DEVELOPMENT OF INTERACTIVE SIMULATIONS
FOR
CONSTRUCTION ENGINEERING EDUCATION

A Thesis in
Architectural Engineering
by
Shrimant Jaruhar

© 2008 Shrimant Jaruhar

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 2008
The thesis of Shrimant Jaruhar was reviewed and approved* by the following:

John I. Messner  
Associate Professor of Architectural Engineering  
Thesis Adviser

M. Kevin Parfitt  
Associate Professor of Architectural Engineering

David Riley  
Associate Professor of Architectural Engineering

Chimay J. Anumba  
Department Head & Professor of Architectural Engineering

*Signatures are on file in the Graduate School.
Abstract

4D CAD models are increasingly being used in the construction industry for detailed schedule reviews. Currently, the commercial applications which create these models are not ideal for use in construction engineering education as they do not combine schedule creation and schedule review. This research is aimed at developing a schedule creation and review application titled the Virtual Construction Simulator (VCS) 2 which is easy to use and has an intuitive user interface. This application is aimed at improving upon and addressing some of the limitations of a previously developed VCS 1 application at Penn State by using an open source expandable rendering engine.

The educational value and usability of this educational application were tested by conducting a student exercise in a construction management class at Penn State. A case study model of the MGM Grand Hotel was used for developing this educational simulation exercise. Surveys and a focus group discussion related to the application and the class exercise revealed that the VCS 2 is a valuable 4D model creation and schedule review application. 3D visualization and 4D modeling were also found to be valuable as a communication tool. A test of the comprehensiveness of student discussion during the 4D modeling exercise was also performed by using content analysis techniques. The results showed that while students were using VCS 1 and VCS 2 for 4D model creation the discussions were less detailed than expected.

Another contribution of this research is the creation of guidelines for the development of similar educational simulations which aid educators in developing future case study exercises. They address the development of goals and objectives for the
educational simulation; developing the simulation according to those goals and objectives; and testing and improving the educational simulation.
Table of Contents

List of Figures .......................................................................................................................... ix

List of Tables .......................................................................................................................... xi

Chapter 1: Introduction .............................................................................................................. 1

1.1 Goal ....................................................................................................................................... 6

1.2 Objectives ............................................................................................................................ 6

1.3 Research Contributions ....................................................................................................... 7

1.4 Background Information .................................................................................................... 8

1.5 Thesis Organization ........................................................................................................... 10

Chapter 2: Literature Review .................................................................................................. 11

2.1 Construction Engineering Education .................................................................................. 11

2.2 Construction Project Sequencing ...................................................................................... 13

2.2.1 Critical Path Method (CPM) Scheduling ...................................................................... 13

2.2.2 4D CAD ....................................................................................................................... 15

2.3 Use of Simulations in Education ....................................................................................... 17

2.4 Virtual Reality and Immersive Environments .................................................................. 19

2.4.1 Virtual Reality (VR) ................................................................................................... 19

2.4.2 Use of VR in Engineering Education ......................................................................... 19

2.5 Summary ........................................................................................................................... 21

Chapter 3: Research Methodology .......................................................................................... 23
<table>
<thead>
<tr>
<th>Chapter 6: Evaluation of the Virtual Construction Simulator 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Evaluation Procedures</td>
</tr>
<tr>
<td>6.1.1 Case Study Exercise</td>
</tr>
<tr>
<td>6.1.2 Surveys</td>
</tr>
<tr>
<td>6.1.3 Focus Group Meeting</td>
</tr>
<tr>
<td>6.1.4 Content Analysis</td>
</tr>
<tr>
<td>6.2 Results</td>
</tr>
<tr>
<td>6.2.1 Surveys</td>
</tr>
<tr>
<td>6.2.2 Focus Group</td>
</tr>
<tr>
<td>6.2.3 Video Analysis</td>
</tr>
<tr>
<td>6.3 Summary</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 7: Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Research Summary</td>
</tr>
<tr>
<td>7.2 Research Contribution</td>
</tr>
<tr>
<td>7.2.1 Improved VCS Features and Interface</td>
</tr>
<tr>
<td>7.2.2 Value of 3D Visualization and 4D Models as Schedule Generation and Review Tools</td>
</tr>
<tr>
<td>7.2.3 Guidelines for Developing Future 4D Modeling Simulations</td>
</tr>
<tr>
<td>7.2.4 Identification of Items for Comprehensive Discussion on Schedule Creation</td>
</tr>
<tr>
<td>7.2.5 Dissemination of 4D Modeling Educational Application</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traditional 4D Modeling Approach</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Revised 4D Modeling Approach</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>VCS II Screenshot</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>VCS I Screenshot</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>ICon Lab 3-Screen Display</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>MGM Grand Hotel Single Floor</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>VCS Application Structure</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>VCS 2 Opening Screen</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Main Menu and Dropdown Menus</td>
<td>37</td>
</tr>
<tr>
<td>10</td>
<td>Grouping Menu</td>
<td>38</td>
</tr>
<tr>
<td>11</td>
<td>Group Creation</td>
<td>39</td>
</tr>
<tr>
<td>12</td>
<td>Activity Menu</td>
<td>40</td>
</tr>
<tr>
<td>13</td>
<td>New Activity Creation</td>
<td>41</td>
</tr>
<tr>
<td>14</td>
<td>New Activity Creation</td>
<td>41</td>
</tr>
<tr>
<td>15</td>
<td>Sequencing Menu</td>
<td>42</td>
</tr>
<tr>
<td>16</td>
<td>Create Relationship</td>
<td>43</td>
</tr>
<tr>
<td>17</td>
<td>Playback Menu</td>
<td>44</td>
</tr>
<tr>
<td>18</td>
<td>4D Model Playback (Screenshot 1)</td>
<td>44</td>
</tr>
<tr>
<td>19</td>
<td>4D Model Playback (Screenshot 2)</td>
<td>45</td>
</tr>
<tr>
<td>20</td>
<td>ICon Lab Display Systems</td>
<td>60</td>
</tr>
<tr>
<td>21</td>
<td>Canon Video Camera</td>
<td>61</td>
</tr>
<tr>
<td>22</td>
<td>Pressure Zone Microphone</td>
<td>61</td>
</tr>
</tbody>
</table>
Figure 23: Students Participating in the Experiment ........................................................ 63
Figure 24: Student Group Presenting Their Solution ....................................................... 64
Figure 25: Value of Large Scale 3D Model ...................................................................... 70
Figure 26: Utilization of 3D Model .................................................................................. 70
Figure 27: 3D Model for Idea Generation and Evaluation ............................................. 71
Figure 28: 3D Model as Common Media ......................................................................... 71
Figure 29: Confidence in Initial Schedule ........................................................................ 72
Figure 30: 4D Model for Schedule Examination .............................................................. 72
Figure 31: Level of Enjoyment ........................................................................................ 73
Figure 32: Communication Tool ....................................................................................... 73
Figure 33: Confidence in Schedule After 4D Model Review ........................................... 74
Figure 34: SIPS Understanding ........................................................................................ 74
List of Tables

Table 1: Discrepancies on Item Ratings in Inter-Rater Reliability Test........................... 67
Table 2: Results of Content Analysis................................................................................ 79
Acknowledgements

I would like to thank all those people who have helped me in completing this thesis. First of all, I would like to thank my Adviser and mentor Dr Messner for his unflinching support and guidance not only towards my research but towards all academic and career matters. His hard working nature and deep knowledge of things in general have always provided me the motivation to follow his example.

I would also like to thank Professor Parfitt and Dr Riley for their valuable suggestions and support along the way.

My fellow CIC research group members have always supported my efforts and have been invaluable friends.
Chapter 1

Introduction

The construction industry needs skilled professionals who have the ability to learn on the job and come up with innovative solutions to construction problems. These skilled construction managers need to ensure that construction on projects is speedy, economical and safe. It is important for construction engineering programs at universities to produce such professionals who not only have the required technical skills but also have the ability to self learn and the ability to approach a problem from various angles. However, construction engineering education is mostly based on the Cartesian view of mind-matter dualism where the context of the knowledge is not provided to the learner and this is reflected in the teaching methods of lectures and case study exercises (Barab et al., 2001). These teaching methods do not always provide a construction management student with the opportunity to think of alternative solutions to construction problems and even with case study exercises there are class duration and class environment limitations to fully utilize the limited opportunity. University education when it comes to teaching Critical Path Method (CPM) scheduling is seen by the industry as too theoretical and on-job training is seen as required for a college graduate before he or she is assigned CPM scheduling duties (Galloway, 2006). Graduating students have to quickly come to terms with the demands of construction projects as they have not been exposed to the need for developing and visualizing alternative solutions for construction project issues.
To overcome these educational challenges and to provide a more rapid scaling of the learning curve upon graduation, the use of simulations becomes important. Simulations offer users an experience which mimics a real world situation (Chen & Levinson, 2006). For a construction educator, it is valuable to be able to have students experience a construction problem like scheduling, site congestion, site layout, proper trades flow, etc. without actually having the pressure of a real construction project.

The major thrust of this research effort is to investigate the creation of an educational simulation experience for construction scheduling, although, the same simulation development process can be used for creating simulations for other construction concepts. Construction schedules enable all involved parties to be aware of the status of a construction project and how different construction activities are related to each other. The construction schedule for a project shows which activities are on the critical path and the relationship between the various activities. Project delays are usually very expensive for contractors and frequently cause damages to the owner. It, thus, becomes important to have a construction schedule which is as compact as possible while still allowing some flexibility to account for unanticipated events on the project. A good schedule should also reflect the logical order of activities to ensure easy constructability. This logical order is often difficult to determine especially on complex projects which may have a multitude of interlinked activities.

The traditional method to develop a construction schedule is to analyze the design documents and then interpret which activities will occur along with the order. This approach is based on the person’s mental ability to visualize the construction schedule based on his or her interpretation of the design drawings. This logical order of activities
may or may not be correct depending on the complexity of the design and the correct or incorrect interpretation of the drawings. For construction students it is harder to learn this logic part in a classroom than it is to learn how to use a CPM scheduling tool (e.g. Primavera Project Manager or Microsoft Project) to create construction schedules. It is widely known that experience is a great teacher, but without extensive project experience it is difficult for students to visualize the logic and structure of a good construction schedule.

The use of 4D CAD models becomes important for the purpose of schedule visualization as it has been shown that these models allow users to visualize the construction process and the built environment (Messner, 2003; Koo, 2000). Currently, a 4D model is generated based on the following procedure (See Figure 1):

1. Develop a 3D model for the project in a CAD application;
2. Develop a construction schedule in a scheduling application; and
3. Link the construction schedule to the 3D model in a 4D CAD application.
Present 4D CAD applications have a limitation that the process of creating a construction schedule is independent of the 3D model visualization. This limitation does not allow users to develop the construction sequence in a 3D environment and thus the 4D model is not based on the logical sequence which a 3D model communicates. It is based on the users’ ability to visualize the sequence in his/her mind.

A Virtual Construction Simulator application was recently developed at Penn State which allowed students to create a construction schedule by interacting directly with the 3D CAD model. Figure 2 shows the revised 4D modeling concept behind the VCS application. The focus of this research is to build upon this previous research.
concept by creating a more robust interactive educational software application, VCS 2, for construction sequencing and 4D model playback (see Figure 3). To assist others in developing future educational simulations, guidelines have also been developed for creating these simulations.

Figure 2: Revised 4D Modeling Approach
1.1 Goal

The goal of this research effort was to:

Create and test the usability of an interactive educational simulation application for virtual construction schedule creation and visualization and to develop guidelines for the creation of similar future educational applications.

1.2 Objectives

To achieve this goal, the following objectives have been met:
• To develop an easy to use and effective 4D CAD modeling application which allows students to create and visualize construction schedules in an efficient manner thereby allowing them to test various possible solutions and to determine the optimal solution for complex construction sequencing exercises.

• To test and improve the usability of the application by conducting a learning exercise in a construction planning class (AE 473 at Penn State).

• To assess the educational value of the application through student perception surveys and focus group discussion.

• To develop guidelines for creating interactive educational simulations for additional construction engineering education scenarios.

1.3 Research Contributions

The research contributions of this research are:

• An open source educational software application which allows users to create construction schedules interactively. The software application has the flexibility to load different 3D models so that instructors can use different case study examples to teach about various sequencing issues. A technical guide for understanding the application code and to build upon the application has also been developed.

• Educational module development guidelines for creating future educational simulations.

• Documentation of the usability of the application along with lessons learned on the interface issues and the case study used.
1.4 Background Information

A Virtual Construction Simulator (VCS) was initially developed at Penn State in fall 2006 (Wang et al., 2007). The simulator was created in a game engine called Deep Creator specifically focused on the MGM Grand Hotel 3D model. The simulator allowed students to group individual objects in a 3D model; to create activities and link the groups to the activities; and to create sequences between activities. Wang et al. (2007) also conducted a classroom exercise in which 2 sets of student groups were asked to perform a construction sequencing activity on the MGM Grand Hotel case study while they were videotaped. The students were asked to sequence the construction activities on one floor of the MGM Grand Hotel. Construction activities like building internal walls, floor and exterior ductile framing were included in the sequencing. One set of student groups used a traditional 4D modeling application (MS Project + Navisworks) while the other used the Virtual Construction Simulator (VCS) (See Figure 4).

![Figure 4: VCS I Screenshot](image-url)
The following conclusions were reached:

1. The VCS was not only a schedule review tool similar to the commercial 4D applications but it was also a schedule generation tool.

2. Students perceived that the VCS interface allowed them to generate more solution ideas, allowed for greater focus on the task at hand and facilitated better communication amongst the group members.

3. Through video analysis of the time spent by the students on different levels of communication, it appeared that the student groups who used the VCS made more effective use of their allotted time than the student groups using the traditional 4D learning module.

The VCS was a valuable application. However, it suffered from several limitations, including:

1. The Virtual Construction Simulator used a dedicated database to store group, activity and sequence data using a Microsoft SQL server. This necessitated manual creation of a database file every time the application was started.

2. The researcher had to manually create LISP coding for each individual object in the 3D model. This limits the use of other 3D models because the objects would have to be coded again.

3. The interface of the simulator was not always easy to use and efficient due to challenges in programming within the Deep Creator Engine.
This initial research effort inspired the development of the Virtual Construction Simulator 2. The VCS 2 was then tested using the same class exercise as VCS 1.

1.5 Thesis Organization

This chapter identified the goals, objectives, and contributions of this research effort. The need for the research along with background information was also presented. Chapter 2 discusses literature which builds the background for this research. The research steps which allowed the researcher to complete this research are presented in Chapter 3. The various techniques employed during the research to obtain valuable data related to user perception and further improvements in the software application are also discussed in Chapter 3. The development process for the application, its structure, and its features are discussed in Chapter 4. In Chapter 5, guidelines for the development of additional 4D modeling simulations are provided. Chapter 6 shows the results of the user perception surveys, video analyses and, improvements suggested in the focus group meeting. Finally, in Chapter 7, the conclusions of this research are discussed along with suggestions for future research.
Chapter 2

Literature Review

To understand the background of the research, it was necessary to look at literature on a variety of topics. It was important to understand current construction engineering education practices and needs. The literature review for this research also includes a study of simulation and its use in education. This chapter also covers scheduling and 4D modeling practices along with the use of Virtual Reality (VR) in construction engineering education.

2.1 Construction Engineering Education

Construction engineering is an important part of both Civil Engineering and Architectural Engineering programs. It is a relatively new discipline (Singh, 1993) and it is constantly evolving as the construction industry evolves into a more technology aided industry. As the focus returns to infrastructure improvement in developed countries and infrastructure development in developing countries the graduates from a construction engineering program have a lot of opportunities available to them. The variety of opportunities however gives rise to a problem for educators of how to inculcate the broad range of knowledge into their degree programs.

Chinowsky et al. (1996) argue that in order to meet this challenge, educators have to move from single focus courses and seminars to an educational system which focuses on integrated concepts and lifelong learning. Also, to produce graduates who can meet
the engineering and management challenges on a project site can be a difficult task (Tatum, 1987). Thus, it becomes important to introduce students to current industry practices (Tener, 1996). To address these issues it is important for educators to ensure that the teaching tools employed can help students gain an understanding of the practical aspects of topic at hand.

Abudayyeh et. al. (2000) argue that a successful construction engineering and management program should promote self-learning in students. Such a program should attract experienced faculty and industry participation to share practical experiences with the students. Singh (1993) argues that practical experience is the key in an industry like construction and recommends that doctoral students should have practical experience while urging Universities to place greater emphasis on practical field knowledge.

The researcher details a few advantages of practical experience which are listed below:

- Team building and leadership,
- Decision support facility, and
- Quality of research produced by faculty.

Educators in construction engineering education have traditionally relied on the lecture method, case studies, practical assignments, and in class exercises which detach the learner from the learning context (Barab et. al., 2001). Ideally, site visits should also be an integral part of most construction courses to expose students to real projects and on site problems (Sawhney, 2000). It is not always possible for the instructor to conduct such site visits mainly because of the lack of availability of projects which are in a stage that can provide knowledge about the topics being discussed in class. These teaching
methods, although valuable, are not entirely suitable for teaching all construction engineering topics. One of these topics is construction project sequencing.

### 2.2 Construction Project Sequencing

Scheduling is an important activity for any construction project as a poor schedule can create difficulties for the contractors as well as the owners. Traditionally, schedules have been created based off of 2-Dimensional design drawings by mentally visualizing and interpreting the sequence of activities required for the smooth progress of a project and its timely completion.

Teaching students to mentally interpret and visualize the sequence of construction activities is a tough task specially if based off of 2D drawings (Retik, 1993). Recently, 3D models and schedules have been combined to create 4D models (Koo and Fischer, 2000). These 4D models are ideal for schedule review but even this does not enable students to learn about the logic which goes into creating a construction schedule.

#### 2.2.1 Critical Path Method (CPM) Scheduling

Hartley (1993) defines a ‘project schedule’ as “all basic scheduling documents including network diagrams, bar charts, histograms, and progress curves, as well as computerized reports and listings”. Traditionally, scheduling has been carried out by interpreting 2D paper drawings and then mentally linking construction activities to each other. The prepared CPM schedule is usually presented in the form of a bar chart or Gantt chart for communicating the workflow to concerned parties.
According to a majority of contractors (Galloway, 2006), the main advantages for using CPM scheduling on projects are the following:

• Improved planning before work starts,
• Improved scheduling,
• Improved understanding of the project,
• Improved project control after work starts,
• Improved communications among the workforce,
• Increased control over risk and uncertainty, and
• Reduced delays.

Galloway (2006) conducted an online survey of owners, contractors, engineers, construction managers and consultants to determine the degree of use and applicability of CPM scheduling in construction projects. The researcher found that CPM scheduling has become a standard when it comes to project control tools.

CPM schedules are created by interpreting 2D drawings and then mentally linking construction schedule activities to each other. The visualization of 2D drawings is not always straightforward depending on the complexity of the project (Songer et al., 2001). A similar problem arises when relationships between activities have to be identified and when activities have to be linked to objects from the 2D drawing. It is also not always easy to identify problems when a Gantt chart is used for visualizing a construction schedule because the objects associated with the activity are not displayed. These limitations led to the gradual development of 3D visualization and 4D CAD models.
2.2.2 4D CAD

2.2.2.1 4D CAD Model

A 4D CAD model is created by linking a 3D model with schedule data (Chau et al. 2004). These virtual models represent the relationship between spatial and temporal aspects of a project as they would exist on the project site (Koo et al. 2000). Construction 4D-Planner was developed by Bechtel in conjunction with Hitachi Ltd. was the first application to combine 3D model objects with corresponding schedule activities (Smith 2001).

2.2.2.2 4D Model Development

Wang et al. (2007) describes the process of creating a traditional 4D model. This process is as follows:

1. Develop/obtain a 3D model for the project from a CAD application,
2. Develop a construction schedule in a scheduling application,
3. Separate the model into different construction assemblies, and then
4. Link the construction schedule to the 3D model in a 4D CAD application.

Wang et al. (2007) also describe the limitation of this approach to 4D CAD modeling since the planner must create a CPM schedule of activities without interacting with the 3D model.
2.2.3.3 4D CAD Applications

Hastings et al. (2003) note the advantages of the use of a 4D CAD model on the Ray and Maria Stata Center project on the campus of Massachusetts Institute of Technology. These are listed below:

1. Marketing: A 4D model is an excellent tool for marketing purposes to prospective owners and shows the capabilities of the general contractor.
2. Schedule Development: A 4D model can aid in schedule adjustments due to its visualization aspect.
3. Schedule Visualization: 4D CAD models are an effective mean for communicating the schedule to all concerned parties and ensure smooth workflow.
4. Coordination: 4D CAD models can aid in coordinating the work of subcontractors because it can help the general contractor determine areas of congestion and the correct flow of trades.
5. Communication with City Officials: The 4D model can help the contractor in communicating the need for traffic diversions and parking facilities to city officials.
6. Conflict Resolution: The general contractor was able to determine and resolve conflicts in the model before these conflicts arose on the project site.
7. Owner updates: 4D models provide easy visualization of project updates which are useful for the owners.
4D modeling was also carried out on the Walt Disney Concert Hall project in Los Angeles and researchers found that the project benefitted from the 4D CAD model in schedule creation, schedule analysis, communication and team building (Haymaker and Fischer, 2001). The challenge faced in 4D CAD modeling was the lack of data and inconsistencies in the 3D model and the schedule data, apart from issues arising in linking the 3D model to the appropriate schedule activities.

It is important to note that with the traditional method of creating a 4D model, the schedule of activities is initially created by mentally visualizing the sequence of activities and those activities are then linked to the 3D model objects. This research develops the concept of using a 3D visualization environment to create the 4D model without having to develop a separate CPM schedule. Instead, the CPM schedule is generated along with the 4D model. As discussed in section 1.4, Wang et al. (2007) developed a Virtual Construction Simulator prototype which was not only a schedule review 4D tool but also a schedule generation tool in a 3D environment.

2.3 Use of Simulations in Education

Sawhney et al. (2000) maintain that hands-on experience is lacking for students graduating from civil engineering and construction engineering programs. Simulations provide the ability to experience a situation virtually rather than having to face the same situation in real life. When it comes to educating future engineers, it is useful to provide them with experiences of situations that they are likely to face in the industry. Drew (1968) and Chen & Levinson (2006) define a simulation as “a dynamic representation of some part of the real world by building a computer model and moving it through time”.

17
Chen & Levinson (2006) also lists the advantages which simulations provide in the field of education:

1. Provides experiences to learners,
2. Provides opportunities for learning through doing,
3. Provides interactive learning environment,
4. Diversifies teaching strategies,
5. Helps students move towards higher level of intellectual development, and
6. Engages motivation to learn

There are several cases of simulations being used in education and also in construction engineering education. Al-Jibouri et al. (2005) developed a simulation for project planning and control. The simulation involved planning the construction, monitoring progress and dealing with contingencies which could arise during the construction of a rock and clay dam. Initial results of the classroom implementation indicated that the simulation was a valuable adjunct to traditional teaching methods. Martin (2000) developed a Project Management Simulation Engine for generating customized simulations for project management education. A particular implementation called Contract and Construct for teaching contract management was found to be of value not only in the classroom but also by commercial project engineers and managers. Similarly, Rojas and Mukherjee (2005) developed a web-based general purpose situational simulation environment called Virtual Coach but it was not implemented. Chen & Levinson (2006) used a network growth simulator program called SONG for teaching transportation engineering students about traffic network growth.
2.4 Virtual Reality and Immersive Environments

2.4.1 Virtual Reality (VR)

Rheingold (1991) defines a VR experience as that in which a person is “surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it”. Brooks (1999) puts it in much simpler terms by defining a virtual reality experience as “any in which the user is effectively immersed in a responsive virtual world”. A VR system aiming to deliver a virtual reality experience must be able to allow the user to effectively control their viewpoint dynamically (Brooks, 1999). The VR system must also allow the user to dynamically interact with the virtual environment and this should enable the user to feel a sense of immersion in that environment. The ICon Lab at Penn State has a 3 screen display system which was utilized for this research (See Figure 5).

In the construction industry, VR has been used for a variety of tasks; for visualizing construction plans and schedules (Whisker et al., 2003; Waley and Thabet, 2003), for architectural walk-through (Shiratuddin et al., 2004) and for optimizing site layouts (Tam, 2002).

2.4.2 Use of VR in Engineering Education

Traditionally, the use of VR systems in research has been limited due to the high costs associated with such systems (Otto et. al., 2005). However, with the advent of new
technologies the costs of these systems have reduced to a point to make it more accessible to researchers and educators (Bell and Fogler, 1995).

![Figure 5: ICon Lab 3-Screen Display](image)

Even though newer VR systems are more affordable, the use of VR in construction engineering education has remained limited (Otto et. al., 2005). A VR system should be more valuable for educators because it can provide added interactivity and spatial awareness. This can aid in the development of realistic simulations which can be an ideal substitute to site visits which are often not feasible due to varying project phases and availability, site access and productivity concerns of the owners or contractors, or unfavorable weather. Educators can provide students with the virtual experience of various construction activities and this is especially useful when those activities are hazardous in nature. Several researchers have proposed different applications of VR in construction engineering education. These applications have been
mostly limited to construction site activities visualization (Hadipriono et al., 1996; Haque, 2001).

2.5 Summary

Construction engineering education is constantly evolving as the industry evolves. It is important for construction education programs to develop the ability of self-learning in students. Practical experience is important in the field of construction but it is not always possible to conduct site visits for students.

Scheduling is one such concept in construction engineering which requires substantial on-the-job training. Traditionally, construction schedules have been created by interpreting 2D drawings and then mentally visualizing the sequence of activities for the smooth completion of a project. These CPM schedules are usually represented in the form of a bar or Gantt chart which can make communicating the workflow difficult. 3D visualization and 4D models have made it easier to visualize the construction process. Traditionally, 4D models are created by linking 3D model assemblies to corresponding schedule activities requiring the creation of a CPM schedule before the 4D CAD model can be developed. This necessitates mental visualization of the construction process and of the relationships between activities which is difficult for large and complex projects. This research enables the creation of 4D CAD models along with CPM schedules with the only input being the 3D model.

Simulations are defined as “a dynamic representation of some part of the real world by building a computer model and moving it through time” (Chen and Levinson,
Simulations are valuable in the field of education as they can provide students with experiences of situations which they are likely to face on site or in the trailer. Researchers have shown the value of simulations in construction engineering education. There have been limited implementations of 4D CAD simulations in education.
Chapter 3

Research Methodology

3.1 Research steps

The following are the research steps which enabled the researcher to meet the goal and objectives listed previously.

3.1.1 Literature Review

A literature review was conducted to learn about traditional construction scheduling techniques and 4D CAD modeling. The advantages and disadvantages of both of these scheduling tools were determined. The concept of virtual reality and virtual reality applications were also examined as part of the review process. The literature review also included a study of construction engineering education and the use of simulations in education.

3.1.2 Virtual Construction Simulator Version 2 Development

A 4D CAD software application for schedule creation and review was developed using a rendering engine called Irrlicht. Initially, goals were set for what features the application should be able to support. Thereafter, various rendering and game engines were evaluated on the basis of the features to be developed for the VCS. Irrlicht was chosen because of these reasons:
1. Irrlicht is open source and is available free of cost. This is important if other users want to easily build upon the VCS application.

2. Irrlicht readily supports various common 3D model formats including .3ds, .obj, .x, .blender, etc.

3. The development language for Irrlicht is C++ which allows for easy and quick application development.

4. Irrlicht has a large user base and a helpful support community.

The VCS 2 allows users to create, delete and edit groups of objects, activities and sequencing between activities. This allows users the flexibility needed to create and revise a construction schedule and therefore allowing them to create a variety of solutions for each problem. The VCS 2 has a playback interface where students can visualize their construction schedules providing visual clues to possible problems in the schedule. It supports saving and loading of previous work making it easier for users to create a schedule, and does not require them to complete the work in one linear process. The application calculates the start and finish times of all activities and the finish time of the project. It generates an XML file containing the construction schedule. Thus, students can test a solution against other possible solutions and the VCS 2 application allows them to learn about construction schedule logic from practice and by getting feedback on their sequencing solutions.

Along with the development of the VCS 2, a technical guide for the source code was developed simultaneously. This technical guide will help anybody who would be building upon the application or attempting to make modifications to the application.
### 3.1.3 Application Testing and Data Collection

The Virtual Construction Simulator 2 has been developed to be used for a construction sequencing exercise in an advanced project management class (AE 473 at Penn State). Students from the class performed a construction sequencing exercise in the Immersive Construction Lab (ICon Lab) at Penn State. The ICon Lab hosts a large 3-screen display with supporting computer and visual hardware. The use of an immersive environment like the ICon Lab at Penn State when viewing 4D CAD models provides an added sense of immersion which should enhance the visualization experience for the students. The use of this display system also enables better collaboration among the group members (Wang et al., 2007). A 3D model of the MGM Grand Hotel was used for this exercise. The student groups were required to create a construction schedule of a single floor of the precast concrete structural system. The students were assigned to groups randomly and each group was videotaped (with permission) while they were performing the exercise. At the end of the exercise they were asked to complete a survey containing questions relating to perceptual ease of use and educational value along with a section for providing feedback mainly on the application related to the interface or possible new features. This is further described in Chapter 6.

### 3.1.4 Application Assessment and Improvement

The VCS was improved based on the observations of the researcher during the class exercise, the survey feedback, and a focus group meeting after the class exercises had been completed.
If any specific application related problems arose during the exercise, they were fixed at the earliest possible opportunity. Additional features to be added were also identified and are discussed in Chapter 7. This application including its source code has been disseminated on the internet on the Computer Integrated Construction Research Group webpage and also as a Google Code project.

3.1.5 Development of Guidelines for Educational Simulation Development

A set of guidelines for the development of educational simulations based on the VCS 2 platform has been created. These guidelines provide a starting point for anybody who plans to develop such educational simulations. The guidelines cover determining goals and objectives for the simulation, the actual development of the educational simulation, testing the educational simulation and the variety of problematic issues which can arise in any of these stages.

These guidelines have been developed mainly based on lessons learned through the process of developing the MGM Grand Hotel simulation for the VCS 2. A review of related literature has also been carried out. Another educational simulation has been developed based on the guidelines created to test their usefulness. These guidelines are presented in Chapter 5.

3.1.6 Documentation of Conclusions and Lessons Learned

The results of the surveys, focus group meeting and personal observations were documented and conclusions on the usability, value and limitations were formulated based on those results and observations. The guidelines for educational simulation
development and the technical guide for the application are available for dissemination. The lessons learned throughout the development, testing and improvement phases have also been documented. Possible directions for future research have also been suggested in the Conclusions chapter.

3.2 Research Techniques

The following research techniques were used to perform the research steps mentioned above:

3.2.1 Case Study: MGM Grand Hotel

A case study provides a holistic view of an event or a situation consisting of the details of the event or situation as well as a description of its contextual setting (MacNealy, 1997; Yin, 2002).

The case study used for the classroom exercise was the construction sequencing of the precast concrete structural system of the MGM Grand Hotel in Las Vegas, NV for a single floor of a wing as shown in Figure 6.

Figure 6: MGM Grand Hotel Single Floor
3.2.2 Surveys

Survey research can be used to obtain information about social phenomena through observations and by asking (Corbetta 2003). Surveys are usually carried out using interviews and questionnaires (Fellows and Liu 2003). Questionnaires are either open or closed. Open questionnaires allow respondents to provide answers in any form they wish without a fixed set of answer choices. Closed questionnaires, however, have a fixed set of answer choices and the respondent can select one or more choices depending on the questions. Open questionnaires are easier to administer but the results are difficult to analyze whereas closed questionnaires are difficult to setup but it is easier to analyze the results.

Two closed questionnaires were used to obtain feedback on the perceived educational value of the scheduling application, its usability and interface design, and general exercise procedure. The student groups also provided open ended feedback in the survey.

3.2.3 Direct Observation

Directly observing how users interact with a new system or object can be a simple way of determining the system’s or object’s usefulness. Care should be taken however to ensure that the observation does not affect how the users would interact with the system or object naturally. The researcher was present while the exercise was being conducted to be available for any logistical help and for observing the working groups as well. The different student groups were videotaped with permission while they were performing the scheduling exercise.
A test of comprehensiveness of discussion was carried out using the recorded videos and this is discussed in the content analysis section below.

3.2.4 Focus Group

A focus group meeting is a qualitative research technique to obtain group knowledge (Easton et al., 2003) Focus group meetings are informal discussions among a small group of people usually consisting of five to nine people and a moderator to focus the discussion (Massey & Wallace, 1991). Usually this discussion lasts 90-120 minutes but it can be shorter or longer in some cases (Easton et al., 2003). Focus groups can not only tell the developers what people think about a product or system but they can also reveal why people think the way they do (Morgan, 1997). Thus, focus groups can provide quite useful results. However, for the use of focus groups as a useful research technique it is important to ensure that the discussion is focused and all participants are able to express their opinions without any intimidation or inhibition. The presence of a strong moderator is thus essential to obtain accurate information about the product or service.

The aim of using such a focus group for this research was to identify interface issues or possible new features for the VCS 2. The hour long discussion involving five students allowed the researcher to not only improve the application but to also determine future scope of development.

The focus group participants consisted of Architectural Engineering students who had performed the MGM hotel scheduling exercise in the class. The meeting was held in the ICon Lab and was videotaped to allow for further analysis.
3.2.5 Content Analysis

A test of the degree of comprehensiveness of discussion during the student group exercises was also performed. This test was performed based on the video recordings of each group’s discussions during the MGM Grand 4D modeling exercise. A list of important items which groups should have considered while performing the exercise was developed in consultation with the course instructor and the teaching assistant of the course. Along with the discussion content list, a 3 point rating system was also developed. While watching the videos, each item on the list was given a rating based on how detailed the discussion on that item was. A rating of 0 signified no discussion on the topic while a rating of 1 was given to items in which the group members talked about the item for less than 30 seconds. A rating of 2 signified detailed discussions on that item in which the duration was greater than 30 seconds. For example, if the group talked about ‘crane movement’ for more than 30 seconds then it was decided to give a rating of 2 to the item ‘crane movement’ on the discussion content list.

To ensure that the ratings given to the discussion content items in the content analysis are consistent and repeatable both stability and inter-rater reliability tests were performed. According to Milne et al. (1999), a stability test is performed to determine if the results obtained in a content analysis exercise are repeatable by the viewer himself or herself. However, an inter-rater reliability test is a test to verify the reliability of content analysis amongst several viewers. The stability and inter-rater reliability tests were performed on one sample video which was one hour and forty five minutes long. The researcher performed the stability test while for the inter-rater reliability test the help of two doctoral students majoring in Architectural Engineering was employed.
The reliability was measured by dividing the number of matches between viewers by the total number of decisions taken by those viewers. After the inter-rater reliability test, the researcher went through the ratings given by each viewer and tried to determine the causes of discrepancies between ratings given for an item by the viewers. Coding errors and unclear definitions of some items on the checklist were determined to be the main cause of rating discrepancies. The analysis and results are presented in Chapter 6.
Chapter 4

Development of the Virtual Construction Simulator 2

4.1 VCS 2 Development Background

As mentioned in Chapter 1, the first VCS was developed using the Deep Creator Engine. The limitations discussed in Chapter 1 related to interface issues and the VCS’ program and database structure were taken into consideration during the VCS 2’s development process. It was decided to employ the same 4D modeling concept as the original VCS, i.e. requiring only a 3D model for schedule and 4D model generation rather than requiring a 3D model and an already created schedule to develop a 4D model.

The first development decision was focused on the choice of rendering or game engine to be used in the development process. The simplest option would have been to use Deep Creator and try to expand the functions and improve the interface of the simulation since the existing VCS 1 could provide a well developed foundation to build upon. However, Deep Creator is not a free open-source game engine which limits free dissemination of the simulation, and it was also difficult for future researchers to expand the functionality of VCS 1. LISP coding of objects was another major limitation associated with VCS 1. Apart from limiting the VCS 1 for use with the MGM Hotel model only, LISP is also not as common a programming language as C, C++ and Java. So, a decision was made to develop the VCS 2 in a C++ development environment which would make future development of the VCS easier. These two factors along with an active user-base requirement for support narrowed the available choices of rendering
engines significantly. After a period of testing some of the engines which met our requirement criteria, a decision was made to use Irrlicht as the rendering engine upon which the VCS 2 would be developed.

Another major limitation with the VCS 1 was the method of storing runtime data. In VCS 1, any data related to the groups, activities and relationships for schedule creation was stored in a Microsoft SQL database which had to be manually created each time the application was run. This limits the capability for simple and rapid generation of solutions while also limiting the portability of the simulation to other computers. Looking at Irrlicht’s modules, it was decided to store simulation runtime data of groups, activities and relationships in the form of runtime arrays which will not require the creation of a database file of any kind. However, to help students keep track of their progress it was decided to create a Microsoft Access database file which would read the runtime data at the click of a button and display the status of grouping, activities and relationships. It is important to note that the VCS 2 does not require the existence of such a database file to be used and if needed, this Microsoft Access Database file can simply be copied to another machine on which the VCS 2 is being used.

A list of new features which could and would be developed in the new VCS was created based on the results of assessment of the VCS 1. These included features like:

- Add groups to an existing activity,
- Remove groups from an existing activity,
- Preset viewpoints,
- Easily sequence activities in a chain,
• Automatic schedule generation, and

• Ability to save and load work at any point of time.

Each interface screen for creating, modifying and deleting groups, activities, and relationships, along with the 4D model playback screen were storyboarded in the initial stages of development. These storyboarded screens allowed the researcher to program the VCS 2 accordingly. The endeavor was to have a logical and smooth flow of interface changes as the VCS 1 interface was seen to require some development in this regard.

### 4.2 VCS 2 Structure

The Virtual Construction Simulator 2 was developed using the Irrlicht rendering engine. A Visual C++ project was created for the VCS 2 in Microsoft Visual Studio 2005. The Irrlicht engine was then included as a source file and as an available library. This allowed the researcher to use the functions available in the engine in the VCS 2 C++ project. Once the programming for the application was complete, compilation of the code produced an executable file (.EXE extension) for the VCS 2 application. The VCS application can then be used with or without a Microsoft Access Database file to produce a 4D model along with a CPM schedule in the form of an XML file.

The structure of the VCS 2 application is shown pictorially in Figure 7.
Figure 7: VCS Application Structure
4.3 VCS 2 Interface

The application opens up with a window as shown in Figure 8. The user is asked to choose the display system which could be a one screen, two screen or three screen display. The user is also required to enter the number of workhours every day. This information is required to display the current workhour and day in the playback mode of the 4D model. The application does not currently support having more than one kind of workweek for a single run of the simulation although this could be added in future versions.

![Figure 8: VCS 2 Opening Screen](image)

**General application environment:**

Once the display system and number of workhours have been chosen, the software application displays the main interface along with the 3D model. Figure 9 shows the main menu along with the top toolbar containing the file, viewpoints, activities and hide/show objects menus. These are positioned towards the left side of the application window. The main menu is the starting point for going to different application modes such as grouping mode, activities mode, sequencing mode and playback mode. The dropdown file menu lets the user save his or her work to an XML file and these saved XML files can be
loaded into the application at any time through the ‘load’ option in the file menu. The file menu also contains the option to close the application.

The viewpoints dropdown menu contains three set camera positions which are helpful for navigating the model. There is a top view, a side view and a front view.

The activities dropdown menu allows a user to change the durations of already created activities.

The Hide/Show Objects dropdown menu can be used to selectively show or hide components in the model like walls, frames, steel beams, slabs and grout connections.

Figure 9: Main Menu and Dropdown Menus
Grouping:

The creation of activities and relationships between those activities requires the model objects to be in groups. The user can enter the grouping mode by clicking on the groups button in the main menu. This menu is the starting point for creating groups of individual objects. For example, a user may choose to group a set of north and south interior walls together to convey that those walls will be put in one after the other. The grouping menu also contains options to add an object to an existing group, to remove an object from an existing group and to delete a group (see Figure 10).

![Grouping Menu](image)

Figure 10: Grouping Menu

To avoid the need for a user to create groups for each individual object, the application is programmed to put individual model objects into their own separate groups. Once the
user has finished creating and modifying groups he or she may click on the finish grouping button on the grouping menu to inform the application to put all ungrouped individual objects into their own separate groups (see Figure 11).

The steps required to create a group are as follows:

1. Click on the ‘Group’ button in the Grouping Menu.
2. Right click on all the objects in the model that you want to group together.
3. Click on the ‘Done’ button.
4. Enter a name for the group and hit Enter.

Figure 11: Group Creation

Activities:

The Activities menu can be accessed by clicking on the ‘Activities’ button on the main menu. Figure 12 shows this menu. Schedule activities can be created, modified and deleted using the buttons available in this menu. These activities must be linked to pre-existing groups for at the time of creation. Additional groups may be added to that activity later or removed from an activity as and when required. These activities also
have a duration associated with them. The duration is in minutes and this duration can be changed at any time using the ‘Change duration’ option available in the ‘Activities’ dropdown menu on the main menu screen. For example; a user may choose to create an activity titled “Erect Ductile Frame_North_1” and choose to attach a group of 2 ductile frame elements in the model to that activity.

Figure 12: Activity Menu

The activity creation dialog box is shown in Figure 13. The user is first required to input the name and duration of the activity.
The user is then required to attach groups to the created activity. Figure 14 shows the group attaching interface.

Relationships:

The sequencing menu is accessed by clicking on the ‘Sequencing’ button on the main menu. This menu allows for the creation and deletion of Finish-Start relationships.
between already created activities. Figure 15 shows the ‘Sequencing’ menu with the available add and remove relationship buttons.

Figure 15: Sequencing Menu

Figure 16 shows the new relationship creation dialog box which appears once the preceding and succeeding activities have been selected. A lag (in minutes) can be introduced in the Finish-Start relationship. The ‘Continue Sequencing’ button allows the user to efficiently create chains of Finish-Start relationships. Once the button is clicked, the VCS automatically selects the second activity of the previous relationship to be the first activity of the new relationship and thus, the user will only need to select the second activity.
Figure 16: Create Relationship

**Playback:** After the creation of relationships, the 4D model playback mode can be entered by clicking on the ‘Playback’ button on the main menu. The application creates a CPM schedule from the relationship and activity information, and displays the result visually in the form of a 4D model. The playback menu shown in Figure 17 has 3 buttons: Back, Play and Pause. Apart from these buttons, the menu also displays two scroll bars which show the present workhour and the current day depending on the choice of workhours per week chosen initially. The 4D model playback can display the 4D model in discrete time steps of 0.25 hours (15 minutes) corresponding to a second in real time. To go to a specific workhour in the playback, the pause button can be selected and the top scroll bar can be moved to that workhour to display the 4D model at that instant in time.
Figures 18 and 19 show the progress of a 4D model.
4.4 Description of Features

Some of the features of the VCS 2 application include:

1. The application can be used on any windows based system ensuring easy portability.

2. It provides a virtual 3D environment for 4D model creation supporting up to 3 displays.

3. The application does not require an existing schedule to develop the 4D model. In fact, it generates a construction schedule in the form of a list once the 4D model has been created.

4. Users can save their current work in the application as an XML file which can be reloaded at a later time.

5. It allows the user to input activity durations in minutes providing more flexible and accurate schedules.

6. The application is not 3D model specific and any 3D model can be used with the application to create 4D models.
7. The 3D model in the application is broken down into specific individual objects which can be joined together to form groups. After a group is created, more objects can be added to it or objects can be removed from that group. Users can also delete that group if required. Any object which is not part of a group is put into a group of its own ensuring consistency.

8. Users are able to create construction activities in the application and these activities can then be linked to groups. After an activity is created, additional links to other groups can be created or links may be removed depending on the user’s schedule creation preferences.

9. After the creation of groups and activities, activities need to be sequenced as preceding and succeeding activities, and a lag time may be introduced into these relationships. The application calculates start times for activities once the relationships are created.

10. The playback mode of the application allows the users to view the 4D model. The 4D model shows the gradual buildup of the project and the percentage of completion of activities is also displayed. The playback may be paused and stopped. Rewinding and fast forwarding the playback are also supported.
Chapter 5

Guidelines for 4D Modeling Simulation Development

To aid the development of future 4D modeling simulations based upon the VCS, guidelines for the process have been developed. Additional 4D modeling simulation exercises for project management and scheduling courses can be developed by following these guidelines. These guiding concepts cover both general educational guidelines as well as technical guidelines for simulation development.

These guidelines were developed based on the researcher’s experience with developing the VCS 2 and the MGM Grand Hotel 4D modeling simulation combined with literature on the use of simulations in education and Irrlicht’s module information.

5.1 Educational Guidelines

The educational/learning guidelines are discussed below:

1. Have a clear, documented learning objective for the simulation.

*Description:*

A learning objective should be student focused, and it should be reasonable considering the simulation being developed (Carpenter, 2005). A well defined learning objective can be helpful in guiding the development of the simulation. A clear learning objective will also aid in determining the success of the simulation in a class. The development of the assessment metric should be guided by the
learning objective so that the feedback can determine if the objective of the simulation exercise was met.

*Example:*

For the simulation exercise developed for the advanced project management class (AE 473) at Penn State, the objective was to develop better scheduling skills amongst students and to teach students about the Short Interval Production Scheduling (SIPS) process by demonstrating a case study example. One floor of the MGM Grand Hotel model was utilized for the sequencing exercise and the model was broken into components to effectively showcase the SIPS process.

2. Develop a system to test whether the original purpose and goals have been met (did the students learn what they were supposed to learn).

*Description:*

It is important to assess if the learning objective of the simulation exercise has been achieved. This test should not only determine if further teaching of the concept is required but it will also provide feedback on how the simulation can be improved in the future to fully achieve the learning objective. Some of the possible ways to test if the learning objective has been met could be through conducting another simulation exercise, creating a quiz based upon the simulation’s concepts, conducting a survey to see if the students perceived greater
understanding of the concepts, and perhaps by analyzing the discussions of the student groups during the exercise.

Example:

Due to the constraints of the course schedule it was not possible to conduct another set of group experiments to test the understanding of scheduling or the SIPS process after the MGM case study exercise. A decision was made to conduct two sets of surveys. One survey was conducted right after each group’s MGM class experiment while the other was conducted right after the class and course instructor discussed the various solutions and issues which students should have thought about. The learning objective was designed to be met through both the 4D modeling exercise and the instructor’s class discussion.

3. The instructor should hold a class discussion after the simulation exercise is performed by the students.

Description:

The simulation should ideally be made available to the students well before a class to make sure students have enough time to perform the simulation exercise on their own, following which a discussion should be carried out in the class on the core concepts of that simulation. This will save class time while also ensuring that students spend enough time attempting the simulation exercise on their own. These discussions should focus on the student’s solutions. Thereafter, the
instructor may choose to discuss the core concepts behind the simulation if he or she feels that the learning objective has not been met. However, based upon the MGM case study discussion and feedback from the students, it may be helpful to at least summarize the key concepts to reinforce the learning objective.

*Example:*

As mentioned earlier, the MGM simulation exercise was followed up by a class discussion on: the 4D models developed by the students, the model elements and how they were erected or installed, and construction management issues related to materials, equipment and crew. The survey which was conducted after this discussion and the focus group meeting revealed that from the class discussion, students were able to acquire a better understanding of the SIPS process, the MGM Grand Hotel construction issues, and scheduling aspects.

4. The students should get feedback on their attempts at the simulation.

*Description:*

To guarantee that students learn from the simulation exercise, it is important to not only discuss the concepts which the simulation attempted to teach but also to provide feedback to each student or student group about their simulation solution. This will ensure that students understand the pros and cons of their solution and if needed, how they can approach the problem differently on their next attempt at the simulation. The feedback provided can be in the form of a numerical or
alphabetical rating on a fixed scale or another measurable metric. Subjective value of the attempts can be discussed in class by the instructor. For detailed feedback on a solution, a course instructor should be consulted.

*Example:*

As mentioned earlier, the MGM simulation exercise was followed by a class discussion on student groups’ 4D model solutions. This gave students a chance to explain the thought which went into creating their models and also allowed students to look at other possible solutions presented by others. The course instructor and teaching assistant were also present to critique the solutions. Thereafter, the instructor explained how the actual construction was carried out and why it is important to consider material, equipment and crew issues while creating a construction schedule.

### 5.2 Technical Guidelines

Apart from learning/educational guidelines, a few technical guidelines for the development of additional 4D modeling simulations in the VCS are discussed below:

1. Develop/Modify the 3D model for efficiency, while keeping flexibility.

*Description:*

If a new 3D model is developed specifically for creating a simulation then only relevant 3D data should be incorporated into the model. Additional details which do not add value to the simulation should be omitted. This will ensure that the
model navigation is smooth due to lower polygon count, and at the same time the effort required to develop the 3D model will be minimized. The relevance should be judged from the learning objective and from the effort required for additional details to be included when it is not clear if those details will enhance or impede the effectiveness of the simulation exercise. This may apply to existing 3D models as well, depending on the level of detail included in those models.

For using a 3D model with the VCS, individual 3D objects which will be used in the scheduling exercise will need to be exported into a file format which Irrlicht supports. The remaining objects in the 3D model which will not be required for anything other than background purposes should be exported as one single file. To avoid excessive complexity, students should not be required to sequence too large a model or portion of a model. This might require grouping objects in the 3D model before exporting them for use in the VCS. However, to ensure flexibility these pre-groupings should not be so large as to limit a student’s ability to come up with a range of solutions.

Example:
For the MGM simulation an already existing 3D model (Autodesk Viz file) was modified for use with the VCS. The Autodesk VIZ file contained a total 108 precast concrete floor planks and they were distributed such that there were 9 planks supported upon underlying interior walls. To avoid burdening students with having to sequence 108 floor planks, it was decided to group together each of the sets of 9 floor planks into 12 floor slabs. This provided students with
enough flexibility to come up with different solutions while making the sequencing process less cumbersome.

2. Consider additional functionality that may be required to achieve the objective.

Description:

If the core functionality is not available in VCS, the application is open source which will allow for expanding the VCS application as needed. This will require C++ programming and an understanding of Irrlicht’s modules and functions. This process will require at least basic C++ programming skills. Irrlicht allows for a lot of in built functions which could suffice for adding new functionality to the VCS. Furthermore, Irrlicht itself is an open source rendering engine which means that additional functions can be created in the engine itself. This allows for a lot of expandability but it also requires a substantial programming effort.

Apart from adding core functionalities, interface changes can also be made to the VCS. The source code of the VCS application contains clear documentation of the relevant code sections allowing for changing the interface easily.

Example:

During the MGM class exercises, it was observed that student groups felt limited by the absence of a function to change ‘Activity’ durations. This functionality was added to the application by adding a dropdown menu to the top toolbar in the
VCS’ main interface. The addition of selective viewing of slabs, interior walls, grout connections, beams and frames was another example of functionality added during the MGM exercise.

3. Make model specific changes to the VCS application.

Description:
Some features of the VCS application are currently 3D model centric. The preset viewpoints, objects listed in hide/show objects menu and preset initial camera view will need to be updated according to the 3D model and the objects contained in that 3D model which are to be included in the construction scheduling simulation. Efforts are underway to enhance the application to limit these model centric issues and to make the VCS application truly independent of the 3D model.

Example:
Presently, the VCS application’s preset viewpoints, objects listed in hide/show objects menu and preset initial camera view are all programmed according to the 3D model of the MGM exercise. Since only the frames, slabs, interior walls, beams and grout connections of one floor were to be scheduled, only these objects were listed in the Hide/Show objects dropdown menu. It is planned to have a structure of exported .3ds files such that the VCS can parse the file names and populate the Hide/Show objects dropdown menu automatically. The viewpoints
can be set by taking the extreme coordinates of the entire 3D model and performing calculations on these coordinates to set the camera positions and camera’s view target position automatically. This may require proper reorientation of the 3D model in Autodesk 3D Studio MAX or another 3D modeling application.

4. Use familiar models/scenarios to make it easy for students to understand the core concepts behind the simulation.

Description:

Ideally, 3D models which are easily recognizable and to which the students have been exposed to before should be used for these simulation exercises. If a familiar model/scenario is not available then adequate background information should be provided beforehand. This will ensure that students are able to focus on how the different objects in the model interact with each other rather than trying to identify what those objects are. In other words, students should not feel lost in the 3D environment.

The background information provided should contain details about the number of elements in the 3D model, the classification of the elements, structural significance of the 3D model objects and details about erection/installation of the elements including details about temporary supports.

Example:
For the MGM Grand Hotel model, students were provided a list of all the 3D model elements along with an order of activities for each floor cycle. The students were then required to determine the erection sequence. The MGM model was shown in a demonstration class for the VCS before students were required to work with it on their own. The students were also shown installation or installed pictures of each of the elements they were required to work with.

After observing the group experiments and thereafter the discussions in class about each group’s solution, the lesson learned from the MGM case study was that more details should have been provided about how elements were to be structurally connected to each other.

5. The navigation and interface should not be too different from what students have been exposed to earlier.

_Description:_

Even though the VCS is built in an open source environment, it is imperative to have a simple interface and navigation system which is similar to other software programs the students have had experience with. At the same time realizing that this application is not built to compete with the slick interfaces of other Windows based applications because of limitations of time and development resources. A simple navigation and main interface will keep the students’ focus on learning the concepts rather than fumbling with the simulation interface or in the 3D environment which can be frustrating.
Example:

In the VCS, objects were selected by right-clicking with the mouse on those objects. Left clicking was used to click on buttons in the menus. Clicking and holding the left mouse button while moving the mouse around allowed users to orbit in the 3D environment while doing the same thing with the right mouse button allowed for panning in the environment. The same action performed on the middle scroll wheel allowed for zooming in and out.

During the MGM simulation experiments, it was observed that since the navigation system was not common it took students some time to get used to the navigation system. It would have been easier for students to get immersed in the 4D modeling problem had the navigation system been simpler.

A technical guide has been developed which provides step-by-step how to instructions on developing these 4D simulations. It is available at the following web address:

http://bim.wikispaces.com/Virtual+Construction+Simulator
Chapter 6

Evaluation of the Virtual Construction Simulator 2

This chapter presents the evaluation process for assessing the value of the Virtual Construction Simulator 2 along with the results of these procedures. The data and data collection processes are described in this chapter. The data collection was based mainly upon the case study experiment conducted as part of a construction management course at Penn State although a focus group discussion and content analysis of videos also provided valuable data regarding the value of the VCS application as a teaching tool. The results of perception surveys conducted both at the time of the experiment and following a discussion of case study solutions in class are presented in this chapter. The results of the focus group discussion and content analysis for checking the comprehensiveness of discussions are also presented.

6.1 Evaluation Procedures

6.1.1 Case Study Exercise

The MGM Grand Hotel’s floor scheduling experiment was conducted in a project management course at Penn State (AE 473). The aim of this experiment was to evaluate the value of the VCS 2 application as a teaching aid and to receive feedback on the application. From the course, groups of 3 or 4 students were formed randomly. These
groups were asked to perform the scheduling simulation activity which was set up in the Immersive Construction (ICon) Lab at Penn State with a large three screen display and a SMART Board was used for the experiment. The specific details of the experiment setup are described in the following sections.

6.1.1.1 Experiment Setup and Logistics

The experiment was conducted in the ICon Lab at Penn State. The main display system in the lab is a 3-screen rear projection display. Each of the screens is 6 feet high and 8 feet wide. The left and the right screens are angled at about 135° from the middle screen. This setup aims to provide an immersive experience for viewing 3D models because of the scale of the screens. This display system also supports stereoscopic viewing of 3D models using passive stereo rendering and polarized glasses. However, the VCS 2 currently does not support stereoscopy and so only single projectors were used for display purposes. The VCS 2 application was implemented on this display system.

The SMART Board is a touch sensitive white board which is linked to a desktop computer and the image from the computer is projected onto the SMART Board. Students are able to interact with software programs using electronic pens and their fingers in the same way as they would interact with the program using a keyboard and mouse. During the experiment, the SMART Board displayed the Microsoft Access database for the student group’s 4D modeling exercise which was helpful for the student groups in keeping track of their progress. These display systems are shown in Figure 20:
The equipment used for recording the group sessions is shown in Figures 21 and 22. The video recording was done using a video camera secured on a tripod which was placed behind the student group to cover the 3 screen display and the SMART Board. The camera was connected to a Macintosh computer and the recording was saved to an external hard disk for later evaluation. The audio recording equipment consisted of two Pressure Zone Microphones (PZMs) which were attached to the tables at which the groups were working for clear audio recording.
6.1.1.2 Experiment

The experiment consisted of student groups coming into the immersive display environment to use the VCS 2 application for creating a 4D model of a single floor of a wing of the MGM Grand Hotel project (see Figure 23). The aim of the experiment was to get feedback on the value and the interface of the application by direct observation of the researcher, video & audio recording, perception surveys and quality assessment of the final assignment deliverable.
The construction management class of 36 students was broken into 10 groups and each group had 3 or 4 students. These students were randomly distributed into these groups. Time slots of 4 hours each were made available in the ICon lab on a first come first serve basis and these groups were asked to pick their time slots. The student groups were given a brief introduction to the application with the researcher detailing the features of the application. A one page handout of navigational and interface instructions was also made available to each group (see Appendix D). Students were provided a list of construction quantities per precast floor per wing along with time constraints for the entire project. Students were asked to determine activity durations for a complete floor cycle from the constraints provided. The entire MGM Grand Hotel project was to take 40 weeks including earthwork and foundations which were to take a total of 8 weeks. The first four floors were cast-in-place concrete and were to take another 8 weeks. Groups were to allow 1 extra week for the fifth floor and 1 extra week for topping out due to inefficiencies with the first and last sequences. Groups could assume that the core construction could stay ahead of the construction of the hotel wings. The hotel was a total of 30 floors (4 floors of cast-in-place and 26 floors of precast). The assignment is attached as Appendix E.

The researcher was present during these time slots to assist with any software issues which could arise during these sessions. The researcher also made sure that the audio and video were being recorded properly. It was the researcher’s responsibility to hand out research consent forms at the beginning of the session and the perception survey at the end of the session.
Once the 4D model had been created, as part of the assignment, the student groups were also required to present their solutions in class for discussion and questions (see Figure 24). The 4D model was saved in an XML format and the VCS 2 application was made available to the student groups along with their XML file in case the groups wanted to make changes to their model.
6.1.2 Surveys

Two perception surveys were used to collect data about the value of the VCS 2 application, feedback on the application interface and on the value of 3D visualization and display systems. Survey 1 and Survey 2 are included in Appendix A and B respectively.

Survey 1 was handed out at the end of each group’s session in the ICon Lab for the 4D modeling exercise. This survey consisted of 4 parts: the first part included biographical information questions like age, sex and academic standing; the second part contained questions on 3D environment familiarity; the third part contained questions which related to the value of the application and 3D visualization; and the fourth part was a set of 5 open ended questions to allow students to provide suggestions and comments. The second and third part of this survey contained 5-level Likert items with the students
having to express their level of agreement or disagreement with the statements. The level of agreement varied from ‘strongly disagree’ to ‘strongly agree’ with ‘disagree’, ‘neither’, and ‘agree’ in between.

Survey 2 was comparatively much shorter with just 4 Likert items and one open-ended question for comments. This survey was distributed at the end of the solution presentation and discussion class. The aim of this survey was to judge the value of the 4D modeling exercise.

6.1.3 Focus Group Meeting

Soon after the solution presentation and discussion class, a focus group meeting was held with 5 students from the same AE 473 class who had performed the 4D modeling exercise in the ICon Lab. The aim of this meeting was to discuss in more depth the VCS 2 application and the 4D modeling exercise. It was determined that this feedback would help in making improvements to the VCS 2 application and also help in guiding future research.

In Survey 1, students were asked if they wanted to participate in a focus group discussion. After the assignment was over, a suitable time was communicated to these students for the focus group discussion. The focus group discussion moderator was a doctoral student who had previous experience with moderating focus group meetings. This discussion lasted for about 45 minutes, and video and audio recordings of the meeting were performed. The advantages and disadvantages of the application were discussed with the student participants suggesting improvements for the interface and
navigation. Some of the challenges faced by the students during the 4D modeling exercise were also discussed in the meeting.

6.1.4 Content Analysis

The 4D modeling experiment in the ICon Lab and the subsequent solution presentations and discussion revealed various items which student groups should have discussed while they were creating their construction plan. It was determined that a test of comprehensiveness of discussion should be conducted from the audio and video recordings of the experiment from both the 2007 class and the 2006 class. Such a test of comprehensiveness of discussion and then comparing the results from both years can suggest differences in the value of VCS 1 and VCS 2. This test can also determine what changes to the assignment should be made or what additional information may be valuable to ensure that students consider these relevant items during the assignment in future classes.

Before an analysis of recorded videos could be performed, it was necessary to create a list of items which student groups should have considered while they were creating the 4D model. An initial list was created after looking at the solution presentations, discussions held in class and watching three randomly selected videos from 2007’s 4D modeling exercise. This list was modified by the researcher in consultation with the course instructor and teaching assistants from both years’ classes. They were again consulted during the researcher’s efforts towards the creation of a 3 point rating system for the items on the discussion content list. In this rating system, 0 represented ‘no
discussion’, 1 represented ‘discussion up to 30 seconds’ and 2 represented ‘thorough discussion lasting more than 30 seconds’. The researcher selected a single video of 100 minute duration from 2007’s 4D modeling experiment. This video was analyzed and ratings were given to each item on the discussion content list based on the length of discussion. A stability test was carried out by the researcher by watching the same video and rating the items again to ensure consistency in coding. The researcher also asked two doctoral students to view the same video and to provide ratings for the items on the discussion content list. This was part of an inter-rater reliability test in content analysis which indicates whether the rating system and items on the list are clear for consistency and repeatability of results. The inter-rater reliability test and discussions with the other two viewers indicated that some of the items on the discussion content list were not defined absolutely clearly which led to discrepancies in ratings between the different viewers. A few of the discrepancies were also attributed to coding errors by the researcher or the other 2 viewers. Out of 29 items there were discrepancies on 2 items (see Table 1).

<table>
<thead>
<tr>
<th>Items on the discussion content list</th>
<th>Researcher rating</th>
<th>1st Viewer rating</th>
<th>2nd Viewer rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was crane cycle time considered?</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Were element connections discussed?</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
The resulting inter-rater reliability was calculated to be 93.1%. This factor was calculated by dividing the number of agreed upon rated items by the total number of items in the discussion content list. The list of items was then revised and the items were more clearly defined. Thereafter, 4 videos from the AE 473 class of 2006 and 10 videos from the AE 473 class of 2007 were used in the test of comprehensiveness of discussion. The results of the content analysis are shown later in this chapter along with the complete discussion content list in Table 2.

6.2 Results

SIPS assignment grades were compared for the same course with the previous year’s class (2006). The class average for this assignment was 87.9 in 2007 compared to 82.75 in 2006 for the VCS 1 groups while it was 82.4 for the groups who used Navisworks and MS Project to create the 4D model. The assignment in the previous year was exactly the same with the only difference being the use of the software application. The significant difference in scores could indicate that VCS 2 is a better application for developing these 4D models but this is assuming that the two different teaching assistants for both years graded the assignment in the exact same manner which may or may not be true even though the same scoring rubric was used for both classes.

6.2.1 Surveys

Shown in this section are some of the important results and comparisons of 2007’s survey responses to the ones from 2006 when students groups used either VCS 1 or Navisworks
to perform the 4D modeling exercise. The graphs show the percentage of respondents who gave the particular rating to the Likert item statement. As explained before, 1 is for ‘strongly disagree’, 2 for ‘disagree’, 3 for ‘neither’, 4 for ‘agree’, and 5 for ‘strongly agree’.

Survey 1 received 35 responses while 18 and 16 students were present respectively in the VCS and Navisworks groups in 2006. A copy of survey 1 is attached as Appendix A along with detailed results. Survey 2 received 23 responses. A copy of survey 2 is attached as Appendix B along with detailed results.

Figures 25, 26, 27, and 28 show that students found the 3D visualization aspect of the experiment to be valuable for performing the 4D modeling exercise. When the resulting means of each set of groups is compared to the other on the 3D visualization items on the first survey, then VCS 1 can be seen to get slightly higher scores than VCS 2 but VCS 2 has better scores than Navisworks. The comparisons on the other items of the surveys did not show any particular trend between VCS 2, VCS 1 and Navisworks. In general, the mean of the response scores to survey questions which were common between 2006 and 2007 were above 3.5. Any score over 3 represents a positive response from the students. The comparative scores between 2006 and 2007 for VCS 2, VCS 1, and Navisworks were also quite close to each other and the differences could be accounted for by the differing AE 473 class makeup between 2006 and 2007.

Students perceived that 4D modeling was very valuable as a communication tool and helped their understanding of the SIPS process. The survey data also showed that students gained greater confidence in their schedule after performing the 4D modeling
exercise. The students agreed slightly with the statements that VCS 2 was ‘easy to use’ and that the interface was ‘logical and smooth’. These results are shown in Figures 29-34.

It was valuable to have a large scale 3D model when developing our schedule.

Figure 25: Value of Large Scale 3D Model

Our group adequately utilized the 3D model when developing our schedule.

Figure 26: Utilization of 3D Model
The 3D model helped me in generating ideas and evaluating other people’s ideas.

![Figure 27: 3D Model for Idea Generation and Evaluation](image)

The 3D model provided a common media to keep the whole group focused throughout the process of developing the schedule.

![Figure 28: 3D Model as Common Media](image)
I felt confident in the initial schedule that we developed before reviewing the 4D model in the ICon Lab.

Figure 29: Confidence in Initial Schedule

The 4D model in the ICon Lab was helpful for examining the schedule we developed.

Figure 30: 4D Model for Schedule Examination
I enjoyed performing the exercise in the ICon Lab.

![Survey 1 - Q14](image1)

Figure 31: Level of Enjoyment

The 4D model made it easier for me to communicate with my team members when we worked on the assignment.

![Survey 2 - Q4](image2)

Figure 32: Communication Tool
I felt more confident with our schedule after reviewing the 4D model.

Figure 33: Confidence in Schedule After 4D Model Review

The 4D modeling activity helped me gain a better understanding of the SIPS process.

Figure 34: SIPS Understanding
Apart from these rating results, the students also provided open-ended feedback to certain questions. These questions along with a few student quotes are shown below.

**Survey 1: Open ended questions**

**What challenges did you have when you were performing this exercise?**

“Just the initial ‘getting familiar’ with the program. There were certain instances we did not know what to do and that weren’t addressed in the user guide…”

**What did you like about the SIPS activity in the ICon Lab?**

“Cool environment. Liked interacting to my group + computer. Model helped us to convey ideas”

**What additional items would you like to see included in the model or the SIPS exercise?**

“Erecting more than one floor”

“More parts of the schedule…”

**Please provide any feedback regarding the user interface design for this application.**

“Simple and effective. There are some kinks but overall it is very good.”

**Please provide any additional comments.**

“Good learning tool.”
**Survey 2: Open ended question**

**Additional comments about the presentation and in class discussions?**

“The process of this assignment worked really well. Learning something about the building sequence, doing it ourselves, discussing it as a class, and then seeing the real solution. I felt as if I can understand every reason why the sequence was that way and what made it better.”

**6.2.2 Focus Group**

The focus group discussion consisted of 5 participants apart from the moderator and the researcher. It lasted approximately 45 minutes and produced good feedback on the application, the assignment, and suggestions for future research.

**6.2.2.1 Application**

The focus group participants were of the opinion that the VCS 2 application was good for presentation purposes and helped students visualize the construction process. They suggested several interface and navigational improvements to the application including:

- Better usage of colors in the model for easier viewing,
- An undo button with infinite undos possible,
- A more familiar MS Windows like interface,
- A selection tree for easier item selection,
- A hide/show object panel, and
6.2.2.2 4D Modeling Assignment

During the focus group discussion, the participants mentioned that while performing the 4D modeling exercise they were not sure if this was a SIPS exercise. They had problems determining activity durations and sometimes weren’t clear on how detailed the 4D model needed to be. They felt clearer instructions and additional information should have been provided for the assignment. They also suggested that the SIPS process would have been more apparent had they performed 4D modeling for two floors instead of one. The participants also recommended providing greater detail in the 3D model and possibly including additional items for the 4D modeling exercise like doors and windows.

6.2.2.3 Future Research

The focus group participants were asked if they would like a real-time feedback system on how they were doing in the 4D modeling exercise. They felt that the way the whole assignment was carried out was better, i.e., performing the 4D modeling exercise without a real-time feedback system and then having to present their solution to be critiqued by the class. They felt that their understanding of the schedule for this project was enhanced by the class discussion and by the instructor’s description of the actual project details.

6.2.3 Video Analysis

The list of items which should ideally have been discussed by each group during the 4D modeling exercise is shown in Table 2. This table contains two columns titled VCS 2 and
VCS 1 which represent the number of times the item was rated either 1 or 2, i.e., it was either mentioned or discussed during the whole content analysis, divided by the total number of videos of that version of the VCS. This number which is obtained on division is the mean number of times a rating of 1 or 2 was given to that item in one video. There were 10 videos in which groups used VCS 2 and 4 videos from 2006 in which groups used VCS 1.

The fourth column shows the difference between the means for each item between VCS 2 and VCS 1 (VCS 2 subtracted by VCS 1). Blue indicates that when students were using VCS 2 they tended to discuss that item more than when students were using VCS 1. Red indicates that groups using VCS 1 had more discussion on that item than groups using VCS 2. It is important to keep in mind that these comparisons are made between groups from two years and that the number of samples of VCS 2 and VCS 1 videos are different.

The table indicates that generally VCS 1 generated more comprehensive discussions than VCS 2. It is also important to consider at what point during the semester these experiments were held. VCS 2 experiments were held in the first 2 weeks of November while VCS 1 experiments were held in October. This could have contributed towards students wanting to spend less time in the ICon Lab for the VCS 2 sessions. The average time spent by groups in the ICon Lab for this experiment in 2006 was three hours while in 2007 this average time spent was less than two hours.
Table 2: Results of Video Content Analysis

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>VCS 2</th>
<th>VCS 1</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was crane movement considered?</td>
<td>0.30</td>
<td>0.25</td>
<td>0.05</td>
</tr>
<tr>
<td>Was change of crane attachment considered?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Were crane cycle times considered?</td>
<td>0.50</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Was Crane Size and reach considered?</td>
<td>0.10</td>
<td>0.25</td>
<td>-0.15</td>
</tr>
<tr>
<td>Was the change of crane cycle times with increasing elevation considered?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was interference with other cranes considered?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was the presence of the crane on the core considered?</td>
<td>0.10</td>
<td>0.25</td>
<td>-0.15</td>
</tr>
<tr>
<td>Was worker distribution discussed/How many people per activity?</td>
<td>0.20</td>
<td>0.75</td>
<td>-0.55</td>
</tr>
<tr>
<td>Were crew shifts considered?</td>
<td>0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>What kind of workweek?</td>
<td>0.10</td>
<td>1.00</td>
<td>-0.90</td>
</tr>
<tr>
<td>Was the staging location of precast elements discussed?</td>
<td>0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Was the transportation of grout to the floor discussed?</td>
<td>0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Was there discussion on how the steel beams are being set into position?</td>
<td>0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Were element connections discussed?</td>
<td>0.40</td>
<td>0.00</td>
<td>0.40</td>
</tr>
<tr>
<td>Did the group discuss breaking the model into construction zones?</td>
<td>0.80</td>
<td>1.00</td>
<td>-0.20</td>
</tr>
<tr>
<td>Did the group consider performing more than one construction activity at once?</td>
<td>0.70</td>
<td>1.00</td>
<td>-0.30</td>
</tr>
<tr>
<td>Was equipment access to the floor considered?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was worker access to the floor considered?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Discussion on the construction flow. From core to outer edge or outer edge to core?</td>
<td>0.80</td>
<td>1.00</td>
<td>-0.20</td>
</tr>
<tr>
<td>Was the order of activities discussed?</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Were temporary supports discussed?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was there any discussion on grouting from in or out?</td>
<td>0.00</td>
<td>0.25</td>
<td>-0.25</td>
</tr>
<tr>
<td>Discussion on the activity durations?</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cure Time for grout/concrete pour considered?</td>
<td>0.00</td>
<td>0.25</td>
<td>-0.25</td>
</tr>
<tr>
<td>Did the group discuss the effect of overnight work stoppages?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was learning curve discussed?</td>
<td>0.20</td>
<td>0.50</td>
<td>-0.30</td>
</tr>
<tr>
<td>Did the group discuss the effect of decimal floor cycles on the project?</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Was construction efficiency considered?</td>
<td>0.00</td>
<td>0.25</td>
<td>-0.25</td>
</tr>
</tbody>
</table>
6.3 Summary

This chapter first presented details about the various evaluation procedures for judging the value of the VCS 2 application as an educational aid. The case study exercise consisted of an experiment in which student groups from a project management course were asked to create a 4D model for a single floor on a wing of the MGM Grand Hotel using the VCS 2 application in the Immersive Construction (ICon) Lab. The lab set up and logistics have been described. Each of these group sessions were audio and video recorded for subsequent review. Survey questionnaires were used to get perception based data about the VCS 2, 3D visualization, and 4D modeling. One of these surveys was conducted after each group’s 4D modeling session in the ICon Lab. The second survey was conducted after the solution review and discussion class.

A focus group discussion was held after the solution review and discussion class to obtain detailed student feedback on the advantages and disadvantages of the application and the assignment. This feedback would be used for improving the VCS 2 application and the MGM Grand Hotel case study assignment.

The videos from the ICon Lab experiment of both years, 2006 and 2007, were analyzed for determining the comprehensiveness of discussion. A discussion content list was created containing items which the student groups should have discussed during the 4D modeling exercise. A 3 point rating system was also developed to judge the depth of discussion on those items. Stability and inter-rater tests were conducted to ensure reproducibility of content analysis results. Thereafter, 10 videos from 2007 and 4 videos from 2006 for the same exercise using VCS 2 and VCS 1 respectively were analyzed.
In the second part of the chapter, results from the surveys, video analysis, and focus group discussions are presented. The surveys indicate that students perceive 3D visualization and 4D modeling to be very valuable for presentation and communication purposes. The VCS 2 was seen to have a reasonable degree of ‘ease of use’ and ‘logical and smooth interface’.

The test for comprehensiveness of discussion indicated that in general student groups did not always engage in detailed discussions on the various relevant items for CPM schedule and 4D model creation. The test indicated that discussions during VCS 1 group sessions were slightly more detailed than discussions during VCS 2 group sessions for some categories although this could be because of a lesser number of available videos for VCS 1, and could be impacted by differences in student groups and by assignment timing.

In the focus group meeting students mentioned that the application was good for presentation and visualization of ideas. A number of items for improvement of the VCS 2 feature set and interface were suggested.
In this chapter, first a summary of the research is presented. This is followed by a description of the contributions and limitations of this research. Then, a few suggestions for future research in this area are provided. In the end, concluding remarks are presented.

7.1 Research Summary

This research builds upon the work done by Wang et al. (2007) in the area of 4D CAD utilization for construction engineering education. The Virtual Construction Simulator (VCS) was a 4D modeling application prototype developed by Wang et al. (2007). The VCS was built on the concept that instead of traditional 4D CAD applications requiring the separate creation of a CPM schedule in a scheduling application, it is easier to create a 4D model in a 3D visualization environment by associating activities and relationships with 3D model objects in the 3D environment. The VCS 1 was a valuable application but suffered from several limitations (Wang et al., 2007).

VCS 2 was created forming the main crux of this research effort. This VCS 2 application was developed using an open-source rendering engine called Irrlicht and using C++ programming. A case study exercise using the VCS 2 application and the MGM Grand Hotel 3D model was carried out in a project management course with student groups being required to create 4D models for a single floor on one wing of the hotel. Perception surveys, focus group discussions and discussion analysis of recorded
student group sessions were used to judge the value of the VCS 2 application, 3D model visualization, and 4D modeling for schedule creation and review. The results of the surveys when compared to those obtained in the same class the previous year using the VCS 1 and traditional 4D modeling application for the 4D modeling experiment showed that VCS 2 received higher scores than the traditional 4D modeling application but slightly lower scores than VCS 1. 4D modeling and 3D visualization were seen to be valuable for schedule creation and review. The comprehensiveness of discussion analysis indicated that student groups, in general, did not discuss all of the items which should have been taken into consideration during the 4D modeling process. This analysis also showed that student groups using VCS 1 had slightly more detailed discussions than those using VCS 2.

The VCS 2 was seen to be reasonably easy to use and the interface was seen to be logical and smooth. The value of the VCS 2 lies in the expandability it offers for creating additional 4D modeling simulations without requiring reprogramming of the VCS 2 application. A comparison of assignment grades also indicated that the student groups using VCS 2 performed better than the student groups using VCS 1 and traditional 4D CAD modeling software. This allows for teaching scheduling using several case studies and would thus prove beneficial in construction engineering education.

7.2 Research Contribution

The contributions of this research are described below:
7.2.1 Improved VCS Features and Interface

This research effort has produced a VCS 2 application which has the following improvements over the VCS 1 application:

1. The application is open-source and new features can be added with some C++ programming effort.
2. As there is no 3D model specific coding, it is easier to create additional 4D modeling simulations for different case studies.
3. The VCS 2 application can not only create a 4D model but it also generates a schedule in an XML format.
4. The application has an expanded feature set and an efficient interface.

The research also identified further improvements which could be made to the VCS 2 application and the MGM Grand Hotel case study assignment.

7.2.2 Value of 3D Visualization and 4D Models as Schedule Generation and Review Tools

The results of the perception based surveys and focus group discussions show that immersive 3D visualization and 4D models are valuable communication tools for schedule generation and schedule review. 4D models can help identify problematic issues in a CPM schedule and also help in visually presenting a schedule.
7.2.3 Guidelines for Developing Future 4D Modeling Simulations

A set of technical and educational guidelines have been developed for creating future 4D modeling simulations using the VCS 2 as the 4D modeling application. These guidelines provide valuable recommendations which will prove useful for developing new case study simulations.

7.2.4 Identification of Items for Comprehensive Discussion on Schedule Creation

The discussion content list presented in Table 2 contains items which should be discussed during the creation of a 4D model or a schedule for the case study. This list contains many items which are independent of the case study used. This discussion content list could be used for scheduling assignments to promote more in depth discussions and to ensure that students consider these items while creating schedules or 4D models. A course instructor can also use this discussion content list for creating course content that would cover these discussion items.

7.2.5 Dissemination of 4D Modeling Educational Application

The VCS 2 has been made freely available on a wiki developed by the Computer Integrated Construction (CIC) Research Group at Penn State. The setup files can be downloaded and the VCS 2 installed on any Microsoft Windows based system.

(http://bim.wikispaces.com/Virtual+Construction+Simulator)
7.3 Limitations

The limitations of this research are described below:

7.3.1 VCS 2 Limitations

The VCS 2 application still has limitations which can impede the process of creating a 4D model. These are:

1. The pre-set camera viewpoints are model specific along with the hide/show objects menu. This is not a major hindrance in using another 3D model for a 4D modeling case study exercise but it makes the task more difficult.

2. The VCS 2 interface is not as professional looking as commercial applications for 4D CAD modeling. The use of better skins, fonts and backgrounds along with modifying the application interface to require fewer mouse clicks would improve the application’s interface.

3. The inability to set clip planes can make it difficult to sequence out activities like installation of mechanical components, erecting interior walls, pouring or erecting slabs, etc.

7.3.2 Limited Case Study Application

This research only utilized the MGM Grand Hotel case study for data collection. The use of larger and more complex case studies could reveal a greater difference in the value of VCS 2 and traditional 4D CAD modeling applications for schedule generation and review purposes. The use of more case studies would also show if the VCS 2 is better suited for larger and complex scheduling needs, or for smaller and simpler scheduling needs.
7.4 Future Research

The results and conclusions of this research were used to develop the following suggestions for future research in the use of simulations in construction engineering education:

7.4.1 VCS 2 Improvements

The first tasks which can be performed to continue this research is to improve the VCS 2 in relation to the limitations mentioned in section 7.3.1. Additional improvements can also be made to the VCS 2 application to make the process of simulation creation and 4D modeling using the VCS, simpler and more efficient. These suggested improvements are mentioned below:

1. Navigation: The 3D environment navigation is not the same as other commercially available 3D model visualization and 4D CAD modeling applications. The use of standard mouse button functions in other applications can be replicated in the VCS 2 with some programming effort.

2. Stereoscopic view: The availability of stereoscopic viewing in the VCS 2 along with the large display system would allow students to get more immersed into the 3D environment.

3. Complete 3D model independence: For using another 3D model with the VCS 2 application in the same manner that the MGM Grand Hotel model was used, some programming effort would be required to change the preset viewpoints and hide/show objects menu. The C++ code can be
modified to ensure that any 3D model can be brought into the VCS 2 without requiring additional programming each time.

4. The VCS 2 interface can also be improved by reducing the number of mouse clicks required to create 4D models and by using better skins, fonts and backgrounds.

7.4.2 Serious Game for Scheduling

The VCS 2 application could be used as a foundation to develop a serious game for CPM scheduling and 4D modeling. The concept of the game would be that while students are creating a 4D model in the VCS 2 application environment, they would receive real-time feedback on their 4D model. Based on what the best schedule would be for a given set of conditions and constraints, the students would receive numerical or alphabetical ratings on the quality of their schedule. This would remove the need for students to have an instructor view their 4D model to give them feedback on what were the advantages and disadvantages of their schedule. Such a serious game would not only require a substantial programming effort but also an experienced scheduler to include the if-then triggers in the application. This kind of serious game could be made available on the internet for free distribution and would allow users to gain a better understanding of scheduling without the need to learn from an expert scheduler directly.

7.4.3 Value of the Display System in the Scheduling Exercise

Future research could also analyze the effect of display systems during schedule creation and review. Research can be done to determine if a 3-screen large display system adds
any value to the process of schedule creation and review when compared to a desktop monitor display. Students did indicate that 3D visualization is valuable but further research needs to be done to determine if the size of the display system affects the schedule creation and review process.

7.4.4 Additional Case Study Applications

The use of VCS 2 with other case study 3D models could provide valuable insight into the effect of model size and complexity on the creation of 4D models using VCS 2. A comparison with traditional 4D CAD modeling applications can also be made for these additional case studies to see if the VCS 2 application is better than these commercial applications for 4D modeling.

7.5 Concluding Remarks

The use of simulations for construction engineering education can provide course instructors with the opportunity to teach students with varied and practical experiences on certain construction concepts. Students get the opportunity to create solutions for real project problems and can thus gain a better understanding of the underlying concepts. Scheduling and 4D modeling form an area in which the opportunity to use simulations is apparent. The ability to visualize the construction sequence is easily done using 4D models and computer based simulations offer students the ability to develop a solution, analyze and visualize the solution, and modify it accordingly. The use of simulations for
teaching other construction engineering concepts like safety, site management, and planning etc. could also benefit from this type of investigation.
Bibliography


<http://accvision.ibsystems.com>


visualization in optimizing construction site facility layout." *Distributing Knowledge In Building, CIB W78 International Conference.*, Aarhus, Denmark.


APPENDIX A (Survey 1)

AE473 SIPS Exercise Survey

Team #: ______ Name: __________________________

This survey is conducted for the sole purpose of research and the data collected will be kept confidential. Please give your comments and provide your responses on a scale of 1-5 (1- strongly disagree and 5- strongly agree). Thank you for your time and cooperation!

BACKGROUND INFORMATION

Sex: Male/Female 
Age: _____

1. What is your Academic Standing? (Check Appropriate Box)

<table>
<thead>
<tr>
<th>4th Year</th>
<th>5th Year</th>
<th>Graduate</th>
<th>Other (Please Describe below)</th>
</tr>
</thead>
</table>

2. I am comfortable with using a computer for viewing 3D models.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

3. I am comfortable using a computer for creating 3D models.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

4. I have experience with navigating in a 3D environment.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

PROJECT QUESTIONS

5. It was valuable to have a large scale 3D model when developing our schedule.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>
6. The 3D model was adequately detailed to perform this exercise.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

7. Our group adequately utilized the 3D model when developing our schedule.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

8. The 3D model helped me in generating ideas and evaluating other people’s ideas.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

9. The 3D model provided a common media to keep the whole group focused throughout the process of developing the schedule.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

10. I felt confident in the initial schedule that we developed before reviewing the 4D model in the ICon Lab.

    | 1 | 2 | 3 | 4 | 5 |
    |---|---|---|---|---|
    | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |

11. The 4D model in the ICon Lab was helpful for examining the schedule we developed.

    | 1 | 2 | 3 | 4 | 5 |
    |---|---|---|---|---|
    | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
12. I felt more confident in our schedule after reviewing the 4D model.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

13. The 4D modeling activity helped me gain a better understanding of the SIPS process.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

14. I enjoyed performing the exercise in the ICon Lab.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

15. The application interface was easy to use.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

16. The application interface was logical and smooth.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

17. What challenges did you have when you were performing this exercise?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

101
18. What did you like about the SIPS activity in the ICon Lab?
_______________________________________
_______________________________________
_______________________________________
_______________________________________
_______________________________________
_______________________________________
19. What additional items would you like to see included in the model or the SIPS exercise?
_______________________________________
_______________________________________
_______________________________________
_______________________________________
_______________________________________
_______________________________________
20. Please provide any feedback regarding the user interface design for this application.
_______________________________________
_______________________________________
_______________________________________
_______________________________________
_______________________________________
21. Please provide any additional comments.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Would you be willing to participate in a Focus Group meeting to discuss future research in this area?

Yes / No

If Yes, please provide your email address: ____________________________
APPENDIX B (Survey 2)

Team #:_____   Name ________________

This survey is conducted for the sole purpose of research and the data collected will be kept confidential. Please give your comments and provide your responses on a scale of 1-5 (1-strongly disagree and 5-strongly agree). Thank you for your time and cooperation!

1. The 4D model made it easier for us to present our group’s solution to other students in the class.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

2. The 4D model made it easier for me to understand other groups’ solutions.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

3. The 4D model made it easier for me to understand the SIPS planning issues discussed in class.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

4. The 4D model made it easier for me to communicate with my team members when we worked on the assignment.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

5. Additional comments about the presentations and in class discussions?

__________________________________________________________________________________________

__________________________________________________________________________________________
APPENDIX C

Detailed results for survey questions. Percentage of total respondents for each rating.

Q2. I am comfortable in using a Computer for viewing 3D models.

Survey 1 - Q2

Q3. I am comfortable using a Computer for creating 3D models.

Survey 1 - Q3
Q4. I have experience of navigating in a 3D environment.

Q5. It was valuable to have a large scale 3D model when developing our schedule.
Q6. The 3D model was adequately detailed to perform this exercise.

![Survey 1 - Q6](image)

Q7. Our group adequately utilized the 3D model when developing our schedule.

![Survey 1 - Q7](image)
Q8. The 3D model helped me in generating ideas and evaluating other people’s ideas.

Q9. The 3D model provided a common media to keep the whole group focused throughout the process of developing the schedule.
Q10. I felt confident in the initial schedule that we developed before reviewing the 4D model in the ICon Lab.

![Survey 1 - Q10](image)

Q11. The 4D model in the ICon Lab was helpful for examining the schedule we developed.

![Survey 1 - Q11](image)
Q12. I felt more confident in our schedule after reviewing the 4D model.

Q13. The 4D modeling activity helped me gain a better understanding of the SIPS process.
Q14. I enjoyed performing the exercise in the ICon Lab.

Q15. The application interface was easy to use.
Q16. The application interface was logical and smooth.
Survey 2 had 23 responses.

Q1. The 4D model made it easier for us to present our group’s solution to other students in the class.

Q2. The 4D model made it easier for me to understand other groups’ solutions.
Q3. The 4D model made it easier for me to understand the SIPS planning issues discussed in class.

Q4. The 4D model made it easier for me to communicate with my team members when we worked on the assignment.
## Survey 1 Results (means)

<table>
<thead>
<tr>
<th>Survey Questions</th>
<th>VCS 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am comfortable in using a Computer for viewing 3D models.</td>
<td>4.24</td>
</tr>
<tr>
<td>I am comfortable using a Computer for creating 3D models.</td>
<td>3.85</td>
</tr>
<tr>
<td>I have experience of navigating in a 3D environment.</td>
<td>3.82</td>
</tr>
<tr>
<td>It was valuable to have a large scale 3D model when developing our schedule.</td>
<td>4.18</td>
</tr>
<tr>
<td>The 3D model was adequately detailed to perform this exercise.</td>
<td>3.65</td>
</tr>
<tr>
<td>Our group adequately utilized the 3D model when developing our schedule.</td>
<td>4.06</td>
</tr>
<tr>
<td>The 3D model helped me in generating ideas and evaluating other people’s ideas.</td>
<td>4.09</td>
</tr>
<tr>
<td>The 3D model provided a common media to keep the whole group focused throughout the process of developing the schedule.</td>
<td>4.15</td>
</tr>
<tr>
<td>I felt confident in the initial schedule that we developed before reviewing the 4D model in the ICon Lab.</td>
<td>3.47</td>
</tr>
<tr>
<td>The 4D model in the ICon Lab was helpful for examining the schedule we developed.</td>
<td>4.26</td>
</tr>
<tr>
<td>I felt more confident in our schedule after reviewing the 4D model.</td>
<td>4.21</td>
</tr>
<tr>
<td>The 4D modeling activity helped me gain a better understanding of the SIPS process.</td>
<td>3.53</td>
</tr>
</tbody>
</table>
I enjoyed performing the exercise in the ICon Lab. & 3.88 \\
The application interface was easy to use. & 3.41 \\
The application interface was logical and smooth. & 3.40 \\

**Survey 2 Results (means)**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>The 4D model made it easier for us to present our group’s solution to other students in the class.</td>
<td>4.17</td>
</tr>
<tr>
<td>The 4D model made it easier for me to understand other groups’ solutions.</td>
<td>4.52</td>
</tr>
<tr>
<td>The 4D model made it easier for me to understand the SIPS planning issues discussed in class.</td>
<td>3.96</td>
</tr>
<tr>
<td>The 4D model made it easier for me to communicate with my team members when we worked on the assignment.</td>
<td>4.00</td>
</tr>
</tbody>
</table>
APPENDIX D

Virtual Construction Simulator: USER’S GUIDE

The model provided represents one floor cycle but it may not correspond directly to the sequence of a floor cycle listed in the assignment.

Mouse Operations:

Left Click: To click on buttons; select boxes; select list items.

Right Click: Select 3D model objects.

Left Click and Hold while moving the mouse: Move sideways or up-down.

Right Click and Hold while moving the mouse: Rotate the model.

Press and hold scroll wheel while moving mouse sideways: Zoom In & Zoom Out

Pre-created viewpoints should aid in navigation around the model.

Keyboard Operations:

Use Keyboard to enter information into boxes. Press the Escape key (Esc) to return to the Main Menu at any time.

Grouping: (Important)

It is recommended that you use the Hide/Show function in the main toolbar while creating or modifying groups. This will ensure that you will not have to add/remove objects added or removed accidentally to the group which can be frustrating for users.

File Saving and Loading:

Save your work often. A folder for each group will be created and 5 XML files for saving purposes will be created for each group. This should enable you to load your work from various stages in the rare case that the application crashes. Use the File->Save and File->Load options from the menu to do this.

You will have to delete the relationships an activity is in before you can delete that activity and you will have to delete the activities before modifying any groups attached to those activities.

Activity Durations

Use the main toolbar at the top of the screen to change activity durations by going to “Activities->Change Duration” in the top toolbar. All durations have to be in minutes.
APPENDIX E

SIPS for MGM Grand Hotel Site

AE 473 – Assignment 2

PURPOSE: To learn the Short Interval Production Scheduling (SIPS) method for performing a detailed construction plan for a repetitious construction activity and determine the best applications for the SIPS planning method.

BACKGROUND:

The MGM Grand Hotel is a construction project constructed in Las Vegas, Nevada. When the hotel was completed in 1994, it was the largest hotel in the world. The hotel has over 5,000 guest rooms, a casino, 33 acre amusement park and a 5,500 car parking garage. The project cost was over $1 billion and the project schedule for the structure of the hotel building was around 9 months. This assignment will focus on the construction of the structural system for the hotel building.

The MGM Hotel structure is composed of primarily precast concrete elements with some steel and grouted connections. The design contains only three different types of precast members. These members are:

- Ductile frame members which serve as exterior walls and structural system members
- Interior wall members which act as supports for the floor members and as shear walls
- Floor members (slabs)
All of these members are cast at a location which is a 30 minute drive from the site.

**Construction Constraints:**

The hotel structure must be constructed in 9 months (40 weeks) for the owner to meet their requirements. The excavation and foundations will take 8 weeks. The first four floors are cast-in-place concrete and will take another 8 weeks. Allow 1 extra week for the fifth floor and 1 extra week for topping out due to inefficiencies with the first and last sequences. Assume that the core construction can stay ahead of the construction of the hotel wings. The hotel is a total of 30 floors (4 floors of cast-in-place and 26 floors of precast).

Construction quantities per precast floor per wing:

- 27 ductile frames (8' tall x 28' long) with 8 splice connections per frame
- 108 floor members (8' wide x 28' long with a 4" x 8" wedge joint on each side and the end which is filled with grout)
- 22 interior wall members (8' tall x 33' long x 8" thick) with 9 splice connections per wall
- 11 steel beams to connect the interior wall members over the interior corridor
- 28 ductile frame connections (8' x 2.5' x 8" cast-in-place joint)
Construction equipment and manpower availability:

- 160 ton crane for each wing plus a 160 ton crane for the core of the building.
- 20 workers per wing

Physically, the sequence of a floor cycle is as follows:

- Erect interior walls and brace to slabs (with 4 braces)
- Align walls and grout splice connections
- Erect Beams to connect interior walls
- Erect floor slab planks
- Erect ductile frames and brace to slab (with 2 braces per frame)
- Grout joints between floor slabs
- Frame and cast joints between ductile frame members

Assume that the crane hoist time per piece can fit your schedule.

Tasks:

Prior to Your ICon Lab Session:

1. Identify the different construction zones in the building. These areas should be distinct by construction techniques and physical location, e.g., foundation or core.
2. Determine the amount of time that you have to perform the construction of a typical wing of a typical precast concrete floor. Make sure you know this prior to your ICon Lab session.

During Your ICon Lab Session:

3. Determine the different activities which must be completed for one floor of a typical hotel wing. Determine quantities for each activity.

4. Develop the sequence for construction for the different activities so that they can be complete within your time constraint. You will use the applications in the ICon Lab to develop this sequence. At the end of the ICon Lab session, you will have a 4D CAD model of your SIPS.

After Your ICon Lab Session:

5. Review the 4D CAD model that you developed in the ICon Lab session. Make sure that the activities are sequenced and balanced. Post your final sequence file (the xml file) to the dropbox on Angel with your group number clearly marked as the file name.

6. Develop a graphical presentation of your short interval production schedule (SIPS) for a typical hotel wing in Gantt chart format. This schedule should clearly show activity sequences and durations. It should be performed for a
typical floor sequence. The chart should also shows the activities of each crew
during this floor sequence on a daily basis.

7. Develop a 10 – 30 activity schedule for the entire building by combining the
   schedules for each construction zone. Avoid excessive detail by combining
   activities. For example, you can combine multiple floors into a single activity.

8. Discuss the effects of the learning curve and unforeseen project delays on the use
   of the SIPS method.

9. Discuss the best applications of the SIPS planning method for building
   construction projects. Provide several project examples that would benefit from
   the use of the SIPS method.

10. Discuss the different project participants that you would request to review the
    SIPS and how you would present the SIPS to them.