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Virtual Interactive Construction Education (VICE) using BIM Tools

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ABSTRACT: Training and process analysis in the construction industry has not taken full advantage of new technologies such as building information modeling(BIM). The purpose of this research is to develop a framework for the virtual interactive construction education system using three dimensional technologies. The modules will simulate the construction process for a facility from start to finish using information drawn from real projects in the built environment. These modules can be used as training tools for new employees where they attempt to optimize time and cost in a virtual environment given a limited number of equipment, time and employee options. They can also be used as a process analysis tool for new construction where a number of situational variables can change leading to exposure of potential risk. These modules would be particularly useful for repetitive construction where the initial project is analyzed for optimization and risk mitigation. This paper describes the framework and shows a residential construction example using a 900 square foot wood frame single family house designed for the United States.

Keywords: *virtual simulation, games, construction education, training*,
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1. INTRODUCTION

Simulation-based learning modules address the fundamental need to reinvigorate instructional methods and approaches in engineering education, which have changed little in over a century. The expectation is that students need to adapt to traditional delivery methods instead of delivery adapting to the students. This problem is particularly acute with Generation Y students, the so-called "Internet generation," and succeeding generations. Gen Ys frequently play online games for socializing and entertainment (Microsoft 2008). Students will stay up all night with an exciting video game but have difficulty maintaining enthusiasm for some traditional learning methods. Simulation-based learning tools are increasingly being used in the classroom to engage and motivate students, and assist in recruitment of students to meet the demand for qualified personnel in technology-related fields such as information technology (IT), architecture, engineering and construction (Menzel 2005).

Simulation-based learning has been under development for some time. Hornibrook (1996) converted a rudimentary construction education simulation into a computer format. More recently Fuentes (2007) developed a multilevel web-based simulation for students to learn undergraduate Mechanics of Materials. Kolodner et al. (2005) used a computer-based teaching system with case libraries for design and construction education. The University of Washington has developed a framework for situational simulation of construction management process in an interactive environment to train construction managers (Mukherhee 2004). These learning examples are rudimentary when compared with the advancements in visualization software interfaces. Many prove that simulation-based learning is more effective than traditional approaches but have not taken it to the level with the breadth or scope suggested in this paper. In particular, this project will significantly extend these works by leveraging the extensive expertise of the information science experts in the area of formal methods. Recent developments in formal methods is used to automatically analyze failures and to generate visual repair scenarios. Such automated methods can play a crucial role in making learning effective in a simulation setting.

This paper introduces the virtual interactive construction education (VICE) system which is an on-going research project at the University of Nebraska. The framework for the VICE system and the software user interface using 3D technologies are described.

2. RESEARCH APPROACHES

2.1 Define Decisions, Constraints, Options, Rules

This research defines the construction project in terms of decisions, constraints, options and rules as they relate to methods, equipment, personnel, materials, cost, schedule and safety. This task is the foundation for the project in that the information drives every other aspect of the project.

Figure 1 shows the stream of decisions associated with construction of a house. The first decision is to develop a work break down structure (WBS) of tasks organized into a logical sequence with interrelationships, as shown in column 1. For example, the game will not allow the roof to be installed prior to the basements but may allow the basement prior to underground utilities. The former is an impossible situation, whereas the latter is possible at a significant increase in cost. The foundation phase is used as an example for further sequencing of sub-tasks as shown in column 2. One sub-task, excavation of the foundation, is further expanded to include equipment and crew selection as shown in column 3. Each decision affects cost, quality and schedule.

In the prototype, one must decide on the equipment, personnel and sequence of excavating. For example, selecting an excavation crew with an operator, 3 laborers, and an excavator increases the project's cost. The optimal configuration is an operator and an excavator. The simulation will restrict some decisions to available options within the program. For example, three equipment choices are provided in the table for excavation, whereas in reality there are dozens of options. Players will have the option of hiring a consultant to explain why a decision was not optimal. This will increase the cost of the project but enhance learning each time the simulation is run. Figure 2 shows a series of scenes from the simulation showing the foundation installation

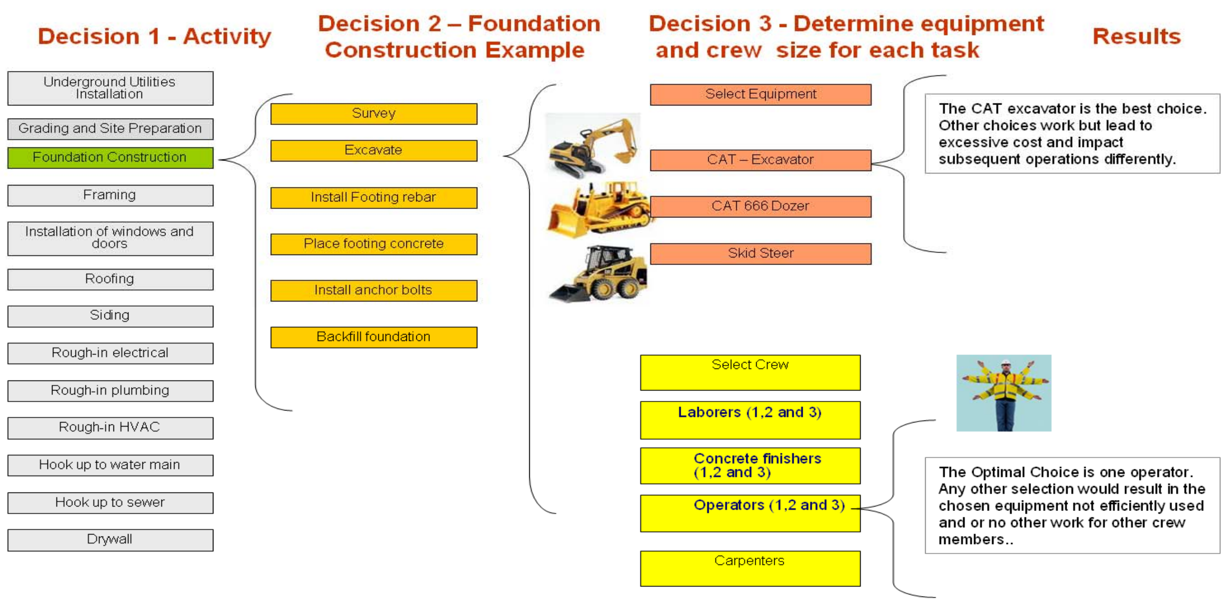
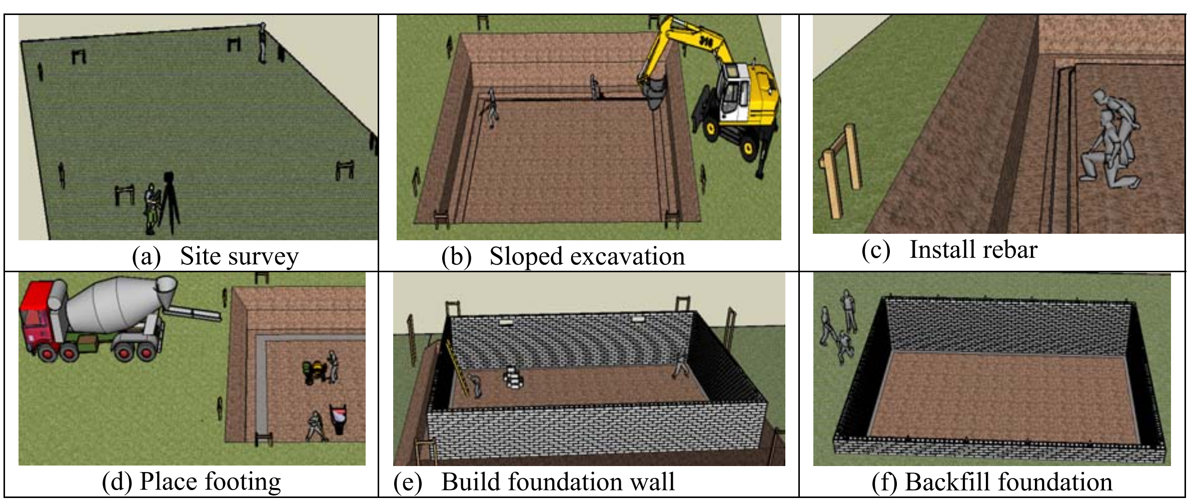


Figure 1. Example Module Decision Development



(a) Site survey (b) Sloped excavation (c) Install rebar
(d) Place footing (e) Build foundation wall (f) Backfill foundation

Figure 2. Simulated foundation construction module for residential house

2.2 Smart Object Representation and Codified Domain Expertise

The Smart object representation (SOR) tool defines each model object within an ontology, which is a data model that represents a set of related objects, their relationships and preference rules. Users can specify temporal order relations (e.g., for job scheduling), quantitative relations (e.g., for composition), membership relation (e.g., for a hierarchical taxonomy), and so on.

Ontologies are a form of knowledge representation used in artificial intelligence (AI), semantic web and software engineering. They can be used for reasoning about the objects, model consistency checking, runtime help message display, and optimization in our construction information system. Preferences are popularly used in AI for a decision making system, to either make a selection or resolve an ambiguous situation. Preferences in the SOR tool can be used to show the user a better alternative to design certain part of a construction model, or check the optimality of the model and how to improve it. An interface is developed in the SOR tool for users to specify certain preference rules in a well-defined syntax and semantics (Guo 2007). Conditional and parametric preference rules are defined in a flexible and declarative way, so that each preference rule can be applied to a class of construction cases.

2.3 Simulation to a Visual Interface

Rendering the simulation is achieved by capturing the domain knowledge required to achieve each task as a collection of construction recipes. This research uses logical frameworks based on first-order logic to codify these recipes. Each recipe defines a sequence of timed moves that a player can make to take the game to a successful end configuration. For each move, the pre-conditions for performing the move, time required to complete the move, the effects of the move on each simulation object on successful completion, and its cost, are all codified. Each time the simulation is run, users successively conduct moves to reach an end configuration with a particular score computed based on the cost of the moves. Each step in the simulation requires the pre-conditions of a chosen move to be checked and its effects analyzed to avoid inconsistent configurations. These tasks are automated using reasoning tools such as the Rewrite Rule Laboratory (RRL) (Kapur and Subramaniam 2000).

Rendering the simulation is dynamically determined based on configuration parameters, e.g. degree of difficulty, to better address the instructional component (Rojas 2006). Training modes at a lower difficulty level use high situational awareness, which means that moves whose pre-conditions are met will only be presented at each step and players will be forewarned of impending failures upon execution of a move. Counter-examples are codified to illustrate failures (Subramaniam et al. 2006) and visual repair strategies (akin to lifelines in games) to patch up failure-inducing moves (Subramaniam et al. 2007).

2.4 Encapsulated Domain Expertise

Domain knowledge is codified as facts using first-order logic rules with domain expert supplied explanation tags. Facts matching similar situations are grouped into fact modules. Activities and constraints for the fact modules matching a situation are automatically and dynamically generated and ranked. The effect of each activity on situations is automatically evaluated.

3. VICE SYSTEM DESCRIPTION

The learning modules are model-based simulations that focus on construction of a particular kind of facility, e.g. a single family home. Visual aspects of the gaming objects for a task are modeled using Building Information Modeling (BIM) tools to simulate the design, construction and operation of the built environment. This creates a data-rich, object-oriented, intelligent, and parametric digital representation of the facility that is incorporated into the simulation modules. Graphics are integrated to multimedia Flash to create the prototype's visual interface (Kaye and Castillo, 2006).

The modules simulate engineering decisions relating to construction of a facility from start to finish. In each module, players will attempt to earn status by completing projects drawn from real scenarios in the built environment at an optimal time and price. The main "character" in each module is a contractor who must make a profit on a contract that includes a selling price and a time constraint with penalties. In the prototype module, the contractor builds a small residential house.

The contractor attempts to maximize profits in an optimal time by making appropriate decisions throughout the building process. The decisions are at the building level, such as order of construction, material delivery, and equipment and crew selections that have cost and schedule implications. The game score will be measured in two metrics; 1) time of completion and 2) cost of completion.

3.1 Learning Experience and Evaluations

Each new learning experience is a pre-determined sequence of situations with associated fact modules. The learning experience is configurable to skill levels such as novice, medium or expert. These skill levels are associated with privileges such as the ability to update facts.

The user can choose opponents either from a system for practice or from multi-user/team for tournaments. Practice play allows for single user to learn and improve skills. Tournament play is multi-user team competitions with situational emergencies. Players are awarded bonuses for successfully handling situational emergencies.

Oracle/community lifelines have a highly negative impact on scores, particularly during tournament play.

3.2 Learning Mode Solution Delivery

Learning modes are also selectable and include supervised, reinforced and unsupervised. The supervised mode allows system prompted solutions with user requested replays. Activities and constraints are compiled into user actionable steps to create a replay capsule. This guides the user through actions in the capsule one at a time.

Reinforced mode is supervised learning with barriers in place. Barriers can be crossed only upon successful completion. Barriers are generated by fact module compilation. Auto-replay is available to help cross barriers. These are generated using explanation tags in the fact modules.

Unsupervised has time-bound solutions provided by users that meet application constraints. In this mode, the system is an implicit player. A replay capsule decision tree is created using an optimal fact module. User actions are evaluated at each step against the expected replay capsule action in the decision tree and assigned a score. Actions leading to infeasible completion of the tree are identified and flagged. An action is infeasible if its effects result in a situation where no subsequent action is possible.

3.3 User Interface

The VICE system will include a web-based interactive software system. As an initial effort, this study develops a user interface for a residential house construction module programmed with Adobe Flash CS3 Professional version 9.0 in which preference rules are defined and various multimedia resources are connected as interactive events including sound, images, animation, interactive flash, and 3D PDF. Figure 3 shows the complete residential house built with a BIM tool, Vico software's Constructor™. 3D PDFs and walk-through animations are created from Constructor™ as well. Table 1 demonstrates the functions of VICE program with example activities.

Figure 3. Complete house model for the first prototype game module

The opening screen of the interface is shown in Cell 1 of Table 1where the project is described. A tutorial is available to describe the interface and the various functions that are available as shown in Cell 2. Players are directed to press start to begin the simulation. The first decision the player makes is to select the first activity as shown in Cell 3. Decisions fall into three categories optimal, less than optimal or feasible, and infeasible. Surveying is the correct first choice to begin construction of the single family residential facility. A simulation will shows the process of surveying a house, and the cost and time associated with surveying will be added to the project. The surveying screen in Cell 5 shows an educational attachment embedded. For example, a player can click on the batter boards and get information about that object.

Table 1. Functional Interface Description

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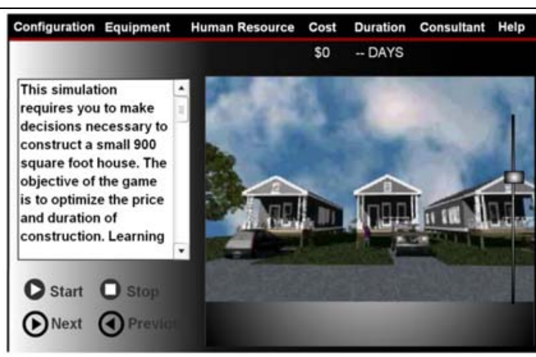
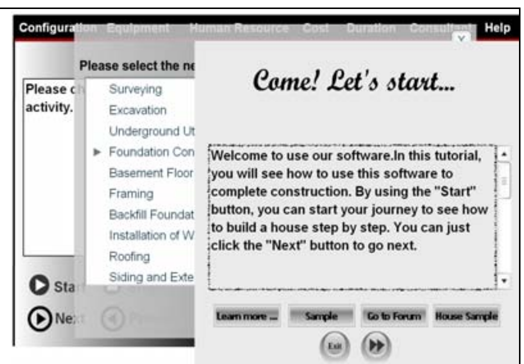
<td>1 

The first screen scene when the VICE program is opened.</td>
<td>2 

When click the 'Start' button, the tutorial starts</td>
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3

Then the player can start a game and select the first activity he/she wants to do.
For example, in the first step, the player selects 'Surveying'

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When the player click 'OK' from the previous activity selection screen, the result will show the cost and duration for surveying with associated 3D scene which is either an animated movie clip or an interactive space for navigation.

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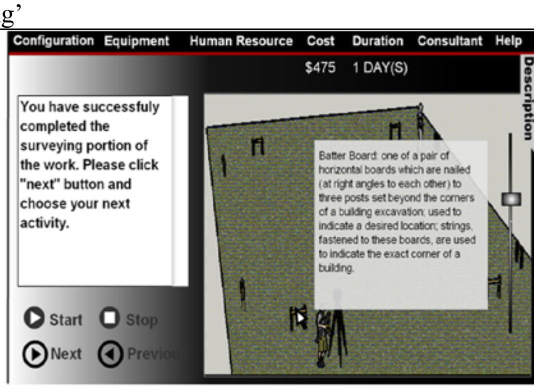

If the player wants to learn more about the surveying, it provides the educational interface.
For example, when the player puts the mouse on the Batter Board in this animation, the player will see the educational interface for the Batter Board. Once one activity is completed, the player can click 'Next' and select the next activity:

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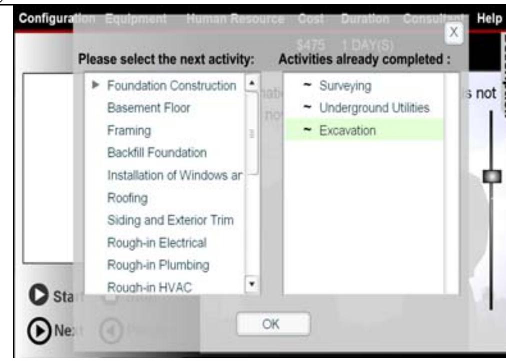

In the next step, if the player chooses 'Underground Utilities,' then 'Excavation,' there would be an additional cost:

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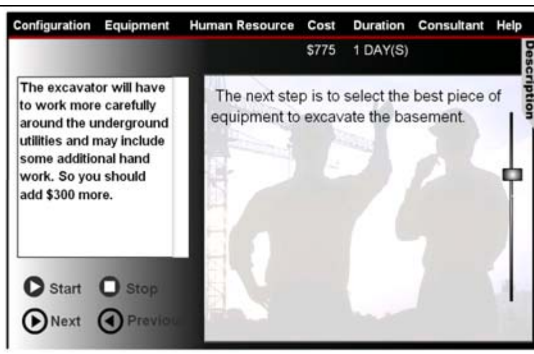

In this example, the player needs to cost $300 more, and the VICE tells the player the reason.

Additionally, the VICE reminds the player that he/she needs to select the equipment for excavation.

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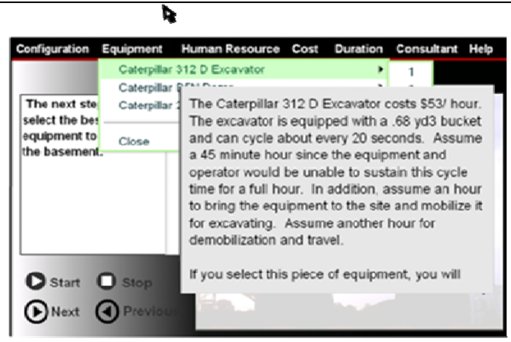

When the player clicks 'Equipment' and selects the best piece of equipment he/she thinks.
When the player puts a mouse on the one piece of equipment, the educational interface appears which helps the player make decision, then the player can also decide how many pieces he/she wants.
In the same way, the operator can be selected from 'Human Resource' menu.

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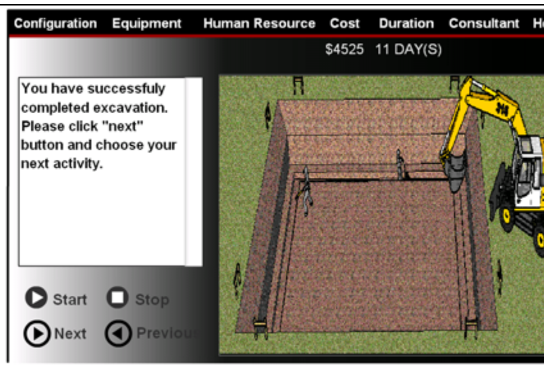

After selecting equipment and personnel, the player can see an interface showing the total cost for such selection:

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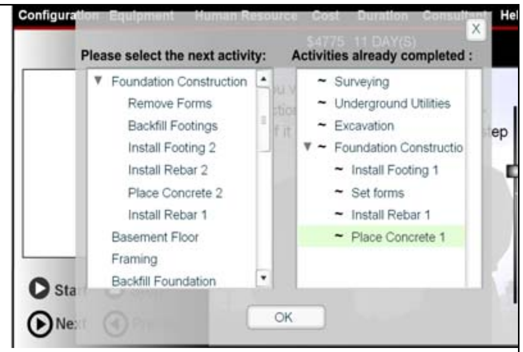

If the selection leads to no solution, the player is required to ask the consultant and go back to do them again. Whenever the player asks consultant by clicking it, he/she has to pay for it. For example, if the user tries to install rebar after placing concrete, there is no solution. It tells the player to ask consultant for help.

Upon successful completion of surveying the player is prompted to select the next activity. The player could choose underground utilities which is a feasible but not an optimal choice. The cost to complete underground utilities will be greater since the excavator will have to work more carefully around the utilities. This is explained as shown in Cell 8 but only after the decision was made and the cost added.

Once a player selects excavation, it will be necessary to pick from a limited selection of equipment with production rates and cost provided as shown in Cell 8. The player will also need to select the number of hours needed. If a player selects more hours than necessary they will be charged for the extra hours. Much larger penalties are assessed if fewer hours than necessary are selected. Human resource requirements will be selected in a similar manner.

Cell 9 shows the completed excavation with the price and time adjusted based on the sequence of previous decisions. Players are prompted to select the next major activity which is foundation construction.

Foundation construction has a number of sub-activities as shown in Cell 10. Players must select the first sub-activity, the material, equipment and human resources as described in the previous activities. At any point during the simulation a player may “Ask the Consultant” for the optimal decision. Each time the consultant is asked a charge is assessed the job. When an infeasible decision is made, the player is required to ask the consultant before proceeding thus incurring the cost of the infeasible decision.

4. FUTURE RESEARCH

Future research includes expanding the base and breadth of available modules for education and training. The expanded base of knowledge could include a variety of project types such as commercial buildings, high-rises, bridges and highways. The expanded breadth could include larger and more complex projects in the expanded base such as including larger or more complex multifamily residential facilities. The ultimate research objective is to replace the traditional subject based educational curriculum with a project based curriculum. A full spectrum of construction projects modules could replace the typical lecture series presented in hundreds of construction programs. Students could learn scheduling, estimating, equipment and manpower selection from a project perspective rather than a subject perspective. This more closely relates to the real world experiences and should better prepare graduates for entry into the workforce.

5. CONCLUSION

The United States construction industry is in a training crisis with an aging workforce and little if any effort toward utilizing new technologies such as BIM in the educational effort. This paper describes a framework for virtual interactive education systems using domain expertise from the construction industry as an example. The training module simulates the construction process of a facility from start to finish with player levels, player interaction and modes as options within the simulation. Players attempt to optimize the time and cost of construction. These modules can be used as training tools for new employees where they attempt to optimize time and cost in a virtual environment through a sequence of limited choices regarding equipment, time and employee options. The modules can also be used as a process analysis tool for new construction where a number of situational variables can change leading to exposure of potential risk. These modules would be particularly useful for repetitive construction where the initial project is analyzed for optimization and risk mitigation.

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