation game attributes, such as immediate feedback, variability, goal-driven exploration and competition, integrated with the learning content create the VCS3 as an environment to support learning and a rapid testing of construction-related decisions. While automated calculations of planned and simulated construction activities support easier and faster testing of different strategies, the engaging aspect of the VCS3 aims to support sustained attention and time investment in the learning exercise.

This study aims to investigate the effects of the VCS3 simulation game on learning construction planning and management concepts, as well as student engagement and motivation. More specifically, the VCS simulation game is evaluated to improve students' understanding of project constraints, different construction methods, activities and resources; as well as gaining an understanding of dynamic changes, risks, and tradeoffs. Specific competencies targeted by the simulation game include:

Fundamental engineering and management competencies critical for effective construction process planning. Examples include the development of skills to understand activity sequence relationships, resource leveling and utilization, construction method selection, and cost control.

Problem-solving competencies as abilities to identify problems, test, and optimize solutions. A stepped decision-making process embedded in the simulation game encourages students to practice problem solving and test relatively fast variety of solutions, evaluate the performance of these solutions, and explore alternative methods.

To understand the effects of the VCS simulation game on meeting the objectives and provide guidelines for future improvement, specific learning evaluation questions include:

- How has the students' learning changed based on the simulation gaming activity?
- Does the simulation activity result in significant learning gains?
- Was the time commitment for learning appropriate for the skills and information gained?
- Were the students engaged and did they enjoy the simulation activity?
- How do students feel that the simulation activity needs to be changed in order to maximize learning?

Research Design

Research in using simulation and game technology in education has traditionally focused on qualitative methods to determine the effectiveness of these types of instructional tools. To measure the effectiveness of an experiential learning tool such as a simulation game, experimental design with random subjects and control groups is a preferred approach. In the large pool of research, a few studies have used quantitative approaches but they have come under scrutiny for the lack of rigor and confounding results. The comparison of traditional teaching methods and those that involve games and simulations have long been the focus of a great number of studies that aimed to determine the advantages of the latter. More recent studies however, challenge the validity of comparing the two teaching methods that are very different in nature due to the content, involved activities, and abilities they are intended to support. Traditional measurement methods mainly utilize test scores which measure the ability to recall information and not necessarily the ability to apply it (Norman and Spohrer 1996). The meta-analysis of studies in computer based simulations by Gosen and Washbush (2004), identifies some common challenges in measuring the effectiveness of simulations, and thus recommendations that:

- Research design should be experimental, randomized, with pre- and post-tests, and control groups;
- Learning outcomes should be clearly defined, with objective learning measures tied to explicit learning objectives;
- The measurement should be valid, with reliability confirmed through repeated testing of the instrument and triangulation.

To test the effectiveness of the VCS3 simulation game on learning and motivation, a one-group pretest-posttest design was conducted. Students in the third year introductory course to the building industry (AE 372) were selected for the study because of their relatively little practical experience on the construction site, as well as their limited knowledge on the concepts of construction scheduling and management. A detailed description of the measurement, setting, and procedures is provided in the following sections.

Measurement

To determine the effectiveness of the VCS3 simulation game, both qualitative and quantitative methods are employed to evaluate the level of learning and motivation. Pre-test and post-test questionnaires with closed- and open-ended questions were developed to assess the change in learning as well as students' perception on learning as an effect of the simulation game. The pre-test and post-test questionnaires are included in Appendix A and Appendix B respectively.

The Kirkpatrick's framework of four levels of learning (Kirkpatrick and Kirkpatrick 2006) was used as a reference to develop the learning assessment and evaluation questions about cognitive and affective effects. Based on this framework, as well as previously discussed educational research and learning theories, learning was operationalized and measured through the following components:

- **Content knowledge and conceptual understanding**
    - Measuring the domain knowledge and the conceptual understanding of the material before and after the simulation exercise provides the information on changes which can be contributed to the simulation game application. In this level, learning outcomes are grouped into question types that measure:
        - **knowledge** of the construction scheduling domain and basic concepts of the scheduling process, activity durations, resources, productivity, and construction methods. Existing knowledge and any changes post simulation are measured through both open-ended questions asking students to identify and *list* specific information (eg. "List factors that affect construction activity duration"), and closed-ended questions asking students to rank the information based on given criteria such as importance of the effect factors have on the schedule (eg. "rate the difficulty to control each factor").
        - **comprehension** of the construction planning and management concepts, as the ability to further synthesize, summarize concepts, and estimate or predict possible outcomes. Comprehension is measured both before and after the simulation exercise through open-ended questions asking students to estimate specific outcomes given a hypothetical scenario, such as deciding on the measures to accelerate the schedule in the event of delays and estimating the most likely effects of chosen measures on schedule duration and cost.
    - These specific questions aim to measure any difference in understanding, interpreting, or acquiring of new information as a result of the simulation experience. The open-ended format is deemed the most appropriate for students to reflect on specific construction issues that pertain to general construction management domains and are also relevant to the simulation exercise.

- **Motivation**
    - Research in education has recognized motivation as a driving force behind the learning process. Motivation is broadly defined as the willingness to engage in a specific task and invest time and effort in an experience (Garris et al. 2002; Gee 2007; Squire 2006). Motivation is considered as an important aspect in the learning process as learners who are highly motivated are more likely to invest time in an activity and learning experience (Aldrich 2003; Garris et al. 2002). Hannafin and Hooper (1993) discuss the relationship between engagement and learning suggesting that the increased engagement during the learning process leads to a longer information retention. The motivation to learn greatly depends on the learner's personality, the type of information to be learned, and how the learner perceives the difficulty and values of the information to be learned (Keller and Burkman 1993). As discussed earlier, from an educational perspective motivation is a complex construct and concerns the following components:
        - Learner's emotional response to the task;
        - Perceived importance of the task;
        - Perceived competence;
        - Invested effort in the task;
        - Persistence.
    - This study focuses on exploring the effect of simulation games on the level of student motivation and the relationship between this motivation and learning. The hypothesis was that the level of student motivation would score higher after using the VCS3 simulation game. Motivation was measured using a 13-item scale adapted from the On-Line Motivation Questionnaire (Boekaerts 2002). The pre-test and post-test motivation assessment part of the questionnaire is adapted

from the situation-specific online motivational questionnaire developed by Monique Boekaerts (2002). The questionnaire represents a self-report instrument of students' cognitions and emotions related to a specific task while the learning process is taking place (Boekaerts 2002; Crombach et al. 2003). The pre-test questionnaire evaluates the students' emotional response to the task after being introduced to it, as well as their intention to invest effort in the task before they start. It comprises of items measuring the task judgment (e.g. "How useful do you consider this exercise?"); the learning intent (e.g. "How well you intend to perform on this exercise?"); and the emotional state (e.g. "How do you feel before starting the assignment?", "nervous", "fine", "annoyed", etc.). The post-test questionnaire follows the completion of the task and parallels the pre-test part in evaluating the emotional state, perceived importance, and the effort invested in the task. In addition to asking students how they felt immediately after the simulation experience, questions such as "how *useful* do you consider this kind of exercise?", "how much *effort* did you put into this exercise?" and "how much *attention* did you provide to this exercise?", sought to measure students' motivational orientation and perception about the importance and interest in the task that could have impacted their performance.

- **Attitudes and reactions**
    - Measuring attitudes and reactions to the simulation game provides an initial level of the students' acceptance of the tool. Assessment of learner's satisfaction is important to determine if there was favorable reaction as a necessary condition for increased motivation and potentially increased learning. Although positive reaction does not necessarily ensure learning, negative reaction significantly impedes it. Positive reactions to the simulation game precondition the learning and provide the information of the strengths and weaknesses of the

educational tool. Questions such as "what do you like (or dislike) about the simulation game?", "What would you change in the simulation game?", as well as Likert scale questions to rate specific simulation features, aim to provide the information about overall reaction, as well as detailed feedback on specific aspects of the simulation application. This information as a formative evaluation provides guidelines for future simulation game improvements.

The pre-test survey questionnaire is organized in three sections corresponding to the demographic and general information; the motivation level and task perception; and the content knowledge. The post-test survey questionnaire is similarly structured in three sections corresponding to the motivation level; the application use; and the simulation and learning experience. Both pre- and post-test surveys were administered online. The complete pre-test and post-test questionnaires are found in the Appendix A and B respectively.

Procedure

The VCS3 game simulation was tested in spring 2010 in the AE 372 course titled "Introduction to the Building Industry" of 97 students. A two-hour practicum session was used for the simulation exercise, during which students were asked to develop and simulate the project sequence using the VCS3 application and complete the pre- and post-test surveys. Students completed the assignment as a class requirement; however the decision to participate in the study was voluntary.

Two practicum sessions of two-hour duration in one week were allocated for the study. Two class sections with 46 students and 43 students respectively, were seated in a local computer laboratory with 35 work stations, each having two monitors (Figure 33). At the start of each of the sessions, students were briefed on the nature of the study and their participation. Although completing the assignment was a class requirement, the participation in the study and the completion of surveys was voluntary. Students were assured of the confidentiality of the results, and that performance on the assignment would not affect their course grade in any way.

Figure 33: AE 372 students using the VCS3 game in the computer lab

The first fifteen minutes of the allotted time was spent introducing the assignment and demonstrating and training students how to use the VCS3 application. In addition to live demonstration, students were given the printed version of the VCS3 manual as a reference during the work on the assignment (see Appendix C). An additional five to ten minutes were given for students to practice and become used to the VCS3 user interface. Given that both sections counted more students than available work stations, after the VCS3 demonstration and before the start of the assignment, students were offered a sign-up sheet with additional two-hour time slots if they chose to leave and do the assignment later. Subsequently, sixteen students in the first section, and twelve students in the second section chose to work in pairs, while seven students in total decided to leave after the training part and came back in a different time to do the assignment. Students who decided to start the assignment were given consent forms and assignment sheets (see Appendix D and E). After collecting the signed consent forms, students were asked to start by completing the first survey regarding the demographic information, computer use, their current motivational state, and questions related to knowledge in scheduling concepts. After completing the first survey, students were asked to start the VCS3 application and proceed through the assignment. The competitive aspect of the exercise asked students to test and report on the handout how fast they could build the pavilion under given constraints, including budget and available resources. Upon completion, assignment sheets with the reported results were collected and students were asked to complete the exit survey.

Data Collection

Data collection was done through online pre- and post-survey questionnaires measuring the level of learning, motivation, and students' perception of the simulation experience and the VCS3 application use. Demographic information such as academic standing and previous experience with computer games was collected to improve the accuracy of the analysis and provide a better understanding of the obtained results. The level of knowledge in construction concepts was measured with open-ended questions and compared to determine if any change in learning occurred as an effect of the simulation experience. The open ended format allowed students to reflect on specific issues related to the project problem, as well as any relationships discovered between variables and the conclusions students arrived to. The level of motivation and students' perception of the assignment was also measured. Lastly, a series of both open-ended and closed questions measured learning experience from the student perspective and feedback on the application, user interface, system functionality and useful features for future development and improvement of the VCS3 simulation game.

Data Analysis

All closed-ended questions and Likert-scale items were analyzed by applying appropriate statistical procedures. Each statistical analysis is reported in the results section.

For all open-ended questions of both qualitative and quantitative type, content analysis was conducted to determine trends and patterns in students' responses. Content analysis is broadly defined as a systematic method for compressing large amount of data into fewer content categories based on explicit coding rules (Berelson 1971; Krippendorff 2004; Weber 1996). The content analysis procedure was done in the following steps:

1. The word frequency count was performed as the first step to identify words of potential interest;
2. Identified terms and words were analyzed and grouped to match the context of their use, and to ensure the consistency and strengthen the validity of the subsequent inferences made from the data;
3. Words with similar meanings and connotations were grouped into categories that must be mutually exclusive (Weber 1996). Categories were established through the process of emergent coding following the preliminary investigation of the data, and
4. Based on the established coding categories, data was coded accordingly with ensuring the reliability and validity.

Ensuring the reliability is a two-fold process involving the check for stability and reproducibility. Stability or intra-rater reliability is achieved through repeating the coding process by the same coder to ensure the consistency of the results. Reproducibility or inter-rater reliability is ensured through different independent coders coding the same text in the same categories and measuring the level of agreement between the coders. High level of agreement ensures the clarity of the criteria and coding rules.

To analyze open-ended questions, two researchers independently reviewed the material and identified several concepts which were then compared. Through the thorough review process, differences were reconciled resulting in consolidated coding criteria. The researchers independently coded two random open-ended question data sets. The inter-rater reliability resulted in 84% level of agreement.

The assessment instruments developed to measure a construct – learning and motivation – need to be both reliable and valid. While reliability refers to the consistency of the scores, instrument validity refers to the extent to which it measures the construct. Validity of the instrument ensures that the inferences from the scores for a given population in a particular context are accurate. Reliability of the scales used for assessment is reported in the results section of this study. The process of gathering evidence on the instrument’s validity is however more challenging, and involves multiple sources of measurement. To ensure the instrument validity to accurately evaluate learning gains, the questions and items were reviewed with experts in construction education and learning assessment. Items were reviewed to ensure they were formatted appropriately, covered by the simulation game content, and representative of the content domain.

This chapter outlined the research design and the development of instruments to evaluate the change in learning and motivation as an effect of the VCS3 simulation game. The following chapter reports the results from the class implementation.

Chapter 5

Results

Participants

Out of the total of ninety-seven students enrolled in the AE 372 class, 85 students completed the pre-test survey; 87 students submitted the handouts; and 81 students completed the post-test survey (Figure 34). Both class sections were taught by the same instructor. The average age of the participants was 21; there were 62 male and 23 female students. While completing the simulation exercise was a class requirement, participation in the research study including observations and surveys was voluntary and did not affect student grades.

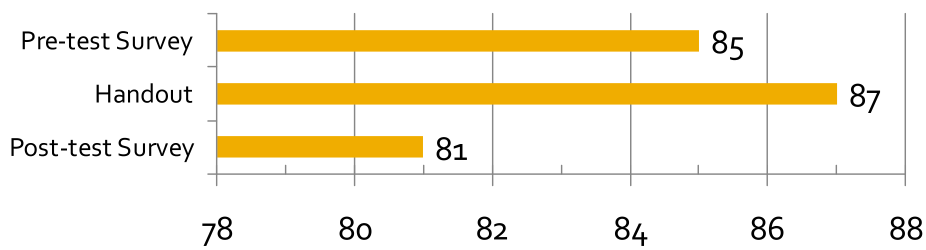


Figure 34: Number of students who completed each part of the study

Motivation

Two new scales were created combining the items before and after the simulation respectively. Both scales incorporated similar questions on emotional state (such as feeling nervous, worried, enthusiastic, annoyed, and confident) and learning intent items (such as intent to perform well, task utility, and amount of effort invested in the task). The reliabilities of these two scales were α=.73 for the pre test α=.82 for the post test. Paired sample t-tests demonstrated that the motivation level after the simulation exercise (*M* = 3.25, *SD* = .41) was significantly higher than the motivation level prior to the simulation exercise (*M* = 2.97, *SD* = .36), t (80) = 4.40, p<.001.

Learning

Short open-ended questions were included in both pre-test and post-test surveys to determine changes in learning that occurred as an effect of the simulation game. Both qualitative and quantitative data analyses methods were used to determine differences in student understanding of factors that impact construction activity duration before and after the simulation exercise. Identified factors were analyzed and grouped into categories and the average rating of each group was calculated. Table 1 shows the list of factors with average ratings before and after the simulation.

Table 3: Comparison of the responses to an open-ended question before and after the simulation

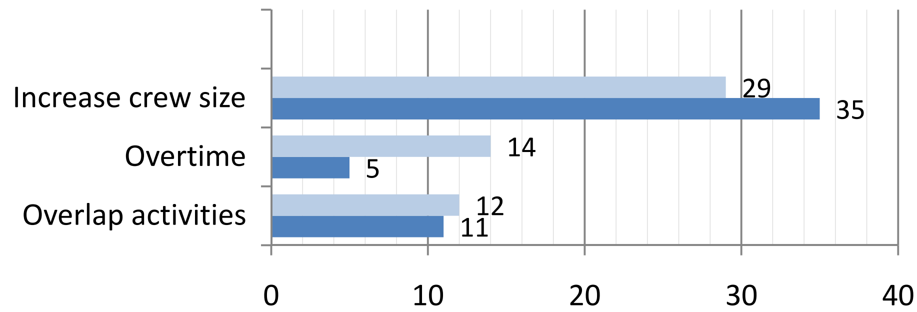
List factors that impact construction activity duration	**Rate difficulty to control the factor**			
	Frequency		Mean	
	before	*after*	*before*	*after*
Schedule (overlapping act)	8	19	1.8	2.4
Labor size	14	21	2.8	2.2
Labor productivity/experience	4	14	2.25	3.5
Weather	25	20	4.96	4.95
Budget	4	2	4.75	4
Equip/Mat. Avail	4	10	3.5	1.75
Random events	4	-	3.5	-
Safety/Quality	4	-	2.5	-
Construction Method	-	6	-	1.5
Other (change order, site logistics)	6	-	3.17	-

Q: List factors that in your opinion affect the construction activity duration, and rate the difficulty to control for the factor.

The data comparison revealed that students listed more general factors pre-simulation that were categorized as *schedule, labor size and productivity, material and equipment availability, weather, budget, safety and quality,* and *random events.* Factors that were mentioned only once were grouped as *other*. One major variation among responses was the increased frequency of fewer factors with more detailed descriptions after the simulation. Three factors showed the most noticeable shift in ratings based on the simulation experience. *Labor productivity* became more frequently cited and perceived as more difficult to control after the simulation experience (*M*=3.5) compared to pre-simulation (*M*=2.25). Likewise, the factor *schedule* initially averaged *M*=1.8 but became more frequently mentioned as the amount of overlapping activities with a slightly higher rated difficulty of control (*M*=2.4) post-simulation. Equipment and material availability remained a frequently cited factor with a much lower difficulty rating after the exercise (*M*=1.75) compared to before the exercise (*M*=3.5). Interestingly, *random events* such as labor strike or equipment failure, as well as *quality* and *safety* were entirely absent in the post-evaluation survey. These results indicate a slight shift of attention to factors emphasized by the simulation game, and could explain the higher-rated difficulty of managing labor productivity as students became aware of the varying productivity based on the labor experience (the learning curve) and the weather. Similarly, scheduling overlapping activities appeared to be more challenging post-simulation, which may be due to embedded activity constraints within the simulation that prohibited certain activities to start before others were complete (e.g. columns cannot be installed until slab has cured for a certain amount of time). Conversely, equipment availability and material delivery as constant factors in the simulation were not perceived as a challenge compared to pre-simulation surveys.

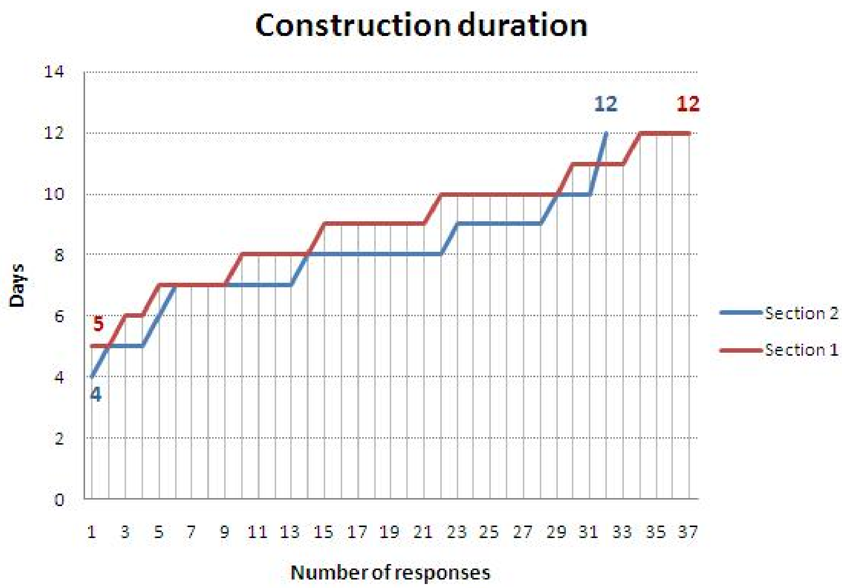
The second open-ended question asked students to think about measures they would suggest for accelerating the schedule in the event of delays and to list the most likely effects of these selected measures. As with the previous question, qualitative analysis showed a similar trend, with post-simulation responses reflecting more of the simulation experience. Table 4 shows that while the proposed measures to accelerate the schedule did not differ as much before and after the simulation, the explanation of the most likely effects became more detailed and reflective of the simulation experience. The most noticeable difference between the responses is the change from very short, declarative answers before the simulation to more descriptive and interpretative explanations after the simulations. For example, cost increase as the most frequently recognized effect of the crew size increase became more specifically identified through the increased cost of idle resources on site and associated with coordination and resource management challenges. These results suggest the potential for the simulation to focus student attention on specific issues and offer an opportunity to develop different scenarios based on learning objectives.

Table 4: Comparison of the responses to an open-ended question before and after the simulation

	Before	After
Measures		
Likely effects	Increased cost (16) Productivity loss (5) Reduced quality (2) Safety (2) Other (2)	Increased cost (35) as a function of: Idle resources (12) Coordination problems (6) Low efficiency/productivity (6) Congestion (4) Activity constraints (2) Safety(1) Fatigue (1)

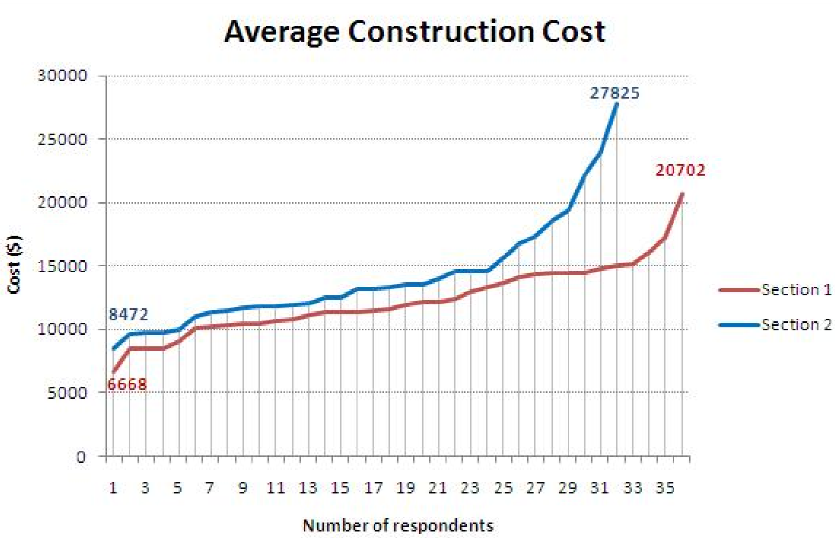
Q: In the event of major activity delays, what measure(s) would you consider speeding up the schedule? What would be likely effects related to the measures?

Students' handouts that were collected at the end of each of the two practicum sessions were analyzed for the final cost and project duration students reported. Although not evaluated for the performance, cost and duration data analysis provided additional insight into the learning process. Figure 35 and Figure 36 show the average project duration and cost between the two class sections. An interesting observation is that the project duration ranges from minimum of 5 days for the first, and 4 days for the second section, to maximum of 12 days in both sections. While an average duration was 8.9 and 7.8 days for the two sections, only one student in the second section managed to complete the project in the shortest possible time while staying under the given budget. Cost data averaged lower for the first section as a result of longer project duration, while the opposite holds true for the second section.



Section	1	2
Means (days)	8.9	7.8
Min	5	4
Max	12	12

Figure 35: Average project durations students reported in both sections



Section	1	2
Mean ($)	12,422	14,116
Min	8,437	8,472
Max	20,702	27,825

Figure 36: Average project cost students reported in both sections

Students' perception of learning

An 11-item section on a nine-point Likert scale from 1 being "*strongly disagree*", to 9 being "*strongly agree*", sought to measure the level of students' agreement with the statements related to the simulation experience, learning relevance, the simulation game value, and the learning perception. Table 5 displays the mean value of each of the statement and reveals an overall positive attitude toward the use of the simulation game, a sense of engagement and learning gains. Students overall highly rated the sense of engagement and the active role they had in the learning process, as well as high level of agreement that the simulation experience is applicable, relevant, engaging, enjoyable, and helpful in better understanding scheduling processes.

Table 5: Students' evaluation of the simulation experience and perceived learning.

	N	Min	Max	Mean	SD
The simulation activity helped me gain a *better understanding* of the scheduling process.	80	1	9	**6.44**	1.59
I felt the use of the simulation game was *relevant* in learning about construction scheduling concepts.	79	1	9	**6.51**	1.69
I felt what I learned in using the simulation game was *applicable* in my field of study.	80	1	9	**6.50**	1.90
I thought the use of simulation game was *thought provoking*.	80	1	9	**6.69**	1.58
The simulation game helped me gain *deeper understanding* about construction schedules.	79	1	9	**6.49**	1.65
I was more *engaged* in class when using the simulation game.	80	2	9	**7.02**	1.59
I took a more *active* role in the learning process when using the simulation game.	80	2	9	**7.10**	1.50
I felt that the use of simulation game in the class was *inefficient*.	78	1	8	**3.63**	1.85
The simulation game took *more time than it was worth it*.	80	1	9	**4.12**	1.95
I *needed more guidance* from the instructor when using the simulation game.	80	1	9	**4.32**	2.06
I *enjoyed* performing the exercise.	80	3	9	**7.10**	1.46

A series of open-ended questions was used to further gauge students' opinion on the simulation experience, asking them to state in their own words what they thought they learned from the experience, what challenges they encountered, what they liked or disliked about the simulation, as well as to provide any suggestions for further improvement. A qualitative analysis was used to categorize the students' responses and detailed results for each of the questions are reported below.

Q1: *What is the most important thing you learned from the simulation?*

Students reported that the most important lessons learned from the simulation related to:

- Developing a **bigger picture** of the scheduling process and a more hands on experience with scheduling. Some of the responses included:
    - *"I gained a more hands on experience with scheduling."*
    - *"An idea of a step by step process to construction."*
    - *"I gained the overall feeling about the construction process and how to manage it."*
    - *"Order of construction tasks and some idea of duration of particular tasks and what has to go through a Construction Manager's head everyday on the job site."*
    - *"I learned the importance of each decision in the final cost and completion dates."*
- The importance and **challenges** in good **schedule coordination** and the constraints in order of activities:
    - *"Learning more about sequencing and considering different methods to complete certain activities efficiently and under budget."*
    - *"I learned a lot about how scheduling works and which activities should be done before another activity. It helped me understand the process."*
    - *"Efficiently sequencing events"*
    - *"That a lot of activities go into such small projects."*
- The efficient use of **resources** and the balance between production capabilities and cost:

- *"Deciding on what methods were appropriate for the scope of work to be accomplished."*
- *"Balance between production capabilities and cost."*
- *"Using the correct amount of people and equipment."*
- *"Don't waste money on laborers that will stand around."*
- *"Planning equipment and crew capacity is very important to remain on schedule."*

- **Changes and delays** are part of the process and the need to account for them on a project:
  - *"A better understanding of the scheduling process and how you must actively make changes and updates."*
  - *"Delays are inevitable and have to make up for it."*

Q2: *What challenges did you encounter during the simulation?*

The analysis of the students' responses resulted in categorization of the challenges into content-related and application-related types of challenges. Table 6 summarizes the most frequently listed challenges students reported.

Table 6: Students' responses about challenges encountered during the simulation

Content-related	Application-related
Scheduling the concrete pour before the end of the day for overnight cure.	Slow simulation
Managing/allocating resources to avoid idling	No "undo" button - inability to go back after the simulation starts and correct mistakes before the next day (redo a day)
Weather	Error messages when sequencing
Changing the crew size during the day.	Error messages when hiring resources

Among the content-related items, the greatest challenges students reported included coordination of activities and resources to avoid idling; the coordination of concrete pour activities to enable subsequent activities; and delays caused by the weather. Changing and adding more resources during the day was also frequently reported indicating the lack of awareness of the nature of decision-making on the superintendent's role when deciding on the resources for the following day.

Among the application-related challenges, students reported the application speed as the most frequent problem followed by sporadic errors during sequencing of the activities and selecting daily resources. A frequently commented challenge was the inability to go back and correct mistakes once the simulation started. In other words, students once they realized they made a mistake either in the activity sequence, or not hiring enough or the right resources, they wanted to redo the previous day instead of completing the simulation run and applying a different strategy in the following run.

Q: *What did you **like** about the simulation activity?*

Qualitative analysis of students responses resulted in a number of key words used to describe the experience and the perception of the simulation activity. Students overall reported in their own words what they liked the most was the activity was:

- Fun, engaging, enjoyable;
- Interactive;
- Visual;
- Realistic, relevant;
- Competitive;
- Easy to use; and
- Ability to see the process and progress.

Some of the quotes reported that the simulation activity:

"Made scheduling for construction understandable."

"It was a helpful learning tool to see the mistakes you can run into while making a schedule."

"It makes you think about time vs. cost"

"I liked that it was interactive and I felt like I actually learned something."

"It was a fun way to learn about CM"

Q: *What did you* ***NOT like*** *about the simulation activity?*

Qualitative analysis of students' responses showed several common challenges student encountered during the simulation activity. Students' responses addressed both the simulation content and the VCS user interface. In terms of the user interface and application features, students reported that they most disliked:

- Inability to go back once the simulation starts;
- Inability to save progress; and
- Slow simulation.

On the content side, most frequently reported things student disliked included:

- The lack of cost comparison of different methods;
- Inability to excavate footings and a slab simultaneously; and
- No best solution to compare to.

The responses addressing the VCS3 application and user interface difficulties are aligned with the challenges students listed previously in the survey. In addition to the simulation's slow speed, the inability to go back and "redo" the previous day in case of making a mistake has been most frequently listed as a challenge. Once in a simulation mode, in case of making any decision that students would later identify as a mistake, students were compelled to rather start the whole simulation again, than proceed and attempt to make up for any oversight. Also frequently commented the inability to excavate footings and slabs simultaneously posed certain challenges in sequencing of activities. This inability resulted from the building object type constraints incorporated inside the application which did not permit slab activities to start until all of the footing activities have been completed. On the content side, an interesting observation was made about the lack of a comparable solution for students to ascertain their performance. For this implementation students were not given any further points of reference such as the optimum schedule duration or cost they could compare to. Students were instead given a rather open-ended task and asked to explore and report how fast they could build the pavilion while staying under the budget. Providing additional points of reference stated in the scenario and project goals, and incorporating performance metrics inside the simulation should be considered in future implementations as well as the application development.

Overall experience with using the VCS3

To determine the overall students' experience using the VCS3 application, a nine-point Likert scale was used to rate their experience ranging from terrible to wonderful; from difficult to easy; from frustrating to satisfying; and from dull to stimulating.

Figure 37 shows the distribution and means for each category ratings. As displayed in the graphs, students' ratings are predominantly in the upper range evaluating the simulation experience as relatively easy, satisfying and highly stimulating. The level of frustration associated with the simulation experience is more distributed across the scale and can be related to the challenges and difficulties described in the open-ended questions.

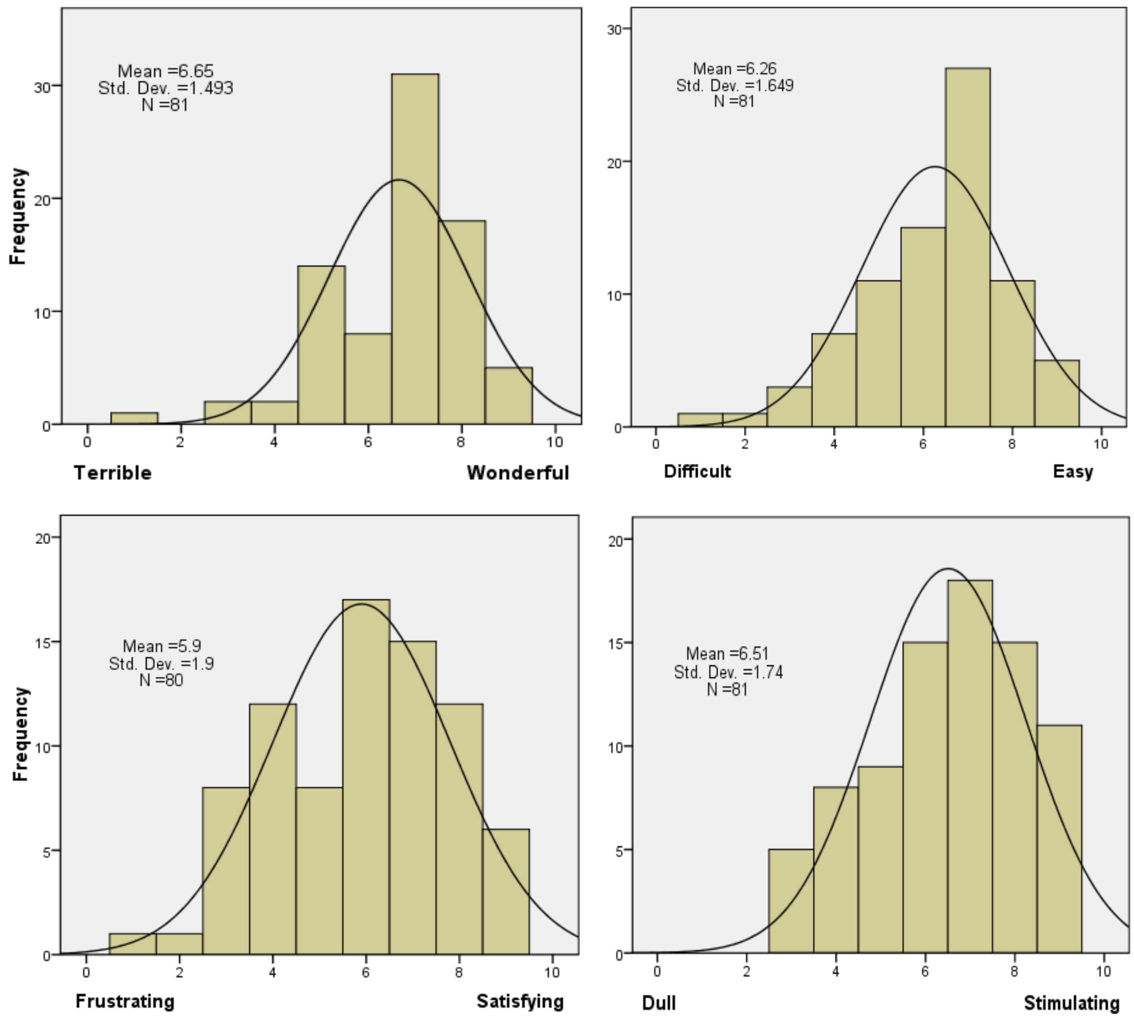


Figure 37: Ratings of the overall experience with using the VCS application

Comments for future improvement

The last section of the post-test questionnaire asked students to comment or suggest any additional items or changes to the simulation that in their opinion would lead to further improvement. Content analysis was used to identify few categories of suggestions related to application functionality, application content, and visual representation. The following is the description of each category with few representative quotations.

- **Functions**: suggestions related to additional functions related to the application performance and/or user interface. Students' responses mostly focused on adding the following:
  - *Saving progress*: at the current stage, the VCS application does not save the simulation progress and requires the student to either finish the whole simulation or start from the beginning.
  - *Undo / Go back*: similarly as in earlier responses, students felt the strong need to repeat the simulation for a particular day. This suggestion mostly relates to situations when during the daily simulation students would realize they should have made a different decision when hiring resources. Although students specified in several instances the need for an undo button, there is no however detailed description on other occasions/decision points/processes where they felt the need to go back and undo.
  - *Changing resources during the simulation*: as frequently commented as an undo function, these two comments seem to be correlated. Students have reported the need to change the number of resources during the daily simulation in situations where there would be insufficient number, or a significant number of idling resources. This comment has been reoccurring throughout the overall feedback and should be addressed in more detail during the instruction and before the actual assignment.
  - *Speed*: performance-wise, students reported on several occasions the frustration with the application/computer speed where the application would run very slow. This feature has been however resolved in the post-implementation development phase.
- **Content:** suggestions relate to additional information that could be included in the simulation in the form of scaffolding to further help and support the decision making process. The most common suggestions content-wise include adding of the following:
  - Tips and explanations during the decision making process;

- Ability to see the planned daily budget spending before the simulation starts;
- Cost comparison of the construction methods – ability to compare labor cost of the different methods inside the construction method window. This feature has been however resolved in the post-implementation development phase;
- Lead times for equipment and material shipments;
- Different projects of different scale.

- **Graphics/Visual representation:** suggestions relate to improving the visual representation of the simulation content through increased level of detail and realism. More specifically, suggestions related to representation include:
  - Adding labor/equipment animation;
  - Detailed representation of certain activities – mostly activities pertaining to concrete placement such as excavation, formwork, and placing of rebar.

A few comments addressed the need for more detailed instruction on how to use the application, and also suggested to add the ability to import different Autodesk Revit models into the VCS3 application.

Learners' characteristics

To understand better the population characteristics, additional analyses of the participants looked into any possible gender differences between groups of students who played at least one computer or video game and students who did not play any video games. In instances where significant differences were identified, further analyses were performed to examine the impact of those differences on the perception of learning and application use.

Gender differences in playing computer games

To determine any possible gender differences between students who play at least one computer game and students who do not play any computer games, a 2x2 chi-square test was conducted. The test results revealed that a significantly larger percentage of males (87.1%) than females (43.5%) play at least one or more video and computer games, χ^2 (1, N=85) = 17.16, V = .45, p < .001. Table 7 shows the percentage of both males and females who have reported to play at least one or more computer games and those who have reported to not play any computer or video games.

Table 7: Percentages of students who play at least one computer game, as a function of gender

gamer * Gender: Crosstabulation

		Gender:				Total	
		Male		Female			
		Count	% within Gender:	Count	% within Gender:	Count	%within Gender:
"Gamer"	no	8	12.9%	13	56.5%	21	24.7%
	yes	54	87.1%	10	43.5%	64	75.3%
Total		62	100.0%	23	100.0%	85	100.0%

Given that there were significant differences between males and females who play computer games, it was of interest to further analyze and see if the sense of enjoyment and the perception of performance were affected within the gender groups.

Gender differences and the level of enjoyment

To determine if males and females differed in their reported level of enjoyment of the simulation exercise, an independent sample t-test was conducted. The results revealed there were no significant differences between males and females in enjoyment of the simulation exercise *t* (78) = 0.328, p = .74. Specifically, on a scale of nine (1 being the least enjoyed to 9 being much enjoyed) both males (*M* =7.07, *SD* = 1.58) and females (*M* =7.19, *SD* =1.07) equally enjoyed the simulation exercise.

Gender differences and the performance perception

To determine any differences in the performance perception among males and females, another 2x2 chi-square test was conducted. Similarly as in the previous situation, the test failed to show any significant differences in the performance perception χ^2(1, N=76) = .081, p = .77 as a great percentage of both males (87.5%) and females (85%) reported to have performed well on the exercise (Table 8).

Table 8: Percentages of students reporting to have performed well in the simulation exercise, as a function of gender

Do you feel you did well on this task? * Gender: Crosstabulation

		Gender:				Total	
		Male		Female			
		Count	% within Gender:	Count	% within Gender:	Count	% within Gender:
Do you feel you did well on this task?	**yes**	49	87.5%	17	85.0%	66	86.8%
	no	7	12.5%	3	15.0%	10	13.2%
Total		56	100.0%	20	100.0%	76	100.0%

Although the students' perception of their own performance cannot be fully indicative of their true performance, the results are useful to reveal the overall suitability of the simulation game as a teaching tool with respect to the learners' differences and their preference for computer games.

In summary, the analysis demonstrated the overall positive effect of the simulation game on students' motivation and engagement, and also demonstrated the potential in influencing students' attention to specific problems and information. Students' perception of the simulation experience was overall very positive with the sense of the learning gains, relevancy, and applicability of the simulation experience in the construction field. Nevertheless, some challenges were identified regarding the application use and the clarity of the rules of what students as players could do. Challenges, limitations, and future recommendations are discussed in more detail in the discussion section.

Chapter 6

Discussion and Conclusions

Interpretation of Findings

The implementation of the VCS3 simulation game demonstrated its value in providing a visual, interactive, realistic and engaging learning experience. Student evaluation of the experience as engaging, enjoyable, and fun is consistent with broad research findings that conclude simulation games are generally perceived as more interesting than lectures and other formats of traditional teaching methods. Student motivation level measured post-simulation reflected that this perception increased significantly after the simulation. The simulation experience was likewise rated as relevant and applicable in the construction domain. Although research on whether higher motivation levels lead to more effective learning is still somewhat limited, educators generally prefer motivated learners as more open to the new learning experiences.

In meeting the learning objectives, students demonstrated the increase in knowledge about the construction planning process and the ability to identify changes and challenges in the efficient management of the construction process and resources. While detailed learning assessment remains limited at this time, the findings nevertheless revealed that the students overall recognized the dynamic nature of a construction project through changes that occur to their as-planned schedule due to factors such as weather or labor productivity. To understand the implications of the findings better, results are interpreted to correspond with the general evaluation questions in the methods chapter.

1) How has the students' learning changed based on the simulation gaming activity? Does the simulation activity result in significant learning gains?

Comparisons of learning outcomes pre- and post-simulation indicated the potential of the VCS3 simulation game to influence and shift student attention to specific content advanced by the simulation. In this phase, the implementation of factors such as construction methods, weather, and varying labor productivity increased and focused the awareness of these factors following the simulation exercise. The indication that experiential learning took place during the simulation exercise was reflected in the students' responses which, although differed little in content, differed greatly in language becoming more detailed and interpretative based on what they observed. Furthermore, the learning process that took place during the simulation exercise was indicated in managerial challenges students identified, such as coordinating activities start time and allocating resources. For example, realizing that curing concrete prevents other activities to start for a period of time causing resources to wait and thus loosing time and money, students used strategies to start the concrete pour activity towards the end of the day so that curing can finish overnight. The VCS3 simulation game has allowed students to visualize these challenges in a more intuitive and dynamic manner and allowed them to discover some of the relationships between different factors which would have been more difficult using traditional approaches.

An interesting and the most frequent comment was the frustration of not being able to "go back" and "re-do" the previous day once the simulation started. When developing a construction plan or hiring resources for the simulated day, if students realized they should have made a different decision, they would rarely complete the whole simulation but rather chose to repeat the process by starting from the beginning. While most of their decisions could be labeled as more or less optimum and not necessarily wrong, students had little patience and motivation to make up for any losses in the following days and instead were inclined to get each step right the first time. Learning from mistakes is recognized as a more effective and memorable experience; however, at the same time students seem to have a low tolerance for what they recognize as mistakes. In this case, the realism of the construction site where the "undo" button does not exist could be conveyed more effectively by introducing students to the application rules more systematically, or through learning scenarios. The habit students have to easily undo actions in various other computer applications should be addressed from the context of a real construction site where decisions and actions cannot be easily altered without a set of other related issues.

Because this study focused on the formative evaluation of the learning process supported by simulation games, students' performance on the assignment was not part of the learning assessment. However, the analysis of students' handouts revealed a wide range of students' reported time and cost to build the pavilion project for a given scenario. When students were asked to test and report how fast they could build the pavilion without exceeding the given budget, they were not given a reference point to what would be the average or expected project duration. This lack of reference resulted in reported time to build the pavilion ranging from four days – the fastest possible time, to 12 days. For the comparison, while it was possible to build the pavilion in 4-5 days under the budget, students' solutions averaged 8-9 days. Although students were encouraged to explore different approaches, the inability to compare their solution to the expected standard may have resulted in the majority of students not knowing how their solution ranked and what was the space for further optimization. The performance metrics is thus an important part of the feedback mechanism that plays a critical role in the learning process and drives the improvement on the students' part. While embedding performance metrics into the simulation game structure may challenge the flexibility of custom learning scenarios, performance metrics can be incorporated in the learning scenario. Thus, instead of asking students to report how fast they could build the pavilion, a better approach would be giving them a more specific goal which would narrow the range of acceptable outcomes to less than 7 days, for example.

To further an understanding of the learning process and obtain feedback from advanced level students, the VCS3 - while being improved - was tested once again in the fall 2010 with nine graduate students in a graduate level production management (AE 570) class at Penn State. All male graduate students averaged with 23.8 years of age and 1.3 years of construction experience. The VCS3 version used in the second implementation had significantly improved speed performance based on the students' comments from the first implementation. The implementation procedure was the same except that students worked on PC tablets, and the handout was changed to include a more detailed project scenario and goal (see Appendix H). Thus, the project scenario set the project to be completed in no more than six days, and offered virtual incentives if completed ahead of the set deadline. Students were also asked to run a minimum of three simulations and report in the handout table their decision steps employed and the final cost and time outcome of each simulation run. The students' reported final completion times ranged from 4 to 6 days. While the more constrictive project goal helped to focus strategies to meet the goal, students in a post-test survey discussed the challenges they identified in employed strategies. In addition to pre- and post-test surveys, the focus group conducted with the students following the exercise provided more in-depth feedback and comments on the experiences, challenges and suggestions for improvement. Similar to the responses from the first implementation, students reflected on the time/cost tradeoffs when choosing more crews to accelerate activities and finding ways to efficiently balance resources. One response added that it took one entire simulation run to understand how to efficiently use resources. Thus, planning the schedule was comparatively easier than actually managing and ensuring the project is constructed efficiently given the changes that were occurring.

Both implementations yielded similar appraisal of the simulation experience as visual, realistic, hands-on and fun, with the benefit of being able to test different decisions and see the outcomes very quickly. At the same time, extensive learning gains were difficult to detect because of the limited number of system dynamic factors implemented at this stage. For that reason, the objective learning measurement items could not include information that was not covered by the VCS3 simulation game. Nevertheless, this information can be very useful when considering different learning scenarios in the future stages of the development and implementation when additional factors such as random events, safety, and quality are included.

2) Was the time commitment for learning appropriate for the skills and information gained?

As briefly mentioned, students in the second implementation ascertained the ability to run several simulations in a relatively short time as very helpful to test different strategies until they found the most optimum one. The simulation speed was noticeably lower in the first implementation and appeared in students' evaluations of application performance as frustrating. In the first implementation, a single day simulation averaged 3-7 minutes which may have limited the number of complete simulation runs in a given two-hour practicum time. Conversely, in the second implementation after additional VCS3 improvements, simulation of a single day was accelerated to under one minute on average. Simulation speed can evidently support more testing of different approaches in a relatively short time and also ensure sustained attention. Thus, increased speed can stimulate more repetition which has been linked to learning through the process of "revisiting" new information until the learner becomes familiar with it (Issa et al. 1999). Although not visible in the first implementation due to slower running simulation, the second implementation demonstrated the value of promoting and allowing multiple runs in a relatively short time. The focus group discussion with the fifth-year and graduate students revealed different strategies students tested in each run. Thus, one student specifically noticed that doubling the crews in the second run did not necessarily accelerate the schedule as intended but increased the cost; and realized in the third run that the sequence was driving the schedule.

An increased VCS3 performance speed after the first implementation promotes more rapid testing of different strategies, which was one of the development objectives. Although not tracked in the first implementation, the number of simulation runs should be incorporated and tracked in the subsequent implementations as an important aspect of the learning process. Both implementations however, demonstrated the value of a simulation game and its potential to support active learning through immediate feedback and rapid testing of different decision outcomes. Controllable simulation speed may be an appropriate solution to respond to the differences in learners and their level of experience by allowing them to focus on either detailed information during the simulation process or final outcomes.

3) Were the students engaged and did they enjoy the simulation activity?

Fun and pleasure are typically not considered as critical attributes of learning environments, but are key driving motivators in constructivist environments in which the learner leads inquiry (Kirkley and Kirkley 2005). The results show a significant increase in the level of motivation after the VCS3 simulation, both as students' general mood and the task perception, indicating that students were engaged in the simulation learning activity. Measuring the motivation to learn is challenging, but studies focusing on the relationship between motivation and learning argue that promoting intrinsic motivation increases the involvement in tasks and therefore learning gains. The majority of students reported that they enjoyed the activity because it was visual, interactive, fun, relevant and realistic. Learning with the VCS3 simulation game thus appeared to have had a positive effect by allowing students to visualize the planning and management decisions and see their immediate outcomes. This form of instruction is consistently rated as more enjoyable and fun compared to the lecture format. For many students, the ability to modify actions and decisions fairly quickly and the sense of controlling the process was contributing to the sense of engagement. Several students reported that the challenges they encountered in managing the construction process and particularly resources to avoid idling, were also fun. While the challenge stimulates sustained interest in the learning experience, several students also commented on the need for more helpful information during the simulation process. In this sense, learners' differences and the level of experience should be addressed in the future development with added scaffolding and helpful information such as explanations or hints during the decision process.

4) How do students feel that the simulation activity needs to be changed in order to maximize learning?

Students seem to have had the most difficulties with the inability to undo actions and decisions once the simulation started. While "undoing" decisions is not a realistic representation of planning and management processes on a real world construction site, the current decision process also restricts any changes that can be made to the planned schedule and the remaining activities once the simulation starts. Thus, the current version of the VCS3 only allows changes to the crew sizes during the simulation, but it does not have the capability of allowing any changes to the activity sequence or the construction methods once they have been selected. The ability to change the as-planned schedule activities which have not started would provide more flexibility to adapt to changes. Several students commented on adding this functionality which has been considered in the development phase but was not completed before the implementation. Related to the ability to make changes, a more intuitive graphic display comparison of the as-planned and as-built schedule would help students understand better how the construction progress differ from the original plan. To summarize, students in both implementations suggested adding the abilities to:

- Change the activity sequence for the remaining days after the simulation started;
- Change construction methods for activities that have not started;
- Add more available crews to the activities that are in progress (currently, once the activity is in progress, it is locked in terms of the number and type of resources assigned);
- See the weather forecast before the day simulation starts to make decisions about which activities to start; and
- Compare the as-planned and as-built schedule to see the progress.

Long term learning gains is another important issue when implementing simulations and educational games. However, information retention was not tracked in this study due to limitations of class structure. The VCS3 simulation exercise was introduced as external to course content and was tested in a discrete two-hour practicum time allotted for the study. Results of learning outcomes would benefit more from a structured simulation exercise embedded within class content and aligned with the learning objectives of the class instructor. For future research, a series of tests extended temporally would be beneficial in evaluating the long term effect of the simulation on learning and the retention of information.

Theoretical, Methodological and Practical Implications

Designing instructional environments greatly depends on understanding the learning theories and assumptions of how learners learn. From the constructivist view, a simulation game environment supports context-based adaptive learning where the learner develops their own understanding through resolving uncertainties (Duffy and Cunningham 1996). The underlying VCS3 system dynamics model captures the core function of simulation games to represent complex systems with uncertainty and changeable processes. As the constructivist framework argues, through this interactive and close to realistic virtual environment, students by managing various decisions start to construct meaning that is personally relevant (Warren 2001). The VCS3 simulation game of a relatively small project and decision-making scope may be a complex and dynamic learning environment to the level where students with little understanding of domain specific concepts may struggle in interpreting the results of their decisions. Therefore, a guided learning process needs to be incorporated through the structures of scaffolding and clear goals.

The design and development of instructional simulation games is difficult due to tensions between having clear instructional strategies and incorporating key simulation game attributes such as variability, challenges, or randomness. Randomness is a characteristic of simulation games which may contribute to the sense of fun, but also requires careful consideration when incorporated in the instructional tool. Randomness can hinder the control of the learning process and cause confusion and frustration on the learners' part if their performance is the function of random events and not employed strategies. Nevertheless, random events may be valuable in advanced levels of the simulation game when learners have sufficient domain knowledge and confidence to tackle more complex situations.

The challenge, achievable goal, and fast turnaround of decision outcomes contribute to the sense of engagement and fun. Koster (2004) defines fun as "the feedback the brain gives us when we are absorbing patterns for learning purposes" (p. 96). Therefore, playing a game involves learning through the sense of fun as the learner discovers the game pattern and masters the process by repeating it until the goal is achieved.

Great focus of the research in educational simulation games is placed on the validity of learning outcomes and their long term retention effect as well as the transferability to real world situations. The real challenge is developing appropriate assessment methods to capture the learning gains. Studies have focused on comparing the effectiveness of simulation games to traditional teaching methods and asserted that simulation games may not be more effective but are at least as good as standard approaches. These inconclusive results on their effectiveness are mainly due to the use of traditional assessment methods which focus on the content retention, although attempts are made to explore students' behavioral changes and attitudes towards learning. Educational simulation games representing complex processes involve more complex learning processes and the focus on content retention should not be the only indicator of the meaning students constructed in this environment.

Thus, this study attempted to capture learning by focusing on the process and not the students' performance or the quality of the final outcome. Though students' reports showed a broad range of results which could be evaluated as better or worse, the majority identified common issues and challenges involved in the planning and management decision process. This is aligned with findings that the performance and learning are not correlated (Washbush and Gosen 2001). The process however, remains difficult to appropriately capture due to individual differences in learners and their ability to adequately express what they learned. Developing an instrument able to fully capture all facets of the learning process, especially those beyond the instructional objectives could be a study in itself.

Limitations

The goal of this study was to explore the potential benefits and challenges of an educational construction simulation game, and establish some trends and recommendations for the future development and incorporation in classes as a teaching tool. The results and interpretations of the findings should be however, considered in the light of the limitations discussed below.

A major challenge in educational simulation game research is choosing appropriate measures to capture the learning process that occurs as an effect of using simulation games. Due to the availability of research participants and class scheduling constraints, the learning process and any occurring changes were measured using the single group pre-test and post-test design. A one-group pretest-posttest design, although fairly common in educational research, with the lack of randomization and a very short period between the two surveys limits the degree of certainty with which results can be interpreted and generalized. In addition, the learning assessment is still predominantly coming from students' self-reports which may have fallen short of capturing more complex learning processes. Challenges associated with this limitation are however difficult to address for several reasons. The learning process involved in using a simulation tool is process based where students cycle through the stages of hypothesizing, generating a solution, testing, reflecting on the outcomes and adjusting the solution accordingly. Capturing these processes can be very difficult for students either because they may not be aware of what they are actually learning or they may not be able to articulate it. The inherent problem with self-reports is they make the learner become aware of their unconscious thought process or experience, and thus change them by making them explicit (Crombach et al. 2003). Objective measures to compare learning gains from other traditional instructional approaches also carries challenges. Lecture formats and exams mostly measure the level of memorized content with problem solving scenarios which are limited in context and variables. Due to differences in the nature of learning, it is very difficult to develop instruments that will consistently and comparatively measure the learning outcomes of both processes.

The debriefing process is identified as an important aspect of learning with simulation games. Debriefing serves to discuss and reflect on the challenges and the processes students encountered when playing the simulation game. Debriefing thus mainly acts as a learning reinforcement that helps students understand and clarify the learned material. The debriefing process in the form of focused group interviews was scheduled to take place within one week after the simulation exercise. However, possibly due to the fact the implementation was done two weeks before the end of the semester, the response rates to participate in focus group interviews were low and thus were not conducted.

Simulation games imply a voluntary action, but in this study it was introduced as a required class assignment even though the performance and participation did not affect students' final class grade. Although the results indicated that students were engaged and had fun with the simulation experience, learning and engagement may have been somewhat affected by the requirement. Though voluntary learning is inherent of games, in educational and class settings this condition can never be fully met.

The learning assessment and the implementation would possibly benefit more from better control over the class content. The interpretation of findings relies only on the data that was collected within a two-hour practicum session which may have not provided a complete picture of the learning processes and their long term effects. In future implementations, a preferable approach is to have the same instructor teaching the class and coordinating the assessment questions aligned with learning objectives. Alternatively, a better coordinated and synchronized implementation team with the class instructor would ensure further refinement of the learning assessment and post-simulation discussion. In this situation, a more time-distributed study could be possible and more beneficial to track long term learning gains. The two-hour practicum time used for the simulation included the introduction, application training, the simulation exercise and both surveys all at once. Ideally, students should be given sufficient time to learn and practice how to use the application until comfortable, prior to the exercise. While the current speed of the simulation would easily allow another implementation within the same time frame, the first implementation did result partially in frustration caused by both learning the application and learning the content at the same time. The learning assessment was as a result confounded with reflections on learning how to use the software instead of focusing on the information learned.

Recommendations

To summarize, recommendations for the following implementation and development should consider:

- **Embedding performance metrics** into the simulation exercise which could take a form of a scoring mechanism within the simulation application adjusted to the learning scenario; a scoring board with the historic or real time data of other players' performance for the given scenario, or within the learning scenario with a reference point to an average outcome. Currently, the students need to interpret the results at the end of a simulation period and evaluate their relative performance compared to given schedule or budget goals. Although appropriate for advanced learners and scenarios, this approach can be wearisome for inexperienced users such as entry level students, and knowing how well they perform during the process is a critical part of comprehensive feedback. While a scoring mechanism is an important aspect of a simulation game, its incorporation may be difficult due to a broad range of possible learning scenarios. Performance metrics that would be fairly consistent across different scenarios could be embedded to complement more specific scenario-based goals. Such metrics would track:

- **Resource utilization** measuring the efficient use of labor and equipment, and the daily fluctuations of the number of resources on site in a more intuitive and informative way through graphs or performance scales. At this stage, resource utilization is displayed as the list of active and idling resources during the simulation, as well as the report summary of hours each laborer spent on the site and the hours worked. This format, although helpful, is insufficient for students to fully understand the metrics of what efficient use of resource is. This becomes particularly relevant when taken into account students' responses to be able to bring more resources during the day. To demonstrate that bringing or releasing resources during the work day is difficult and costly, a more substantive resource utilization metrics would be more effective form of feedback.
- **Cost** metrics on a daily/weekly basis would provide a more detailed overview of planned and actual budget spending. Currently, a cumulative cost of labor and equipment is displayed as a percentage of the total budget. A display of the projected and actual budget spending would provide an additional source of performance feedback.

- **Non-linear simulation** as the ability to make changes to the as-planned schedule once the simulation started, such as changing the sequence of activities that did not start or associated construction methods. Also, a more intuitive display of the differences between the as-planned and as-built schedules would support easier tracking and understanding of the construction progress.

- **Scaffolding and levels of difficulty** are important aspects of the simulation game environments. Helpful information and additional explanations, as well as the level to which the simulation can be customized account for students' respective skills and expertise. This is typically achieved through a variety of support structures that allow the user to modify learning preferences and to provide support materials to match a diversity of learning styles.
- **Continuous vs. discreet activity** distinction would provide an additional content refinement that would add to the realism and flexibility to manage activities. This distinction would help students learn about challenges related to scheduling activities that once started need to be completed (e.g. pouring concrete) as opposed to activities that can stop and continue the following day. With continuous activities, additional factors such as overtime could be further implemented into the system dynamics to reflect any challenges in costs or resource utilization
- **User interface** improvement that would allow saving data and loading simulation at any point of simulated progress would further support the learners' control of the pace and the experience. Adjustable speed and ability to pause the simulation progress would allow students to re-examine the process, help to sustain the attention and thus motivation.
- **Simulation runs log** which would track the number of completed simulation runs would provide data on the number of attempts or strategies students employed. The number of runs which was not tracked in this study is also a recognized metric for students' attention and interest in the task.

Figure 38 displays a detailed summary of recommendations for future development and implementations of the VCS3 simulation game regarding the development of the learning content, application improvement and assessment.

Learning Content

Factors	• Overtime, congestions • Safety/Quality/Owner's satisfaction
Learning scenarios	• Based on real-world problems with optimum solutions • Focus on specific factors (fewer for the beginner level and introducing more with advanced level)
Building projects	• Introduce different projects with varying complexity and different methods • Possibility of developing system-related projects (concrete vs. steel or cast-in-place vs. precast)

Application Features

Performance metrics	• Daily cost / resource utilization performance scale • Comparison against the learning scenario set goal • Comparing with other players
Scaffolding	• Assistance and guidance through the process using tips, pop-up prompts, explanations during the simulation and in the report, visualization of factor relationships • Could be controlled by switching the options on/off with varying levels of difficulty
Non-linearity	• Ability to re-sequence remaining activities • Resource flexibility and ability to add more available crews while activity is in progress • Ability to change construction methods for activities that did not start
Levels of difficulty	• Changing the number of triggered factors in the simulation mode • Adding projects of varying complexity • Introducing random events
User interface	• Simulation: add functions to pause, replay, forward or rewind • Report: allow visual comparison of as-planned and as-built schedule • Save and Load the simulation; track the number of simulation runs

Assessment

Appropriate training time	• Allocate sufficient time for students to become proficient with the application
Reflection	• Within the game – forced moments of reflection through quizzes or pop-up questions • Within the handout – tracking strategies employed and analyzing outcomes
Debriefing	• Discussion with students following the exercise to reinforce learned concepts
Long term gains	• Distribute the implementation and assessment among groups and across weeks • Compare individual and group differences

Figure 38: Summary of future considerations and recommendations for the VCS3 development

Contributions

In summary, this study made the following contributions to the emerging field of educational simulation games:

- The VCS3 *simulation game computational model* represented through its components – system dynamics model and systems architecture. *System dynamics* model distilled construction factors and their relationships into a feedback loop suitable for developing learning scenarios that are realistic and relevant to real-world construction situations. The s*ystems architecture* defined the modular structure of the VCS3 application to allow for future expansion and addition of building project models, content factors, and simulation game attributes to accommodate a broad range of possible learning scenarios. The VCS3 computation model thus provides a basis for the promotion of construction simulation games for education and teaching construction scheduling and management concepts.
- Documentation of the development process; implementation and assessment materials including the manual, class handouts, and procedures reported in the Appendix sections, allow for the model and the simulation game to be further analyzed, scrutinized, replicated, or implemented by future researchers and interested users. A substantial amount of work has been devoted to carefully documenting and commenting the code; documenting the development process through flow-chart and UML (Unified Modeling Language) diagrams, and detailed user guidelines. The simulation game developed and tested in this research is also available for free download at *www.engr.psu.edu/vcs.*
- The research findings further an understanding of the pedagogical value and the applicability of simulation games in construction engineering education. Methodological and practical implications direct future construction simulation game implementations by focusing on learner characteristics, performance metrics and simulation game attributes. Recommendations provide guidelines for the next development, implementation, and assessment steps.

Directions for Future Research

This research provided valuable insight into the effectiveness of a simulation game for teaching construction planning and management concepts. To become widely accepted as instructional tools, further research is needed to understand better the complexity of the design, development and learning processes.

An area pertaining to simulation games for education which could be advanced is measuring the gains against the learning objectives. In addition to using self reports which have been predominantly used in this study, other methods could be considered such as think-aloud protocols which are recognized to provide insight into the learning processes.

To better understand the potential of simulation games in teaching construction concepts, another potential area of research may consider developing a comprehensive list of learning objectives with a validated set of tests and questions corresponding to the learning objectives. One of the reasons why many studies in simulation games fall under criticism for the lack of rigor and validity is the highly contextual nature of classroom settings which may differ among programs, instructors, or students. Also, simulations and games used in various studies differ in purpose, structure and functionality to be consistently compared against common learning objectives. Consolidating a comprehensive list of the learning objectives would provide an additional guide to developing simulation games that can be easily adopted and tested on a larger scale.

Simulation games are still mainly tested as whole systems which may obscure an understanding of factors and attributes that may be more supportive of the learning process. This is partially because there is still no agreed upon definition of simulation games, types, or common attributes that would allow easy comparison of more and less successful simulation games implementations. Another potential research direction may look into specific attributes of simulation games, such as competition or scoring, and how they relate to achieving learning objectives. This could provide more detailed and prescriptive recommendations and methods to incorporate specific attributes.

This study also focused on an individual-based learning simulation experience. The next research step may look into the collaborative and communication aspects of team-oriented simulation exercise. For this step, more complex learning scenarios can be developed with specific roles that would resemble real world construction team work.

Role playing in a team setting would provide valuable data on the learning potential of a team-based and individual-based simulation experience. Applicability of a simulation game could be further explored across different categories of learners such as entry level students with very little to no knowledge of the construction planning and management concepts. Gender differences, learner types, or learner behavioral characteristics may provide another avenue for exploration of simulation game effects and pedagogical benefits to respond to the variety of educational settings.

Future research could also benefit from pursuing more comprehensive industry input and further validation of the VCS simulation game. Examples from real world construction projects and case studies would contribute to having a substantial information database that would serve for developing different simulation scenarios. Although current VCS simulation game development effort is primarily oriented toward an undergraduate education; industry input and involvement could ultimately promote a long term development of a simulation game that is able to support decision making in both academic and practical side of the construction domain.

Conclusions

In education, simulation games are gaining ground for their value in encouraging problem solving, exploration, and creative thinking, all of which are necessary for real world challenges. At the same time, developing appropriate assessment methods to evaluate the effectiveness of simulation games remains incomplete. The development of the VCS3 simulation game sought to address existing challenges in teaching students the dynamic nature of construction through active learning whereby students iterate construction processes to identify problems, make decisions and observe the effect of those decisions. Results of this study demonstrate the benefits of the VCS3 in helping students to form a more holistic view of construction scheduling and increase student interest and motivation in learning about construction processes, cost and time tradeoffs, and inherent management challenges. Based on project goals, the VCS3 simulation game allows students to explore different strategies of construction process optimization and to observe these processes in real time. This immediate feedback shifts the student's role from passive to active learner, complements instructor feedback, and creates opportunities to raise more questions and richer in-class discussions.

This study may not have fully captured the effects of the simulation game on learning given the quasi-experimental nature of the study and a pre- and post-test method used to measure concepts. Sensible incorporation of learning objectives into class content along with the post-simulation debriefing and discussion with students would provide additional insight and reinforce the learning process.

Based on these results, the VCS next step is improving the existing structure and user interface to allow more flexibility in testing decisions. Further VCS3 development to incorporate additional construction factors would support more comprehensive and informative learning assessment. With an elaborate dataset, the effect of gender differences and learner preferences can be further explored to enhance the effectiveness of the VCS as a teaching tool. Using strategies such as role-playing and self-evaluation, game-based simulations in construction engineering education can provide students with opportunities to learn construction concepts through practical experience.

References

AbouRizk, S. (2010). "Role of simulation in construction engineering and management." *Journal of Construction Engineering and Management*, 136(10), 1140-1153.

Ainley, M. (2004). "What do we know about student motivations and engagement?" Paper presented at the annual meeting of the Australian Association for Research in Education, Melbourne, Nov. 29-Dec. 2.

Al-Jibouri, S., Mawdesley, M., Scott, D., and Gribble, S. J. (2005). "The Application of a simulation model and its effectiveness in teaching construction planning and control." *Proceedings of the 2005 ASCE International Conference on Computing in Civil Engineering*, 179(7).

Aldrich, C. (2003). *Simulations and the future of learning: an innovative (and perhaps revolutionary) approach to e-Learning*, Jossey-Bass Inc., Publishers.

Aldrich, C. (2004). "Six criteria of an educational simulation." Retrieved on February 2007 from: http://www.learningcircuits.org/NR/rdonlyres/F2ED000A-7A59-4108-A6CB-1BE4F4CC1CA5/4719/clark_e2.pdf.

Aldrich, C. (2005). *Learning by doing. A comprehensive guide to simulations, computer games, and pedagogy in e-Learning and other educational experiences*, John Wiley and Sons, Inc., Pfeiffer, San Francisco, CA.

Alias, M., Black, T. R., and Gray, D. E. (2002). "Effect of instructions on spatial visualisation ability in civil engineering students." *International Education Journal*, 3(1 - 12).

Bartles, R. (2003). *Designing virtual worlds*, Indianapolis, IN: New Riders.

Becker, K. (2007). "Pedagogy in commercial video games." in *Games and simulations in online learning: research and development frameworks*, D. Gibson, C. Aldrich, and M. Prensky, eds., Hershey PA : Information Science Pub., c2007.

Berelson, B. (1971). *Content analysis in communication research*, Hafner, New York.

Blunt, R. (2007). "Does game-based learning work? Results from three recent studies." The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC), NTSA, Orlando, Florida, USA, 945-954.

Boekaerts, M. (2002). "The on-line motivation questionnaire: A self-report instrument to assess students' context sensitivity." New directions in measures and methods, P. R. Pintrich and M. L. Maehr, eds., Emerald Group Publishing, 77-120.

Bouchlaghem, N., Wilson, A., Beacham, N., and Sher, W. (2002). "Computer imagery and visualization in built environment education: The CAL-Visual approach." *Innovations in Education and Teaching International*, 39(3), 225-236.

Brown, J. S., Collins, A., and Duguid, P. (1989). "Situated cognition and the culture of learning." *Educational Researcher*, 18(1), 32-42.

Chen, W., and Levinson, D. M. (2006). "Effectiveness of learning transportation network growth through simulation." *Journal of Professional Issues in Engineering Education and Practice*, 132(1), 29-41.

Chinowsky, P., and Vanegas, J. A. (1996). "Combining practice and theory in construction education curricula." Frontiers in Education Conference, San Juan, PR.

Cordova, D. I., and Lepper, M. R. (1996). "Intrinsic motivation and the process of learning: beneficial effects of conceptualization, personalization, and choice." *Journal of Educational Psychology*, 88, 715-730.

Coyne, R. (2003). "Mindless repetition: learning from computer games." *Design Studies*, 24(3), 199-212.

Crombach, M. J., Boekaerts, M., and Voeten, M. J. M. (2003). "Online measurement of appraisals of students faced with curricular tasks." *Educational and Psychological Measurement*, 63(1), 96-111.

Dale, E. (1954). *Audio-visual methods in teaching*, The Dryden Press, New York, NY.

de Jong, T., and van Joolingen, W. R. (1998). "Scientific discovery learning with computer simulations of conceptual domains." *Review of Educational Research*, 68(2), 179-201.

Dede, C., and Lewis, M. (1995). "Assessment of emerging educational technologies that might assist and enhance school-to-work transitions." Office of Technology Assessment, United States Congress, Washington, DC.

Dede, C., Salzman, M. C., Loftin, R. B., and Sprague, D. (1999). "Multisensory immersion as a modeling environment for learning complex scientific concepts." in *Computer Modeling and Simulation in Science Education*, N. Roberts, W. Feurzeig, and B. Hunter, eds., Springer-Verlag, New York.

Dempsey, J. V., Rasmussen, K., and Lucassen, B. (1995). "Instructional gaming: implications for instructional technology." Annual Meeting of the Association for Educational Communications and Technology Nashville, TN.

Dev, P. C. (1997). "Intrinsic motivation and academic achievement: What does their relationship imply for the classroom teacher?" *Remedial and Special Education*, 18(1), 12-19.

Dossick, C. S., Rojas, E. M., Locsin, S., and Lee, N. (2007). "Defining construction management events in situational simulations." CONVR2007 7th Conference on Construction Applications of Virtual Reality, Penn State University, USA, 22-23 October 2007.

Duffy, T. M., and Cunningham, D. J. (1996). "Constructivism: implications for the design and delivery of instruction." in *Handbook of Research for Educational Communications and Technology*, D. Jonassen, ed., (pp 170 - 198). New York: Macmillan.

Eastman, C. M. (1969). "Cognitive processes and ill-defined problems: a case study from design." *Proceedings of First Joint International Conference on Artificial Inteligence*, Washington, D.C.

El-Rayes, K., and Jun, D. H. (2009). "Optimizing resource leveling in construction projects." *Journal of Construction Engineering and Management*, 135(11).

Finke, R. A. (1990). *Creative imagery: discoveries and inventions in visualization*, Hillsdale, NJ, Lawrence Erlbaum Associates.

Finke, R. A., Ward, T. B., and Smith, S. M. (1996). *Creative cognition: theory, research, and applications*, Cambridge, MA.: MIT Press.

Frand, J. L. (2000). "The information-age mindset: changes in students and implications for higher education." *EDUCASE Review,* 35 (5).

Fulenwider, M., Helmes, P., Mojtahedzadeh, M., and MacDonald, R. (2004). "Operational labor productivity model." 22nd International Conference of the System Dynamics Society, Oxford, England.

Gagné, R. M. (1985). *The conditions of learning and theory of instruction*, New York : Holt, Rinehart and Winston, c1985.

Galarneau, L. (2005). "Authentic learning experiences through play: games, simulations and the construction of knowledge." *Paper presented at Digital Games Research Association (DIGRA) Conference*, Vancouver, Canada, June 2005.

Garris, R., Ahlers, R., and Driskell, J. E. (2002). "Games, motivation, and learning: a research and practice model." *Simulation Gaming*, 33(4), 441-467.

Gee, J. P. (2007). "What video games have to teach us about learning and literacy." New York : Palgrave Macmillan, 2007.

Gibson, D., Aldrich, C., and Prensky, M. (2007). *Games and simulations in online learning: research and development frameworks*, Hershey, PA : Information Science Pub., c2007.

Gosen, J., and Washbush, J. (2004). "A Review of scholarship on assessing experiential learning effectiveness." *Simulation Gaming*, 35(2), 270-293.

Graven, O. H., and MacKinnon, L. (2005). "Exploitation of games and virtual environments for e-learning." Information Technology Based Higher Education and Training, 2006. ITHET '06. , Ultimo, NSW, 409-421.

Gredler, M. E. (1996). "Educational games and simulations: a technology in search of a (research) paradigm." in *Handbook of research for educational communication and technology*, D. H. Jonassen, ed., New York, Macmillan, 521-539.

Gredler, M. E. (2003). "Games and simulations and their relationships to learning." *Educational Technology Research and Development*, 21 571-582.

Han, S., Park, M., and Pena-Mora, F. (2005). "Comparative study of discrete-event simulation and system dynamics for construction process planning." ASCE, San Diego, California, 133-133.

Hannafin, M. J., and Hooper, S. R. (1993). "Learning principles." in *Instructional message design: principles from the behavioral and cognitive sciences*, M. Fleming and W. H. Levie, eds., Englewood Cliffs, NJ: Educational Technology Publications, 191-231.

Haque, M. E. (2007). "n-D virtual environment in construction education " The 2nd International Conference on Virtual Learning, ICVL 2007, Retrieved on March 2009 from: http://www.cniv.ro/2007/disc2/icvl/documente/pdf/met/2.pdf.

Hays, R. T. (2005). "The effectiveness of instructional games-literature review and discussion." *Technical Report 2005-004* Naval Air Warfare Center Training Systems Division Orlando, FL 32826-3275.

Herrington, J., and Oliver, R. (1995). "Critical characteristics of situated learning: implications for the instructional design of multimedia." in *Learning with technology*, J. P. A. Ellis, ed., Parkville, Vic: University of Melbourne., 235-262.

Hogle, J. G. (1996). "Considering games as cognitive tools: in search of effective "edutainment."", University of Georgia, Department of Instructional Technology. Retrieved on February 2009 from: ftp://twinpinefarm.com/pub/pdf/.

Howard, E., Cory, C., and Dib, H. (2010). "Impact of gaming application use in construction engineering education." *Computing in Civil and Building Engineering, Proceedings of the International Conference*, Nottingham, UK, W. Tizani, ed.

Hummel, H. G. K. (1993). "Distance education and situated learning: paradox or partnership?" *Educational Technology*, 33(12), 11-22.

Issa, R. R. A., Cox, R. F., and Killingsworth, C. F. (1999). "Impact of multimedia-based instruction on learning and retention." *Journal of Computing in Civil Engineering*, 13(4).

Jaafari, A., Manivong, K. K., and Chaaya, M. (2001). "VIRCON: interactive system for teaching construction management." *Journal of Construction Engineering and Management*, 127(1), 66-75.

Jacobs, J. W., and Dempsey, J. V. (1993). "Simulation and gaming: fidelity, feedback, and motivation." in *Interactive instruction and feedback*, J. V. Dempsey and G. C. Sales, eds., Englewood Cliffs, NJ: Educational Technology Publications, 197-227.

Jaruhar, S. (2007). "Development of interactive simulations for construction engineering education," Master's Thesis, The Pennsylvania State University, University Park, PA, USA.

Johnson, S. (1997). "What's in a representation, why do we care, and what does it mean?" *Examining the Evidence from Psychology, Proceedings of ACADIA '97*, Cincinnati, Ohio, October 3-5, 1997.

Jonas-Dwyer, D., and Pospisil, R. (2004). "The millennial effect: implications for academic development " *Transforming Knowledge into Wisdom: Holistic Approaches to Teaching and Learning*, HERDSA 2004 Conference Proceedings, 195-207.

Jonassen, D., Strobel, J., and Lee, C. B. (2006). "Everyday problem solving in engineering: lessons for engineering educators." *Journal of Engineering Education*, 95(2), 1-14.

Jonassen, D. H. (1997). "Instructional design models for well-structured and ill-structured problem-solving learning outcomes." *Educational Technology, Research and Development*, 45(1), 65-94.

Jonassen, D. H. (2000). "Toward a design theory of problem solving." *Educational Technology Research and Development*, 48(4), 63-85.

Ke, F. (2009). "A qualitative meta-analysis of computer games as learning tools." in *Handbook of research on effective electronic gaming in education*. Information Science Reference, R. E. Ferdig, ed., Retrieved on August 2010 from: http://www.igi-global.com/downloads/excerpts/7960.pdf, 1-32.

Keller, J., and Burkman, E. (1993). "Motivation principles." in *Instructional message design: Principles from the behavioral and cognitive sciences*, M. Fleming and W. H. Levie, eds., Englewood Cliffs, NJ: Educational Technology Publications., 3-53.

Kirkley, S. E., and Kirkley, J. R. (2005). "Creating next generation blended learning environments using mixed reality, video games an simulations." *Tech Trends*, 49(3), 42-53.

Kirkpatrick, D., and Kirkpatrick, P. (2006). *Evaluating training programs*, 3rd ed. San Francisco, CA: Berrett-Koehler Publishers, Inc.

Kirriemuir, J., and McFarlane, A. (2004). "*Literature review in games and learning: a report for NESTA Futurelab*." Futurelab Series Research Report No. 8, Retrieved on March 2007 from: http://hal.archives-ouvertes.fr/docs/00/19/04/53/PDF/kirriemuir-j-2004-r8.pdf.

Kirschner, P. A. (2006). "Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching." *Educational Psychologist*, 41(2).

Kolb, D. A. (1984). *Experiential learning: experience as the source of learning and development*, Prentice-Hall, Inc., Englewood Cliffs, N.J.

Konradt, U. (1995). "Strategies of failure diagnosis in computer-controlled manufacturing systems: empirical analysis and implications for the design of adaptive decision support systems." *International Journal of Human-Computer Studies*, 43(4), 503-521.

Koo, B., and Fischer, M. (2000). "Feasibility study of 4D CAD in commercial construction." *Journal of Construction Engineering and Management*, 126(4), 251-260.

Kosslyn, S. M. (1994). *Image and brain: the resolution of the imagery debate*, Cambridge, MA: MIT Press.

Koster, R. (2004). *A theory of fun for game design.*, Scottsdale, AZ: Paraglyph Press, Inc.

Krippendorff, K. (2004). *Content analysis: an introduction to its methodology*, Sage, Thousand Oaks, California.

Lattuca, L. R., Terenzini, P. T., Volkwein, J. F., and Peterson, G. D. (2006). "The changing face of engineering education." *The Bridge*, 36(2).

Lepper, M. R., and Malone, T. W. (1987). "Intrinsic motivation and instructional effectiveness in computer-based education." in *Aptitude, learning and instruction: III. Conative and affective process analysis*, R. E. Snow and M. J. Farr, eds., Hillsdale, NJ: Erlbaum, 255-286.

Martin, A. (2000). "A simulation engine for custom project management education." *International Journal of Project Management*, 18(3), 201-213.

Mayer, R. E. (1992). *Thinking, problem solving, cognition*, (Second edition) W. H. Freeman and Co., New York, NY.

Mayer, R. E. (1998). "Cognitive, metacognitive, and motivational aspects of problem solving." *Instructional Science*, 26, 49-63.

McGuire, C., and Babbott, D. (1967). "Simulation technique in themeasurement of problem-solving skills." *Journal of Educational Measurement* 4(1), 1-10.

Messner, J. I., Yerrapathruni, S. C., Baratta, A. J., and Riley, D. R. (2002). "Cost and schedule reduction of nuclear power plant construction using 4D CAD and immersive display technologies." *Computing in Civil Engineering Proceedings of International Workshop on Information Technology in Civil Engineering* 123(12).

Moreno, R., and Mayer, R. E. (1999). "Cognitive principles of multimedia learning: the role of modality and contiguity." *Journal of Educational Psychology*, 91(2), 358-368.

Mousavi, S. Y., Low, R., and Sweller, J. (1995). "Reducing cognitive load by mixing auditory and visual presentation modes." *Journal of Educational Psychology*, 87(2), 319-334.

Mukherjee, A., Rojas, E. M., and Winn, W. D. (2005). "Interactive situational simulations in construction management." The First Conference on the Future of the AEC Industry, Las Vegas, NA.

Nassar, K. (2002). "Simulation gaming in construction: ER, the equipment replacement game." *Journal of Construction Education*, 7(1), 16-30.

Neil, J. M. (1982). *Construction cost estimating for project control*, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Nguyen, T., Mondragon, F., O'Brien, W. J., and Schmidt, K. (2010). "Understanding our students: a technology and construction baseline survey." *Computing in Civil and Building Engineering, Proceedings of the International Conference*, W. Tizani, ed., Nottingham, UK.

Nikolic, D., Jaruhar, S., and Messner, J. I. (2009). "An educational simulation in construction: the virtual construction simulator." *Proceedings of the 2009 ASCE International Workshop on Computing in Civil Engineering*, ASCE, Austin, Texas, 63-63.

Norman, D. A., and Spohrer, J. C. (1996). "Learner-centered education." *Communications of the ACM*, 39(4).

Oblinger, D. (2003). "Boomers & Gen-Xers, Millennials: understanding the “new students”." *EDUCAUSE Review*, 38(4).

Otto, G. (2002). "An integrative media approach to virtual reality system design and assessment." M.A. Telecom Paper, The Pennsylvania State University, USA.

Park, B., and Meier, R. (2007). "Reality-based construction project management-constraint-based 4d simulation environment." *Journal of Industrial Technology*, 23(1).

Pena-Mora, F., and Park, M. (2001). "Dynamic planning for fast-tracking building construction projects." *Journal of Construction Engineering and Management*, 127(6).

Piaget, J. (1970). *Piaget's theory*, Wiley, New York, NY.

Pintrich, P. R., and Groot, E. V. D. (1990). "Motivational and self-regulated learning components of classroom academic performance." *Journal of Educational Psychology*, 82(1), 33-40.

Prensky, M. (2001a). *Digital game-based learning*, New York: McGraw-Hill.

Prensky, M. (2001b). "The motivation of gameplay or, the REAL 21st century learning revolution." Retrieved June 2009, from: http://www.marcprensky.com/writing/Prensky%20-%20The%20Motivation%20of%20Gameplay-OTH%2010-1.pdf.

Prensky, M. (2001c). "Simulations - are they games?" Retrieved February 2008, from: www.marcprensky.com/writing/Prensky%20-%20Simulations-Are%20They%20Games.pdf.

Prensky, M. (2004). "Interactive pretending: an overview of simulation." Retrieved on March 2008 from: www.marcprensky.com/writing/Prensky-Interactive_Pretending.pdf.

Randel, J. M., Morris, B. A., Wetzel, C. D., and Whitehill, B. V. (1992). "The effectiveness of games for educational purposes: a review of recent research." *Simulation and Gaming*, 23(3), 261-276.

Rice, A. (2003). "Exploring the impact of emerging landscape visualization tools on spatial perception and design education." *Trends in Landscape Modeling, Proceedings at Anhalt University of Applied Sciences 2003*, E. Buhmann and S. Ervin, eds., Wichmann Verlag, Heidelberg.

Rieber, L. P. (1994). "Visualization as an aid to problem solving-examples from history." *Proceedings of Selected Research and Development Presentation at the 1994 National Convention of the Association for Educational Communications and Technology*, Nashville, TN.

Rieber, L. P. (1996). "Seriously considering play: designing interactive learning environments based on the blending of microworlds, simulations, and games." *Educational Technology Research and Development*, 44(2), 43-58.

Roberts, N. C. (2000). "Wicked problems and network approaches to resolution." *The International Public Management Review - electronic Journal at http://www.ipmr.net*, 1(1).

Rojas, E. M., and Mukherjee, A. (2005). "General-purpose situational simulation environment for construction education." *Journal of Construction Engineering and Management*, 131(3), 319-329.

Rojas, E. M., and Mukherjee, A. (2006). "Multi-agent framework for general-purpose situational simulations in the construction management domain." *Journal of Computing in Civil Engineering*, 20(3), 165-176.

Sawhney, A., Marble, J., Mund, A., and Vamadevan, A. (2001). "Internet based interactive construction management learning system." *Journal of Construction Education*, 6(3), 124-138.

Scott, D., Mawdesley, M., and Long, G. (2010). "Simulation for education in construction and construction management - IT or not IT." *Computing in Civil and Building Engineering, Proceedings of the International Conference,* Nottingham, UK, W.Tizani, ed.

Shah, S., and Haque, M. E. (2006). "Web-based 4d visualization of steel structure construction process: an instruction tool." *Proceedings of the 2006 ASEE Gulf-Southwest Annual Conference, Southern University and A&M College, American Society for Engineering Education*.

Shih, C.-C., and Gamon, J. (2001). "Web-based learning: relationships among student motivation, attitude, learning styles, and achievement." *Journal of Agricultural Education*, 42(4).

Simon, H. A. (1996). "Observations on the sciences of science learning." *Paper presented at the Committee on Developments in the Science of Learning for the Sciences of Science Learning: An Inter-disciplinary Discussion*, Carnegie Mellon University, Department of Psychology, Washington, DC.

Squire, K. (2005). "Changing the game: what happens when video games enter the classroom?" *Innovate 1 (6), 2005 - academiccolab.org* Retrieved November 2009, from: http://www.academiccolab.org/resources/documents/Changing%20The%20Game-final_2.pdf.

Squire, K. (2006). "From content to context: videogames as designed experience." *Educational Researcher*, 35(8), 19-29.

Sweller, J. (2002). "Visualisation and instructional design." School of Education, University of New South Wales, Sydney, Australia. Retrieved on June 2009 from: www.cmu.edu/teaching/trynew/sweller-visualinstructionaldesign.pdf.

Swelller, J. (1988). "Cognitive load during problem solving: effects on learning." *Cognitive Science*, 12(2), 257-285.

Szczurek, M. (1982). "Meta-analysis of simulation games effectiveness for cognitive learning," Ph.D. dissertation, Indiana University.

Thomas, H. R., and Raynar, K. A. (1997). "Scheduled overtime and labor productivity: quantitative analysis." *Journal of Construction Engineering and Management*, 123(2), 181-188.

Thomas, H. R., and Sakarcan, A. S. (1994). "Forecasting labor productivity using factor model." *Journal of Construction Engineering and Management*, 120(1), 228-239.

Thomas, R. (2001). "Interactivity and simulation in e-Learning." MultiVerse Solutions Ltd.

Toole, T. M. (2005). "A project management causal loop diagram." ARCOM, London, UK.

Trindade, J., Fiolhais, C., and Almeida, L. (2002). "Science learning in virtual environments: a descriptive study." *British Journal of Educational technology*, 33(4), 471-488.

Van Eck, R. (2006). "Digital game-based learning: it's not just the digital natives who are restless." *EDUCAUSE Review*, 41(2), 16-30.

Van Eck, R., and Dempsey, J. (2002). "The effect of competition and contextualized advisement on the transfer of mathematics skills in a computer-based instructional simulation game." *Educational Technology, Research and Development*, 50(3), 23-41.

Wang, L. (2007). "Using 4D modeling to advance construction schedule visualization in engineering education," Master's Thesis, The Pennsylvania State University.

Wang, L., and Messner, J. I. (2007). "Virtual Construction Simulator: A 4D CAD model generation prototype." Proceeding of the 2007 ASCE International Workshop on Computing in Civil Engineering, Pittsburgh, PA.

Ware, C. (2003). "Design as applied perception." in *HCI models, theories, and frameworks: toward a multidisciplinary science*, J. Carroll, ed., Morgan Kaufmann.

Warren, D. V. (2001). "Design and development of simulation/game software: implications for higher education," Master's Thesis, The University of British Columbia.

Washbush, J., and Gosen, J. (2001). "An exploration of game-derived learning in total enterprise simulations." *Simulation Gaming*, 32(281).

Weber, R. P. (1996). *Basic content analysis*, Sage Publications, Newbury Park.

Williams, K., and Pender, G. (2002). "Problem-based learning approach to construction management teaching." *Journal of Professional Issues in Engineering Education and Practice*, 128(1), 19-24.

Appendix A

Pre-test Questionnaire

General information

This questionnaire is to be filled out before the simulation game.
Its purpose is to evaluate how much students learn from the game.
It will NOT be used for grading purposes or impact your course grade for this class in any way.

General Information

Age

Gender:

- ◯ Male
- ◯ Female

Major:

◯ Architectural Engineering ◯ Other

Academic Standing:

Freshman	Junior	Sophomore	Senior	Graduate
◯	◯	◯	◯	◯

What is the extent of your work experience in construction?

	0	1	2	3	4	6	7	8	9	10	12	
Months												**0**
Years												**0**

Please estimate the average hours per week during this term that you spent using a computer for any course related activities.

	0	5	10	15	20	25	30	35	40	45	50	
Hours per week												**0**

Please estimate the average hours per week during this term you spent using a computer for any personal or leisure related activities (personal e-mail, chat, games, movies, shopping, etc.)

	0	5	10	15	20	25	30	35	40	45	50	
Hours per week												**0**

Please estimate your experience with 3d-modeling with computer aided design software (Revit, AutoCAD, SketchUp, 3dStudio Max, etc) in general.
Enter 0 if you have not used any 3-d modeling software.

	0	1	2	3	4	6	7	8	9	10	12	
Months												**0**
Years												**0**

Please estimate the extent of your experience with interactive video games.
Enter 0 if you have not played any video games.

	0	1	2	3	4	6	7	8	9	10	12	
Months												**0**
Years												**0**

Please list your favorite video games.
Leave blank if you do not play video games.

	Computer / Video games
1	
2	
3	
4	
5	

Section 1

In this section, you will be asked questions about how you view the exercise you are about to start.
Read every question and fill in the circle that suits you best.
There are no correct or incorrect answers.
Fill in one circle per question. <u>Work quickly.</u>

	Not at all	Very little	Somewhat	Very much
1. Are you in the mood to start the simulation exercise?	○	○	○	○
2. How useful do you consider this exercise?	○	○	○	○
3. How important do you find it to do well on this exercise?	○	○	○	○
4. How difficult do you expect this exercise to be?	○	○	○	○
5. How pleasant do you expect this exercise to be?	○	○	○	○
6. How much effort are you going to put into this exercise?	○	○	○	○
7. How well you intend to perform on this exercise?	○	○	○	○

How do you feel now just before starting the assignment?

	Not at all	Very little	Somewhat	Very much
a. Nervous	○	○	○	○
b. Fine	○	○	○	○
c. Worried	○	○	○	○
d. Confident	○	○	○	○
e. Annoyed	○	○	○	○
f. Enthusiastic	○	○	○	○

Section 2

List factors which in your opinion could impact the activity duration. Rate the difficulty to control each factor.

	Easy to control	2	3	4	Difficult to control
a)	○	○	○	○	○
b) ______	○	○	○	○	○

c)	○	○	○	○	○
d)	○	○	○	○	○
e)	○	○	○	○	○
f)	○	○	○	○	○

In the event of major activity delays, what measure(s) would you consider speeding up the schedule?

In your opinion, what would be some likely effects / issues related to the chosen measure(s)?

The following information is important and will NOT be used for grading purposes:

Name:

Appendix B

Post-test Questionnaire

Section 1

Now that you have finished the assignment, we have some more questions for you.

Choose the answer that suits you best. There are no correct or incorrect answers.
Check one field per question.
As you answer the questions, keep in mind the task you have just finished.

How do you feel just after finishing the simulation assignment?

	Not at all	Very little	Somewhat	Very much
Relieved	◯	◯	◯	◯
Fine	◯	◯	◯	◯
Worried	◯	◯	◯	◯
Confident	◯	◯	◯	◯
Annoyed	◯	◯	◯	◯
Satisfied	◯	◯	◯	◯
Concerned	◯	◯	◯	◯
Frustrated	◯	◯	◯	◯

Please answer the following questions:

	Not at all	Very little	Somewhat	Very much
a) How much attention did you provide to do the exercise?	◯	◯	◯	◯
b) How difficult did you find the exercise?	◯	◯	◯	◯
c) How much effort did you put into this exercise?	◯	◯	◯	◯
d) How useful do you consider this kind of exercise?	◯	◯	◯	◯
e) How well do you think you performed in this exercise?	◯	◯	◯	◯

Do you feel you did well on this task?

◯ Yes

◯ No

I did well on this exercise because:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I am good at this type of task.	○	○	○	○	○
I was in the mood to do this exercise.	○	○	○	○	○
I was lucky.	○	○	○	○	○
I did my best.	○	○	○	○	○
I found it to be an easy exercise.	○	○	○	○	○
I thought it was a pleasant exercise.	○	○	○	○	○
I thought it was an interesting exercise.	○	○	○	○	○
I already knew a lot about the subject.	○	○	○	○	○

I did NOT do well on this exercise because:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I am not good at this type of task.	○	○	○	○	○
I don't like doing this type of exercise.	○	○	○	○	○
I had bad luck.	○	○	○	○	○
I did not do my best.	○	○	○	○	○
I found it a difficult exercise.	○	○	○	○	○
I thought it was an unpleasant exercise.	○	○	○	○	○
I thought it was not an interesting exercise.	○	○	○	○	○
I don't know much about the subject.	○	○	○	○	○

Section 2 - Virtual Construction Simulator experience

Have you ever used the Virtual Construction Simulator (VCS) before?

○ Yes

○ No

Rate your overall experience with the VCS software:

Terrible	○	○	○	○	○	○	○	○	○	Wonderful
Difficult	○	○	○	○	○	○	○	○	○	Easy
Frustrating	○	○	○	○	○	○	○	○	○	Satisfying
Dull	○	○	○	○	○	○	○	○	○	Stimulating

Rate your experience with the following tasks when using the VCS.

	Very Difficult	2	3	4	5	6	7	8	Very Easy
Learning to use the VCS.									
Understanding the VCS interface.									
Understanding the VCS workflow.									
Viewing / navigating the model.									
Grouping objects.									
Choosing construction methods.									
Developing the construction sequence.									
Simulating the construction sequence.									
Understanding the report.									

Rate your experience with the following VCS features.

	Confusing	2	3	4	5	6	7	8	Clear
Information organization on screen.									
The sequence of screens.									
Messages prompting user for input.									
Feedback to the user actions.									
Error messages.									
Help and tips.									

Application speed:

Slow ○ ○ ○ ○ ○ ○ ○ ○ ○ Fast

Tasks can be performed in a straight-forward manner.

Never ○ ○ ○ ○ ○ ○ ○ ○ ○ Always

Correcting your mistakes:

Difficult ○ ○ ○ ○ ○ ○ ○ ○ ○ Easy

Experienced and inexperienced users' needs are taken into consideration:

Never ○ ○ ○ ○ ○ ○ ○ ○ ○ Always

Section 3 - Simulation experience

To what extent do you agree or disagree with the following statements:

	Strongly Disagree	2	3	4	5	6	7	8	Strongly Agree
The simulation activity helped me gain a better understanding of the scheduling process.	○	○	○	○	○	○	○	○	○
I felt the use of the simulation game was relevant in learning about construction scheduling concepts.	○	○	○	○	○	○	○	○	○
I felt what I learned in using the simulation game was applicable in my field of study.	○	○	○	○	○	○	○	○	○
I thought the use of simulation game was thought provoking.	○	○	○	○	○	○	○	○	○
The simulation game helped me gain deeper understanding about construction schedules.	○	○	○	○	○	○	○	○	○
I was more engaged in class when using the simulation game.	○	○	○	○	○	○	○	○	○
I took a more active role in the learning process when using the simulation game.	○	○	○	○	○	○	○	○	○
I felt that the use of simulation game in the class was inefficient.	○	○	○	○	○	○	○	○	○
The simulation game took more time than it was worth it.	○	○	○	○	○	○	○	○	○
I needed more guidance from the instructor when using the simulation game.	○	○	○	○	○	○	○	○	○
I enjoyed performing the exercise.	○	○	○	○	○	○	○	○	○

List factors which in your opinion impact the activity duration. Rate the difficulty to control each factor.

	Easy to control	2	3	4	Difficult to control
a)	○	○	○	○	○
b)	○	○	○	○	○
c)	○	○	○	○	○
d)	○	○	○	○	○
e)	○	○	○	○	○
f)	○	○	○	○	○

In the event of major activity delays, what measure(s) would you consider speeding up the schedule?

In your opinion, what would be some likely effects / issues related to the chosen measure(s)?

What challenges did you encounter during the simulation?

What is the most important thing you learned from the simulation?

What did you like about the simulation activity?

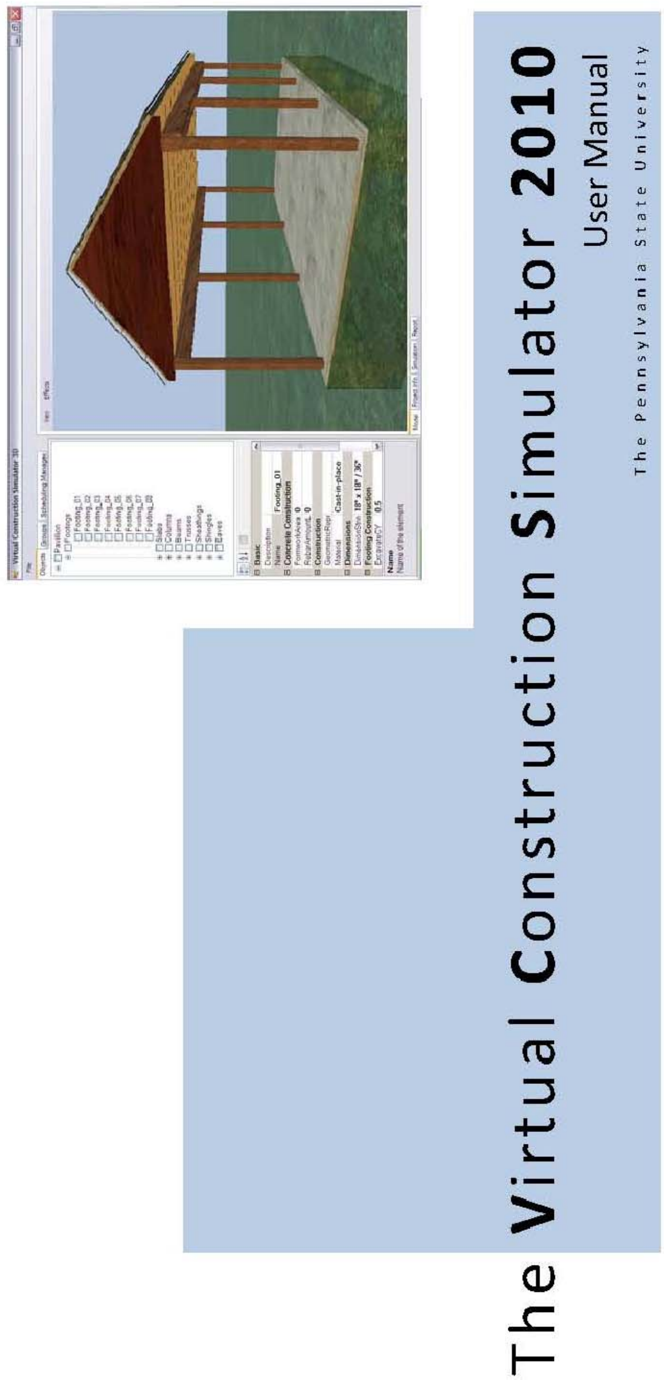
What did you NOT like about the simulation activity?

The following information is important and will NOT be used for grading purposes.

Name:

Appendix C

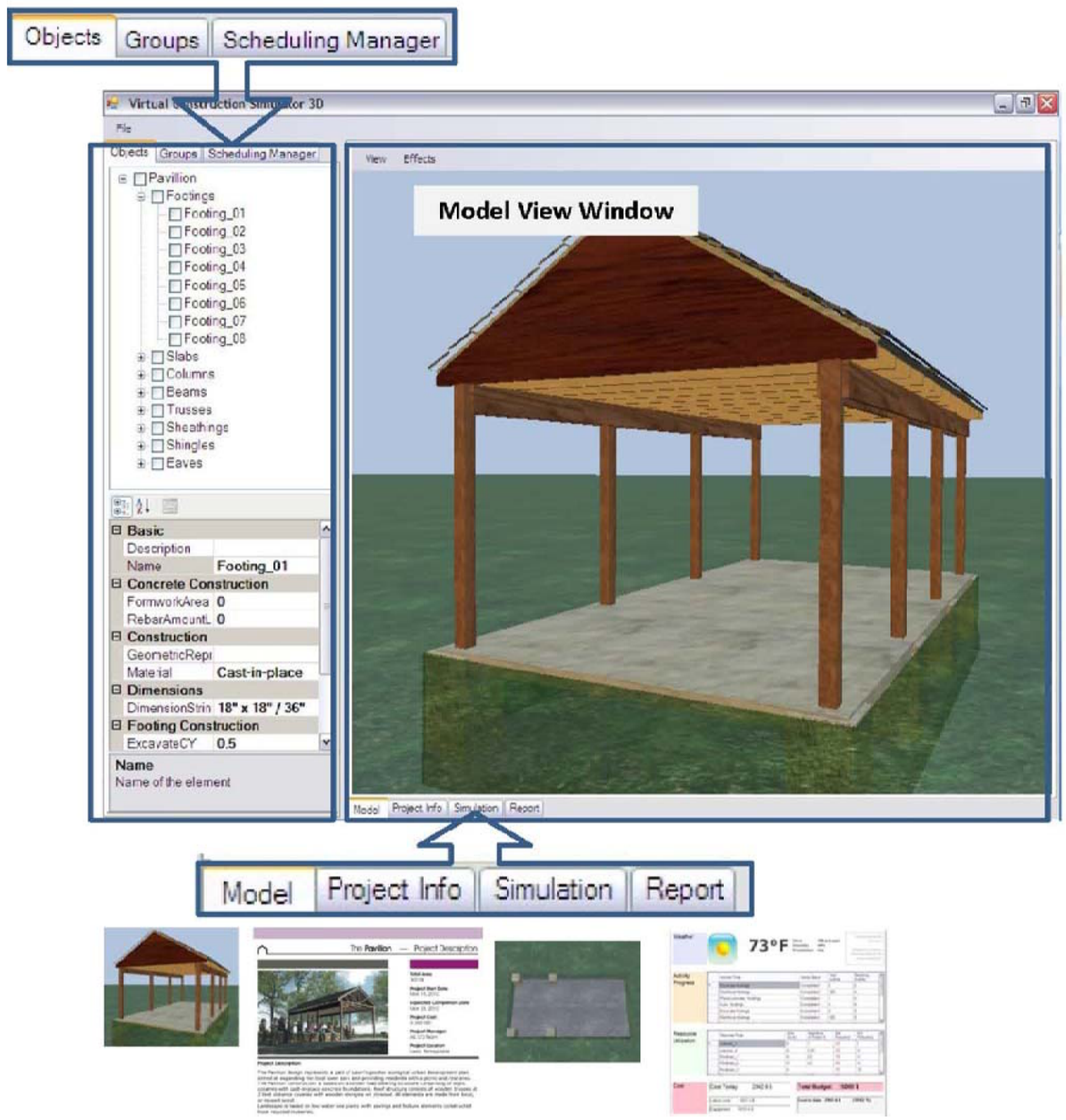
VCS 3 Manual



MAIN WINDOW

TAB GROUP 1

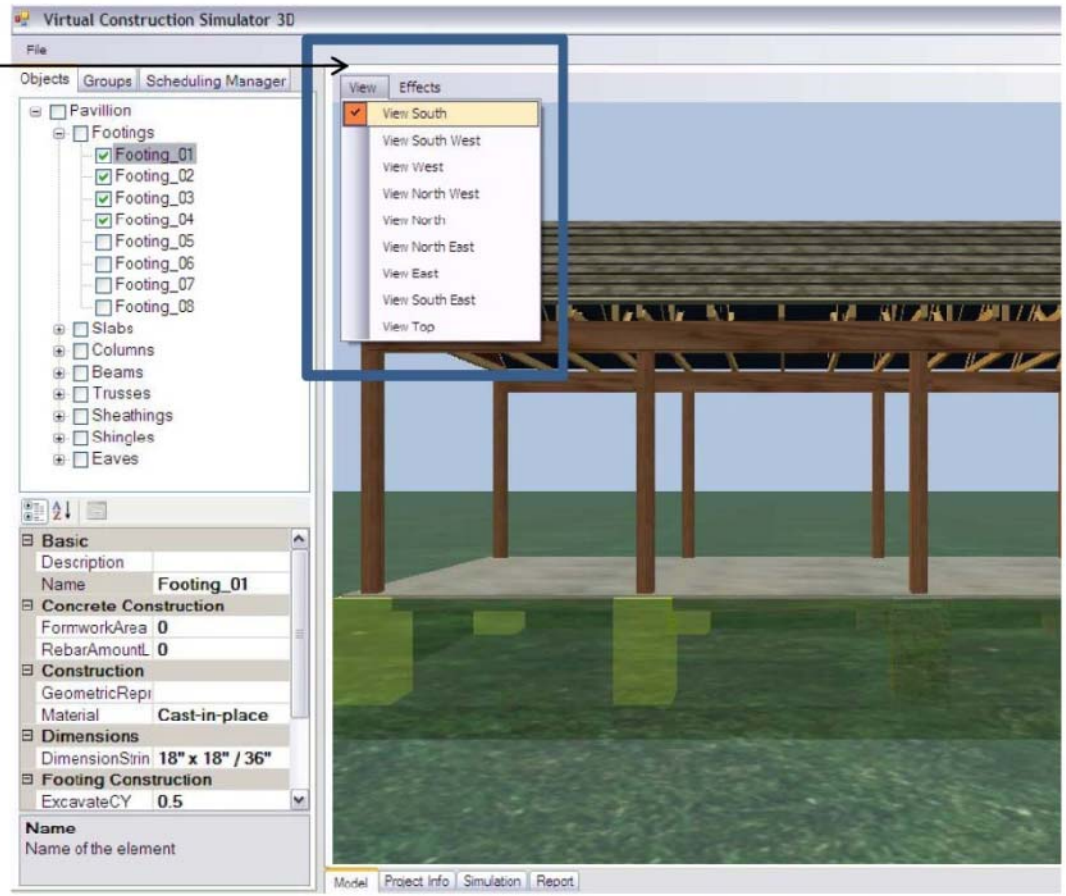
TAB GROUP 2



NAVIGATING THE MODEL:

Navigating the model can be done with the "**View**" menu in the model window, and **mouse controls**.

Predefined view points are listed under "**View**" in the model view tab.



Mouse Controls:

Right click – **start** head movement.

Right click again – **stop** head movement.

Key Controls:

"**Q**" - DOWN ↓

"**E**" - Up ↑

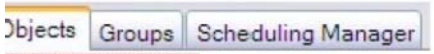
"**A**" - LEFT ←

"**D**" - Right →

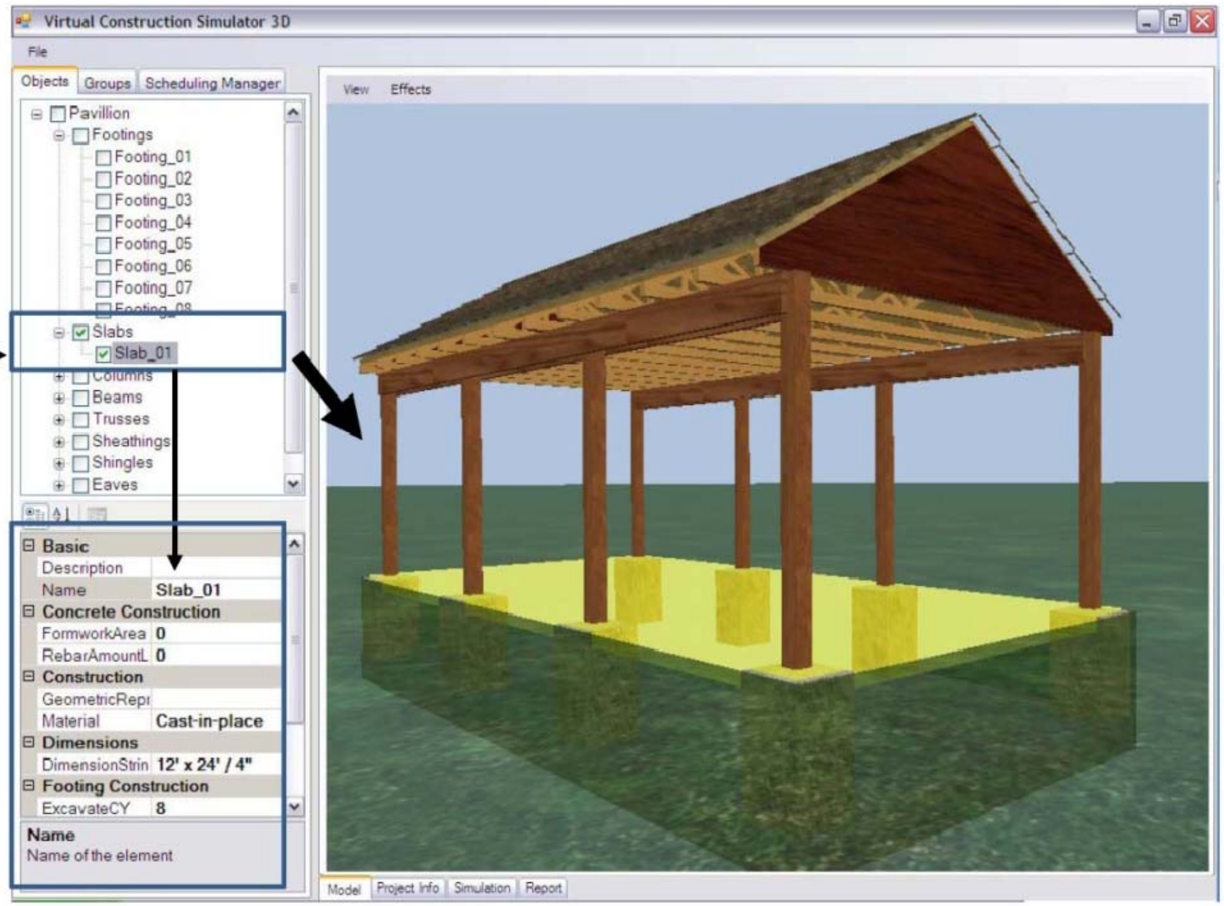
"**W**" - FORWARD

"**S**" - Backward

OBJECTS TAB:



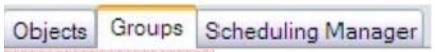
Provides the list of all building elements in the project.



Checking the box will highlight an object in the model window

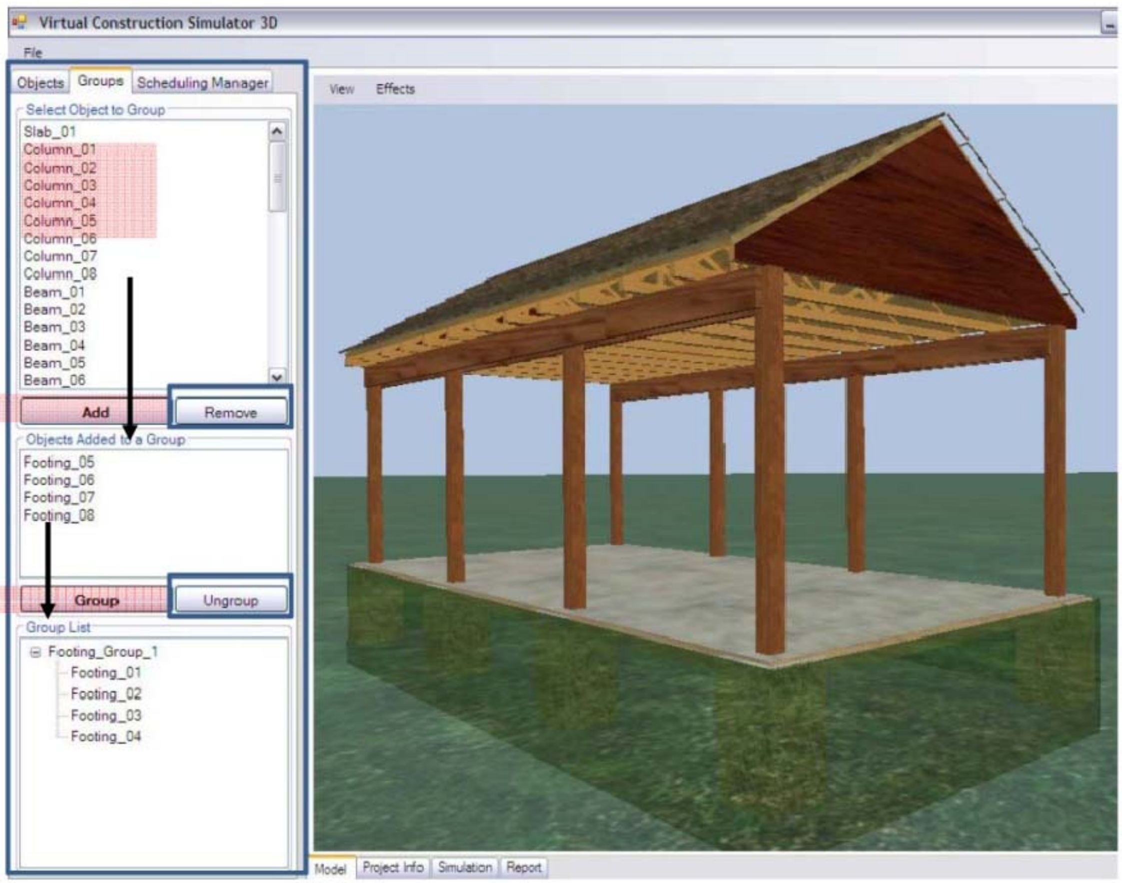
Clicking on an object name will display its properties below.

GROUPS TAB:



Enables objects to be grouped into zones.

Grouping objects:



1. Select objects you want to group.

Note: You can only group objects of the same type (e.g. footings with footings; but no footings and columns)

2. Add selected objects to a group.

Tip: To remove unwanted objects from a group, select an object and click "Remove" button.

3. Group selected objects.

Tip: To ungroup, select the group and click "Ungroup" button

SCHEDULING MANAGER: overview

Objects | Groups | Scheduling Manager

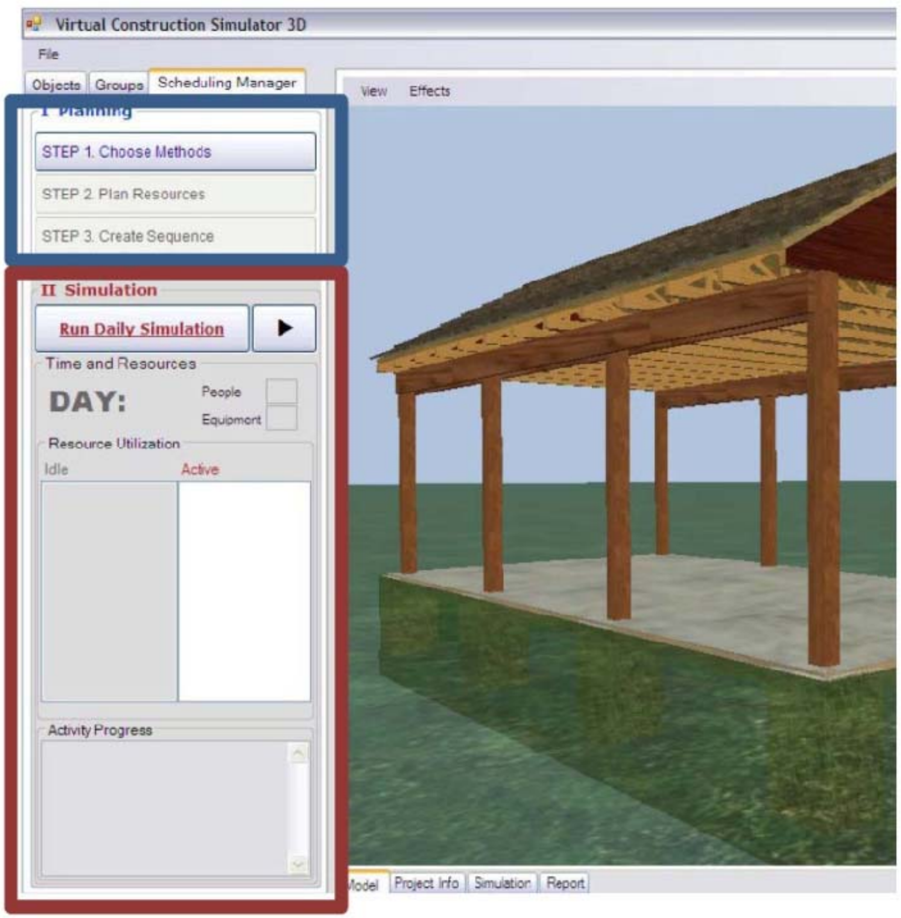
Contains a schedule **planning** and a schedule **simulation** section.

1. Planning the schedule.

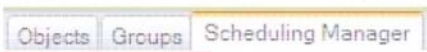
Planning a schedule is a 3 step process. Each step becomes available upon completing the preceding step.

2. Simulating the schedule.

After developing the As-planned schedule, the user starts to run daily simulation.

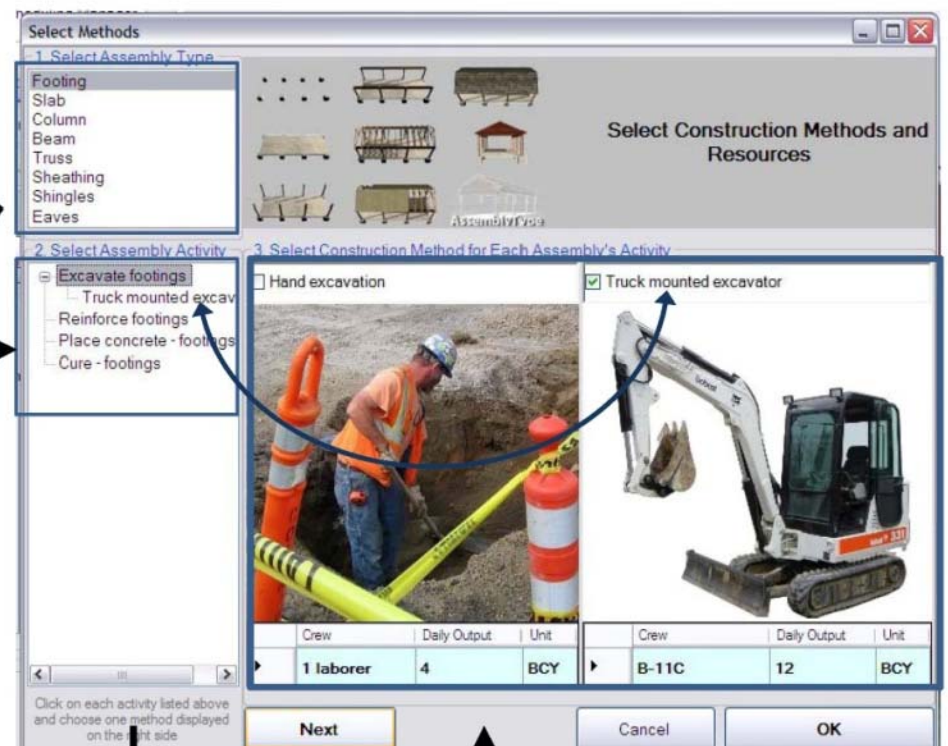


SCHEDULING MANAGER: planning



STEP 1 – Choose Methods. The "Select Methods" window opens.

For each assembly type, list of activities is listed. For each activity listed – choose a construction method.



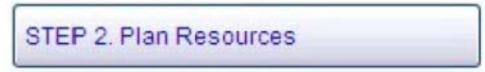
For each Assembly type in the project

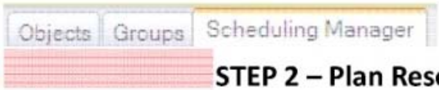
The list of activities is listed.

For each activity listed:

Choose a construction method

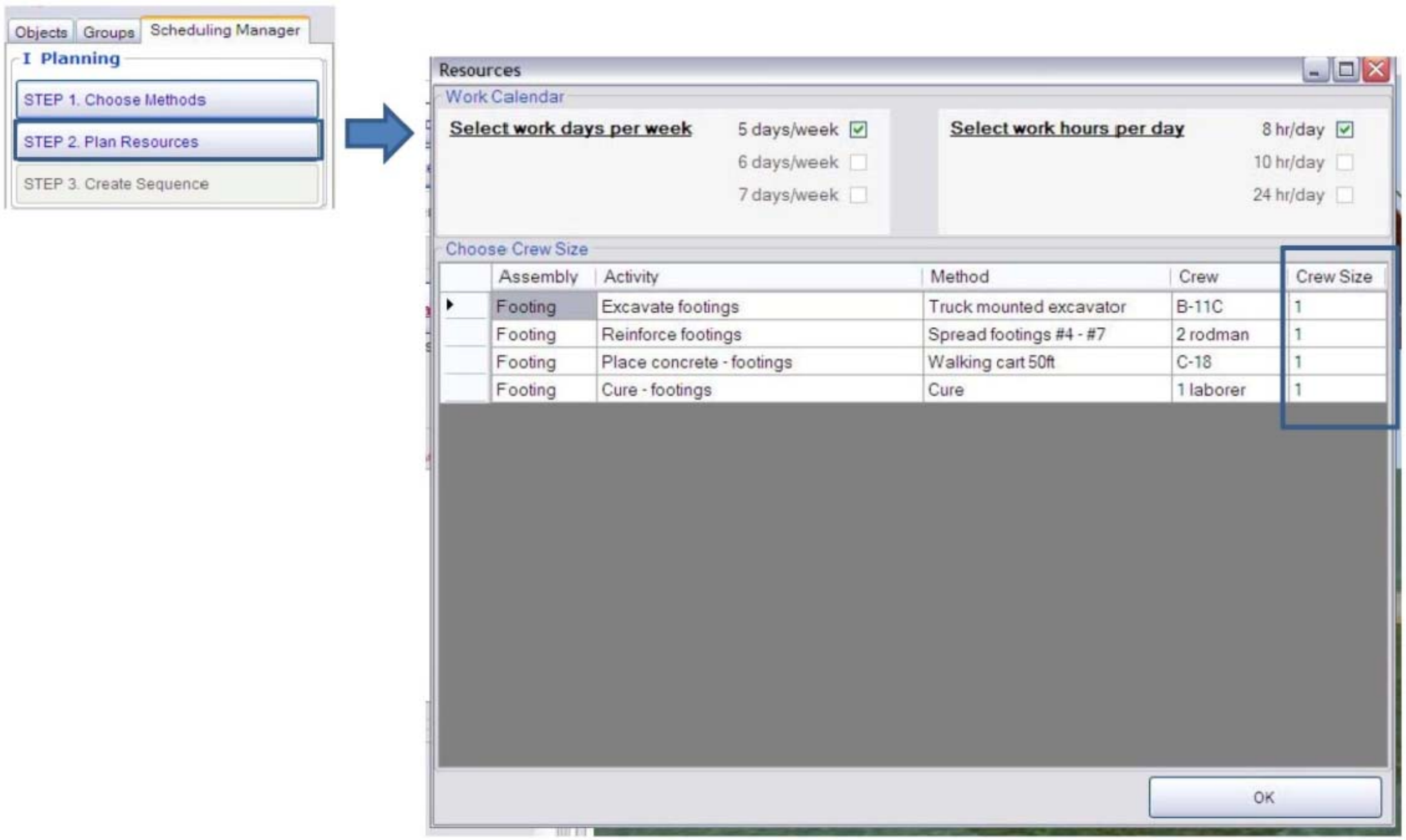
SCHEDULING MANAGER: planning



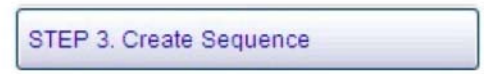


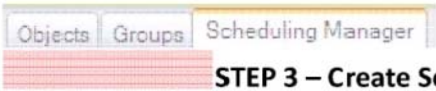
STEP 2 – Plan Resources. The "Resources" window opens.

For each activity, a chosen method is displayed along with the crew type and crew size.
You can review and proceed, or change the crew size to increase the production.
When click OK, it will calculate As-Planned durations given the method and the crew size.

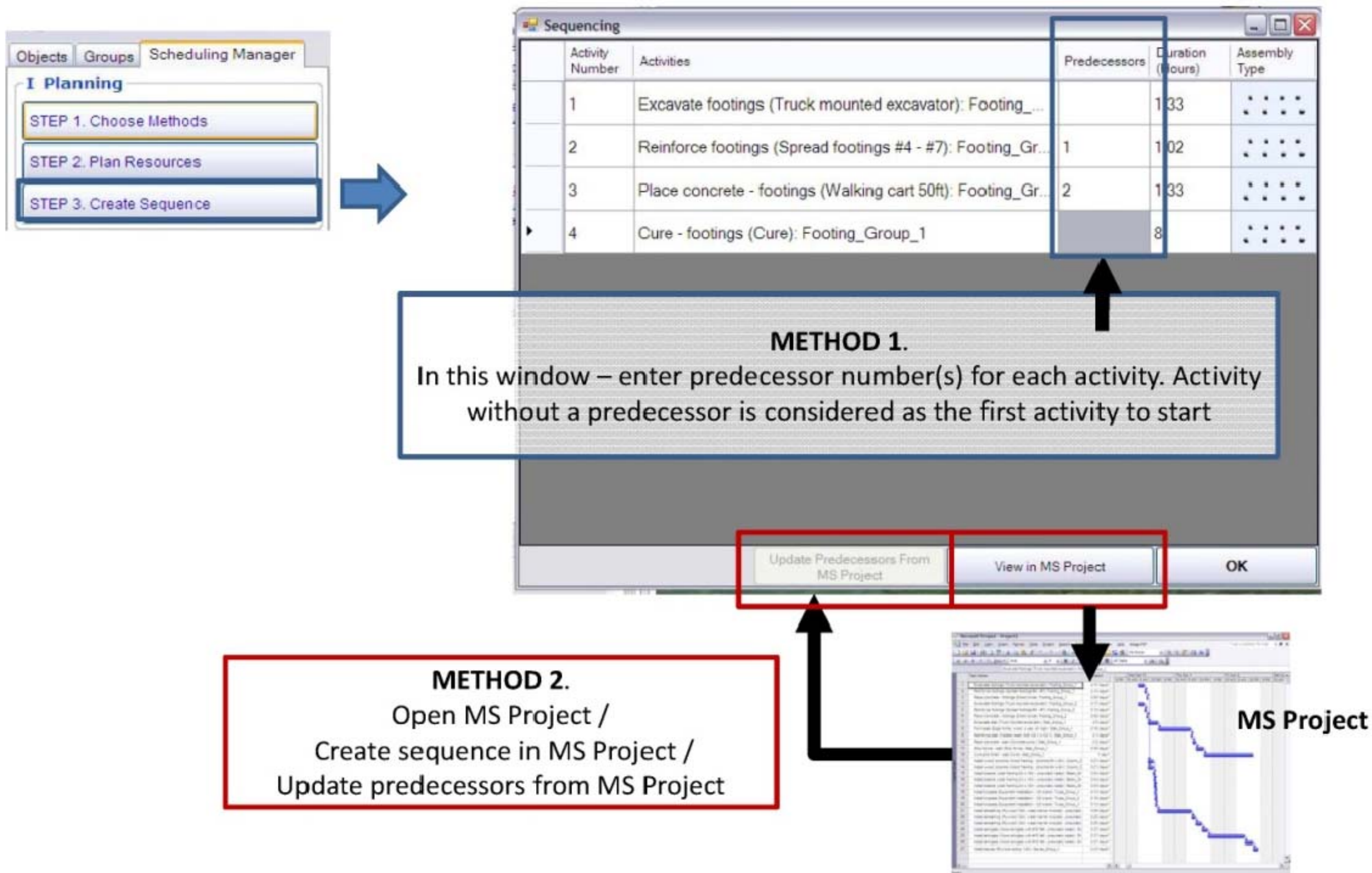


SCHEDULING MANAGER: planning

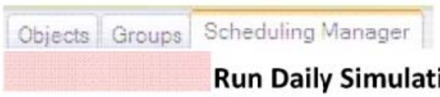




STEP 3 – Create Sequence. The "Sequencing" window opens.
There are **two methods** to create a sequence.



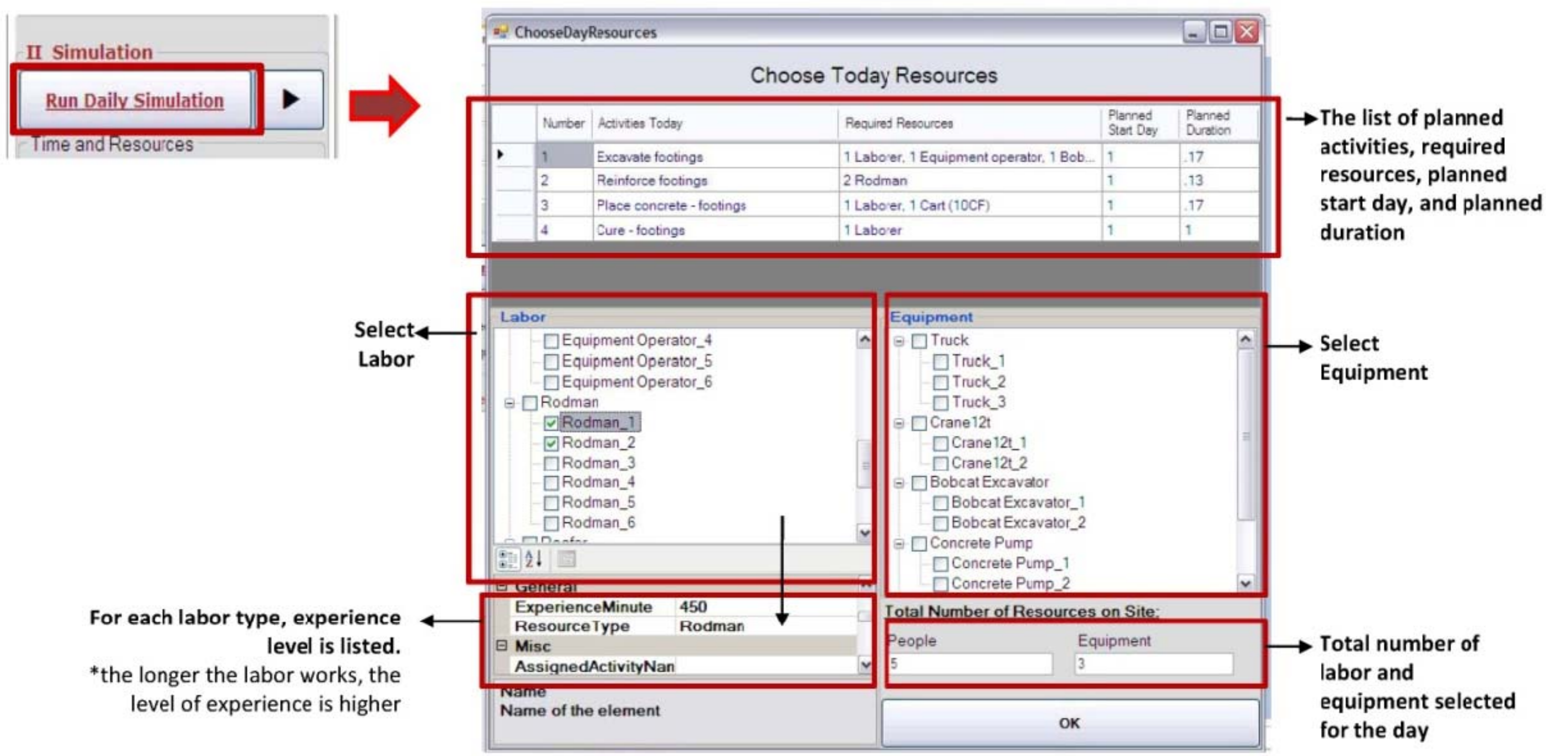
SCHEDULING MANAGER: simulation



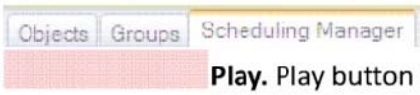
Run Daily Simulation. The "Choose Today Resources" window opens.

Select Resources to be on the site for each day of the project construction.

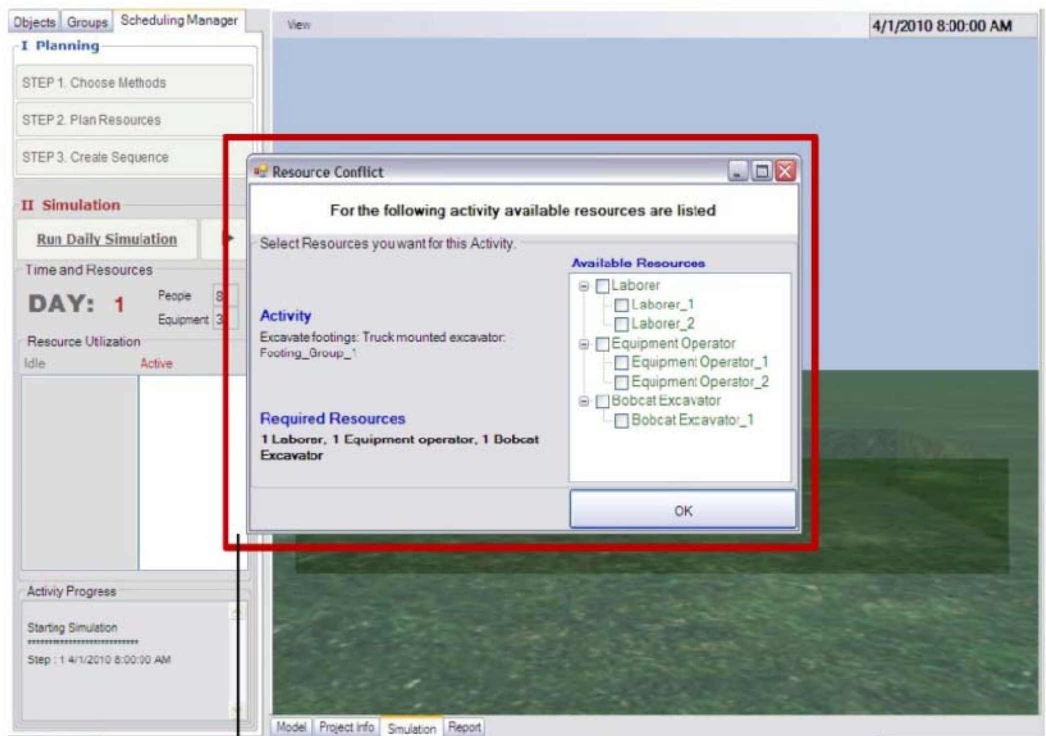
To allow for easier selection, the list of all planned activities is provided, along with the planned start day and the planned duration based on the user's schedule.



SCHEDULING MANAGER: simulation



Play. Play button starts the visual simulation of the as-built schedule.
Actual duration calculation is based on the crew sizes and resources availability.



For each activity that is ready to start, user will be prompted to assign available resources for the activity.
*If no available resources are listed, the message will notify you to wait until the needed resources become available

SIMULATION: - Visualizing the progress

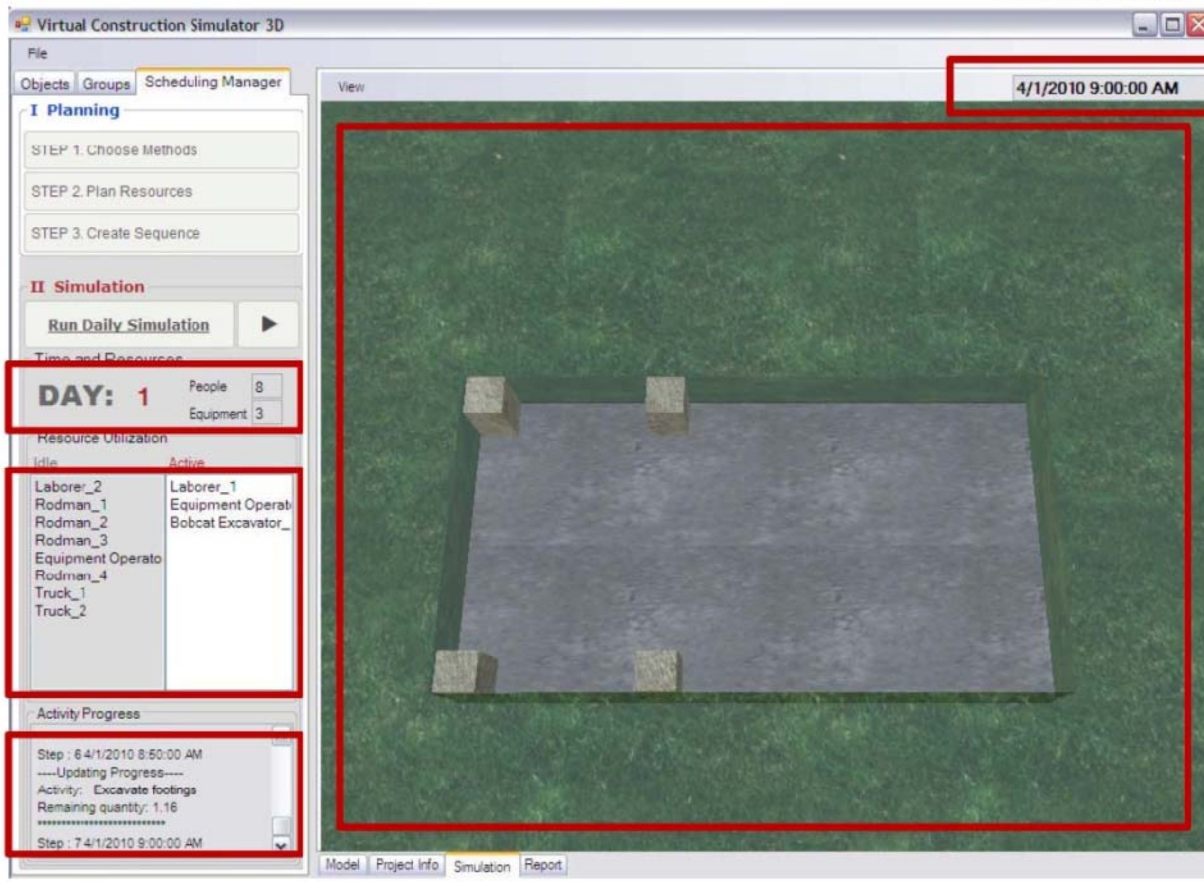
The simulation runs on a daily basis. In the information section, summary of the simulated day, resources on site, resources utilization, and activity progress are displayed.

Information: Day and resource on site

Resource utilization: Shows active (working on the current activity) and idle resources

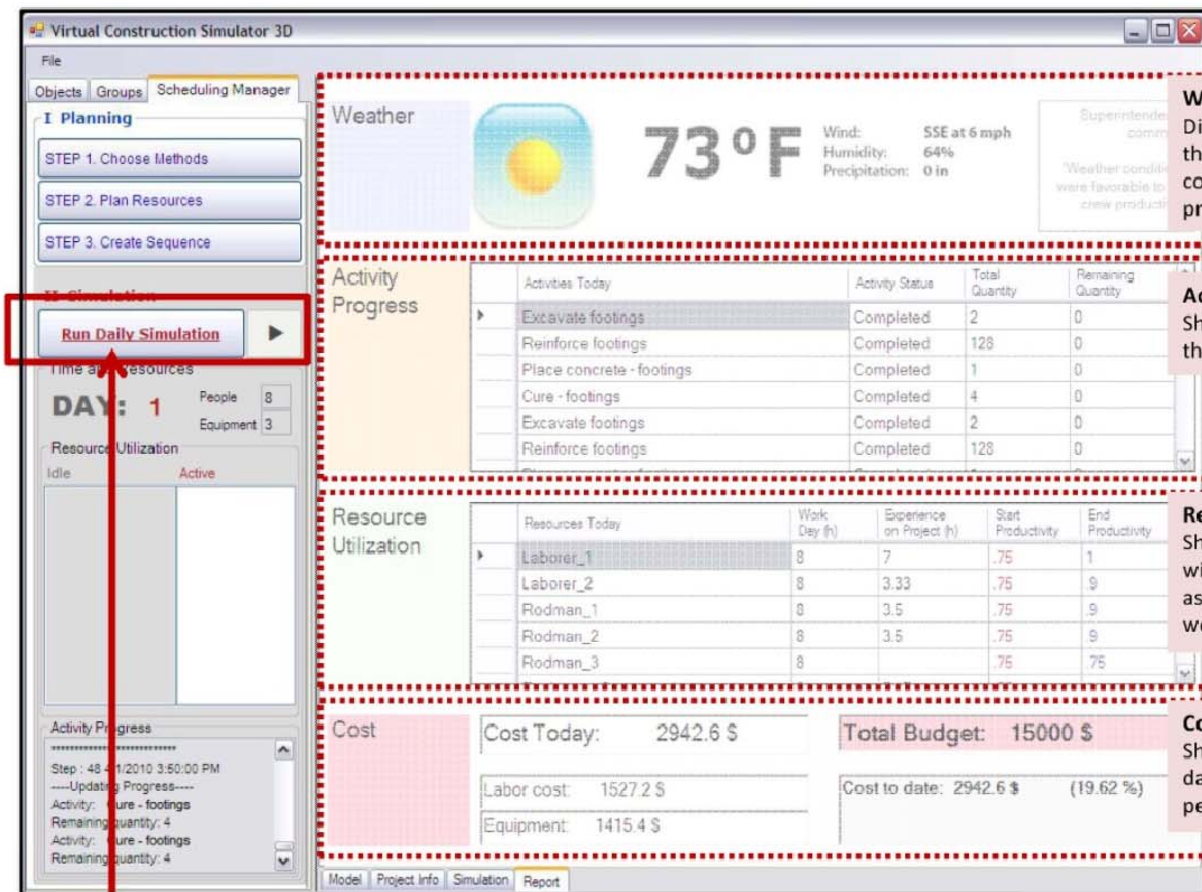
Activity progress: Shows current activity and remaining quantity

Date and time info



REPORT TAB

Once the simulation for the day is finished, the daily report displays the construction progress.



Weather Information:
Displays weather conditions for that day and superintendent's comments whether the productivity was affected

Activity Status:
Shows the activity status and the remaining quantities.

Resource Utilization:
Shows the resources usage with the experience level factor as a function of total hours worked on the project.

Cost:
Shows the daily cost, cost to date and the budget percentage used to date.

After reviewing the Report, continue simulation by clicking "<u>Run Daily Simulation</u>" followed by "<u>Play</u>" button until project is constructed

Appendix D

Handout

Virtual Construction Simulator ® spring 2010

How fast can you build the pavilion without exceeding the budget?

- The budget limit is **$ 15 000;**
- The budget includes **labor** and **equipment**;
- Labor and equipment are paid for the **whole day** on site regardless of how much they actually work;
- For this project, the labor provided is a **union** labor;
- Union labor by this contract does **not** work during the weekend and does **not** work overtime.

Your task :

Plan and develop the construction schedule to build this project within the budget.

To develop and test your schedule, use the **V**irtual **C**onstruction **S**imulator application developed at the AE Department.

Report below how did you do, and compare how well you peer managers did ☺

Choose Your Project Manager Name:		
How long did the construction take?		**days**
How much did the construction cost?		$

Department of Architectural Engineering The Pennsylvania State University

Appendix E

Consent Forms

INFORMED CONSENT FORM FOR SOCIAL SCIENCE RESEARCH
The Pennsylvania State University

Title of Project: Virtual Construction Simulator 3D: A Simulation Game for Construction Engineering Education

Principal Investigator:	John I. Messner jmessner@engr.psu.edu Associate Professor, Dept. Architectural Engineering Pennsylvania State University 104 Engineering Unit A University Park, PA 16802 (814) 865-4578
Co-investigator:	Dragana Nikolic dragana@psu.edu Graduate Student, Dept. Architectural Engineering Pennsylvania State University 104 Engineering Unit A University Park, PA 16802 (814) 865-5022
Co-investigator:	Dr. Sarah E. Zappe, ser163@psu.edu 201 Hammond Building University Park, PA 16802 (814) 865-4016

1. **Purpose of the Study**: The purpose of this study is to gather information about the value of the Virtual Construction Simulator 3D simulation game on students' knowledge acquisition and problem solving related to construction planning and management.

2. **Procedures to be followed:**
   - As an assignment in AE 372, you will be asked to develop a construction plan for a building project using the Virtual Construction Simulator 3D simulation game. To evaluate the use of the VCS 3D application, you will be audio and video-recorded during the work session.
   - As part of your assignment, you will be asked to complete two surveys in class which would have questions pertaining to the assignment you were given and the experience you had using the VCS 3D application.
   - Finally, you will be asked to give the researchers permission to use the responses on the assignment, your assignment grade, and video recordings for research purposes. All identifying information will be removed from all assignments so that individuals cannot be associated with responses.

3. **Benefits:**
   a. You may learn more about construction processes using the simulation technology.
   b. This research may provide a better understanding of the pedagogical value of using simulation games within the engineering domain.

4. **Duration/Time:** Completion of the class assignment may take 2 – 4 hours to complete the study. Completing the survey for the research project will take approximately 15 minutes.

5. **Statement of Confidentiality:** Your participation in this research is confidential. If this research is published, no information that would identify you will be written. Your name will not be associated with any data in any manner. Both the video content and the feedback you provide will be kept confidential from your instructor and teaching assistant until the end of the semester after final grades are assigned. All the data, audio, and video recordings will be stored securely on a password protected computer in the co-investigator's office. Only the principal investigator and the co-investigators will have access to the data collected. Video and audio recordings will be destroyed after 3 years. All identifying information will be removed from student assignments and survey responses. Your confidentiality will be kept to the degree permitted by the technology used. No guarantees can be made regarding the interception of data sent via the Internet by any third parties.

6. **Right to Ask Questions:** You may ask questions about the research. Contact John I. Messner at 865-4578, or Dragana Nikolic at 865-5022 with questions, complaints or concerns about this research.

7. **Voluntary Participation:** Participation is voluntary. This research study is part of regular classroom instruction and everyone will receive the same instruction, regardless of the decision to participate in the research study. Your course grade will not be impacted by your participation in this study. You can withdraw from the study at any time by notifying the principal investigator. You can decline to answer specific questions on the surveys.

You must be 18 years of age or older to consent to participate in this research study.

You will be given a copy of this consent form to keep it for your records.

If you agree to the conditions and statements noted above, please select the appropriate options below:

☐ I agree to give the researchers permission to use responses on the surveys and responses/grades associated with the simulation assignment.

☐ I DO NOT agree to give the researchers permission to use responses on the surveys and responses/grades associated with the simulation assignment.

In addition, please select the response which reflects your agreement with the researchers' use of the video, audio recordings, and photographs:

☐ I agree to allow my videos/audio recording/images from AE 372 to be released to the principal investigator and the research team of this study for the purpose of research. In addition, these may possibly be shown in a presentation setting with names removed.

☐ I DO NOT agree to allow my videos from AE 372 to be released to the principal investigator and the research team of this study for the purpose of research. Please complete the section below:

Student Name	Signature	Date

Investigator Name	Signature	Date

Appendix F

Procedure

Before the implementation:

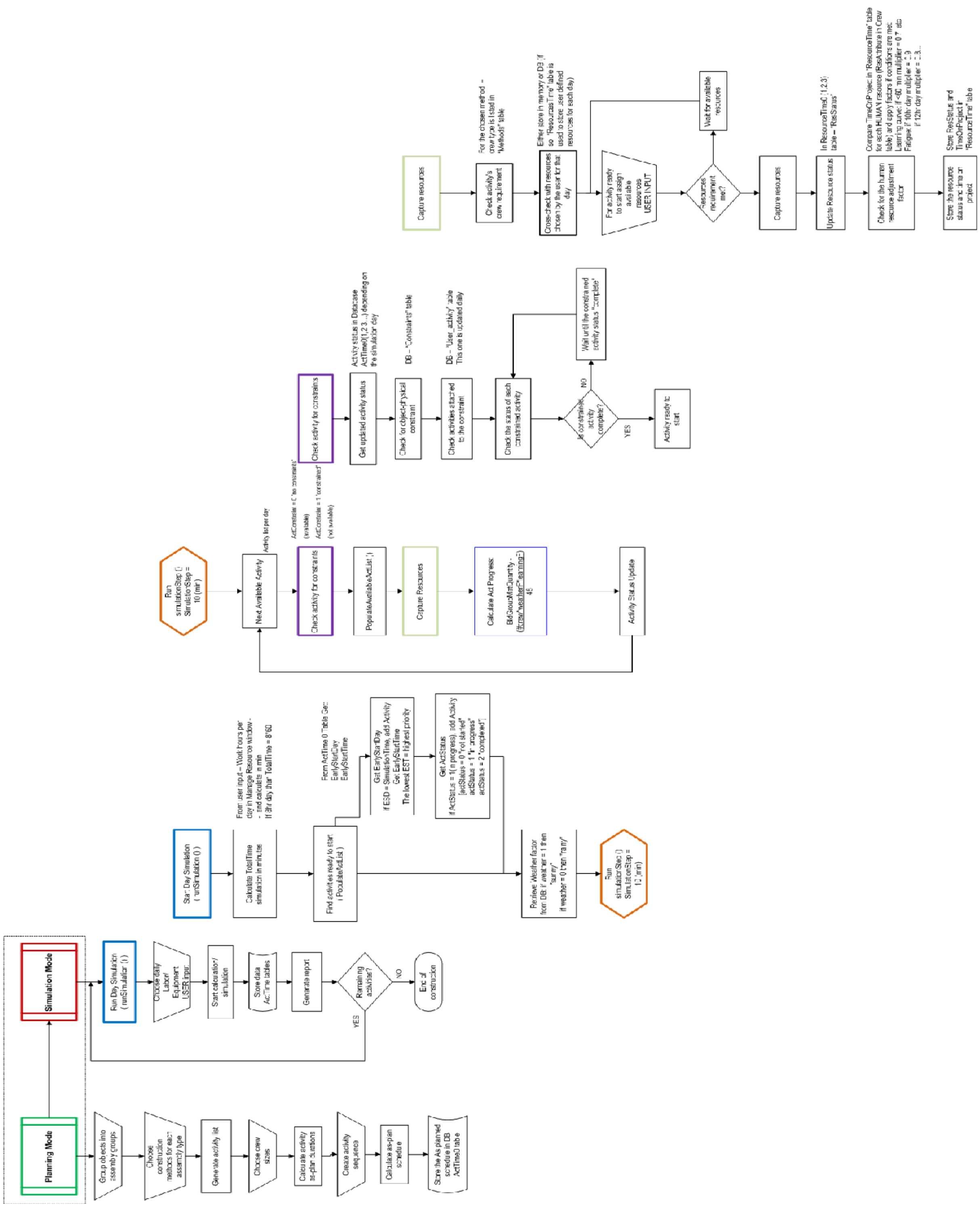
- Reserve time blocks in the 307 Sackett lab
- Check the main computer and the big screen for the demo.
- Check to see if 46 people can be seated during the demo
- Check each computer for bugs and test run VCS
- Prepare the implementation version of the VCS to be distributed to students
- Copy the implementation folder to the Y drive
- Ensure all the necessary files are copied in the shared folder
    - The VCS debug folder
    - The links to the surveys
    - The VCS assignment sheet

Before the practicum sessions:

- Check for additional chairs
- Welcome students
- Introduce students to the nature of the study
- Ask students to copy the files from the shared drive to local documents
- Distribute the VCS manual paper copies
- Ask students to open the VCS
- Perform the demo (15 minutes) + 5 min free practice
- Ask students to close the application
- Offer students a sign-up sheet in case they would prefer to do it later
- Distribute consent forms to students who are about to begin the study
- Distribute the assignment sheet
- Ask students to open the link to the first survey
- Start the VCS assignment
- When close to finish, ask students to save the Microsoft schedule on a shared drive
- Distribute the second survey
- Collect the assignment sheets
- Thank students for their participation
- Store the consent forms and assignment sheets
- Copy all the saved files from the shared drive to a local drive

Appendix G

VCS Flow Chart



Appendix H

VCS Handout – Version 2

The Pavilion Project

Constructing the Pavilion - Introduction

Summary

You are a construction manager at *PSUConstruction*, a mid size construction company based in State College, PA. You have been tasked with providing a construction plan to build the Pavilion project. The owner of this project however, insists that the pavilion is built in no more than 6 days as the reception for the business partners has been already scheduled. While exceeding 6 day time frame induces penalties and additional costs, the owner offers bonus savings if the project is completed ahead of the schedule and under the provided budget. You receive the pavilion documents and notice the structure comprises of:

- 8 cast in place concrete footings,
- cast in place concrete slab,
- 8 wood columns
- 6 pairs of beams
- 13 trusses
- sheathing and shingles

Based on your previous experience and initial look at the project, you are confident that you can build the Pavilion relatively fast and at low cost ensuring the quality and safety.

Managing Your Project

To give your estimate on time and cost, you will plan and simulate the construction of the project. You can repeat the process as many times you want until you are satisfied with the solution. Before you start the project, and each day as it unfolds, you will have an opportunity to adjust certain project parameters. Spend about 5-10 minutes when deciding on:

1. Construction Methods

For each building element type you can choose between different construction methods. One may be faster but more expensive than the other. Think about advantages and disadvantages of both.

2. Project Schedule

You may change your schedule (your target completion time) by changing the activity sequence and/or activity duration. Hiring multiple crews speeds up any construction activity.

2. Resources

More labor can do more work, but of course each additional labor also adds to project costs. The longer any laborer works on the site, the more experienced and efficient they become. Although you can have as many people on the site as you want, be careful as the site becomes less safe.

The Pavilion Project

The project information

- The budget limit is **$ 15 000;**
- The budget includes **labor** and **equipment**;
- Labor and equipment are paid for the **whole day** on site regardless of how much they actually work;
- For this project, the labor provided is a **union** labor; union labor by this contract does **not** work during the weekend and does **not** work overtime;
- For each day ahead of completion you save **$1000;**
- For any remaining amount of the budget unspent, you get to keep **50%** .

Your task :

Plan and **simulate** the construction schedule for the Pavilion project using the **V**irtual Construction **S**imulator application developed at the AE Department.

Document all the decisions you made each day in the table bellow.

Report below your final results, and compare how well you peer managers did ☺

Name: ____________

How long did the construction take? ______ **days**

How much did the construction cost? ______ $

The table below will help you keep track of the progress and any challenges you may encounter

Day	No of People	No of Equipment	Cost	**Comments** (activity progress, challenges..)

CURRICULUM VITAE

Dragana Nikolic

Education

2011 **Ph.D**, Penn State University, Department of Architectural Engineering, Construction Management Option

2006 **M.Arch**, Penn State University, Department of Architecture, Digital Design Option

2003 **Dipl. Engr. in Architecture**, University of Belgrade, Department of Architecture

Research Interest

Design and construction visualization;
The role of simulation technologies in learning and decision-making;

Teaching Experience

Instructor AE 597K Research Methods in Architectural Engineering (Spring 2011)
Arch 130A Basic Design and Research for Architectural Engineers (Spring 2006)

Selected Publications

2011 **Nikolic, D**., Jaruhar, S., and Messner, J.I., (2010) "An Educational Simulation in Construction: The Virtual Construction Simulator." *Journal of Computing in Civil Engineering*. (Submitted 1 June 2010; accepted 4 November 2010; posted ahead of print 11 May 2011)

2010 **Nikolic, D**., Lee, S., Messner, J.I., and Anumba, C. (2010) "The Virtual Construction Simulator – Evaluating an Educational Simulation Application for Teaching Construction Management Concepts." *Proceedings of the 27th International Conference on Applications of IT in the AEC Industry* 2010, Cairo, Egypt

2010 **Nikolic, D**., Messner, J.I., Lee, S., and Anumba, C. (2010) "The Virtual Construction Simulator - development of an educational simulation game." *Proceedings of the International Conference on Computing in Civil and Building Engineering* 2010, Nottingham, UK

2007 Balakrishnan, B., **Nikolic, D**. and Zikic, N. (2007) "Where am I?" Impact of Display and Content Variables on Spatial Presence and Comprehension in Virtual Environments." Paper presented at the annual meeting of the International Communication Association, San Francisco, CA, May 23, 2007

Activities and Service

2009 - 2010 **Expand Your Horizons**, *Penn State University.* Several workshops conducted to introduce young women to the field of architectural engineering and encourage their interest in science, technology, and engineering.

2007 **Solar Decathlon,** *Penn State University.* 4th team in the National competition to design, build, and operate the most attractive and energy-efficient solar-powered house. Assisted with the construction and tours. Entries displayed on the National Mall, Washington, DC.

2005 **Czech Republic Service Project**, *Penn State University.* Bechyne, Czech Republic. Five weeks of intensive design, planning, and public presentation in the Czech Republic.