Virtual Interactive Construction Education (VICE): A Project-Based Pedagogical Model using Cyberinfrastructure Tools

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Abstract

Virtual Interactive Construction Education (VICE) is a project-based pedagogical model that uses cyberinfrastructure tools to improve the quality and efficiency of construction engineering and management education by transforming Building Information Models (BIM) into contextually rich interactive simulations. VICE is a research program with project modules designed to transform undergraduate construction education by institutionalizing an advanced, virtual, and interactive web-based undergraduate construction education program. The interactive web-based bridge module, being completed as a result of funding from the National Science Foundation, will provide evidence-based support for developing a complete set of modules to replace the traditional subject-based lecture series with a project-based curriculum for an undergraduate construction degree. Project-based learning is proven more likely to meet educational objectives when compared to traditional lectures. The purpose of the current research is to place students in the full context of running a construction project through a computer generated simulation or serious game. The simulation is comprised of three main interacting engines – a learning engine, an evaluation/guidance engine, and a consistency engine. BIMs are domain knowledge repositories containing fact modules and factoids that can exchange information with these engines to create the simulations. The simulations use scalable deductive synthesis to formulate situation-specific solutions by using automated reasoning techniques on domain facts and fact components. These are codified using first-order logic extended with arithmetic, recursion and expert-supplied explanation tags. A web-based intranet exchange collects player profiles and level of construction knowledge to measure differences in proficiency and learning rates between groups based on gender or class standing. Players self-select a level of complexity and are scored by cost and schedule parameters. Lifelines and help from Oracles and consultant lesson modules are available to the player at a premium. The ultimate outcome is a project-based simulation curriculum for construction education that replaces the tradition subject-based curriculum.

Keywords: *Interactive, BIM, Project-based, Simulation, Construction*

1. INTRODUCTION

Virtual Interactive Construction Education (VICE) is a project-based pedagogical model that uses cyberinfrastructure tools to improve the quality and efficiency of construction engineering and management education by transforming Building Information Models (BIM) into contextually rich interactive simulations. When completed, the VICE program with multiple construction modules, will transform undergraduate construction education by institutionalizing

an advanced, virtual, and interactive web-based undergraduate construction education program. Project-based learning has proven more successful at meet educational objectives when compared to traditional lectures. The purpose of the current research is to educate students using computer generated simulations or serious games using models derived from actual construction project. There are three interacting engines in this process – a learning engine, an evaluation/guidance engine, and a consistency engine.

BIMs are repositories of domain knowledge containing fact modules and factoids that can exchange information with these engines to create the simulations that place players in the full context of a construction project. Situation-specific simulations are formulated using scalable deductive synthesis with automated reasoning techniques on domain facts and fact components. The simulations are extended with arithmetic, recursion and expert-supplied explanation tags using first-order logic. Player profiles and self-reported level of construction knowledge are logged using a web-based intranet exchange to track and measure level of proficiency and learning rates. Players can select different levels of complexity and are scored using cost and schedule parameters. Players are charged a premium for lifelines, help from Oracles and consultant lesson modules.

2. LITERATURE REVIEW

Contextually rich interactive simulations have proven effective at improving skills and safety in surgical skills (Kneebone, 2003; Gorman et al., 1999), training anesthesiology (Abrahamson et al., 2004) and laparoscopic and cardiovascular techniques (Issenberg et al, 2008). The Army trains this new generation more efficiently using simulation games (Walker, 2009). Active project-based learning in construction education will more likely meet educational objectives than traditional lectures according to Betts and Liow (1993). Ndekurgri and Lansley (1992) found that the linear fragmented nature of traditional teaching methods in construction allow no opportunity for learning the holistic nature of project management in construction. Van Eck (2006) calls for a practical guide to integrate games into the educational process to maximize learning.

Project level simulations in construction management date back to 1957 with the development of Program Evaluation and Review Technique (PERT) later followed by the Critical Path Method. These simulations found their way into the construction classroom in the 1980 because of the availability of computers. Other simulations were also being developed like CONSTRUCTO (Halpin, 1976) and CCS (Borcherding, 1977). Harris and Evans (1977) focused their simulation on line-of-balance scheduling for road construction.

Operations level simulations include Cyclone and Micro-Cyclone (Lluch and Halpin, 1982; Dabbas and Halpin, 1982), ICONS (Pilcher and Flood, 1984), INSIGHT (Paulson, Chan, and Koo (1987). Others focused specifically on subjects like contracting (Dudziak and Hendrickson, 1988), bidding (AbouRizk and Sawhney, 1994) and progress and controls (Rounds et al., 1986)

Simulations with broader education objectives including design, specification reviews and scheduling were developed by Veshosky and Egbers (1991) and Superbid by AbouRizk (1993). Internet applications include Interactive Construction Management Learning System (Sawhney, et al., 2001), MERIT (Wall and Ahmed, 2006), CONSTRUCTO (Veshosky and Egbers, 1991) and virtual coach (Rojas and Makherjee, 2005 and 2006; Rojas, 2006).

Building information models (BIM) have been used for training in a number of applications. Goedert and Meadati (2008) investigated the integration of data collection for educational purposes in the construction process through the BIM. Cho et al. (2010) investigated automation

and robotics (Cho & Youn, 2006) in BIM. Nicholic et al (2011) developed Virtual Construction Simulator to create and review construction schedules using BIMs.

3. METHODOLOGY

VICE is s project-based pedagogical model that relies on actual geometric, cost, schedule and other project data to develop an optimal solution set. The scope of the current work is to build a small number of project based simulation that will be tested for level of student engagement and levels of learning acquired. The bridge module (Figure 1) is currently being funded through the National Science Foundation while the residential module has received some seed funding from FIATECH and some internal sources.

Figure 1: Bridge Module Opening Page

Play starts after a player develops a profile that includes demographic information and self-reported level of construction knowledge. They select a level of complexity and are scored based on cost and schedule. Proficiency of learning is measured by length of time to master a concept, number of attempts, and number of consultant hits. The player is allowed help from Oracles or consultant lesson modules at any stage but is charged a premium.

3.1 Story Line

The first step is to rank order the work breakdown structure (WBS). Solution sets include infeasible, sub-optimal and feasible. Infeasible solutions force the player to "Ask the Consultant". Sub-optimal solutions may take more time and money but are allowed to proceed. Feasible solutions are the optimal path as determined by the module developers from the actual project data. These solution sets are formulated with automated reasoning techniques on domain facts and fact components derived from the BIM or other geometric models and the project database or expert opinions. Each situation specific solution set is simulated using methods described later in this section. The work breakdown elements are shown in Figure 2. The player can select a component to gain more knowledge prior to selecting the order of construction for each component.

Once the WBS is established, play moves on to process-level decision making related to individual construction activities like equipment selection, crew size and makeup, material orders, etc. Equipment cycling, productivity and safety learning segments are built into the

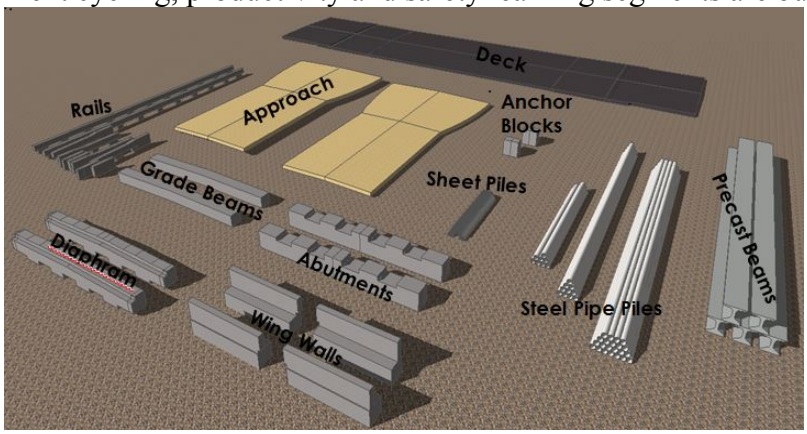

Figure 2: WBS Elements

module. For example: the player may select from a range of crane options for pile driving and be allowed to select one capable of driving the piles that is not able to reaching across the river.
This would require remobilization to the other side at an additional cost. Crane loading learning segments and productivity information from manufacturers are available to the player. Model selection at this stage could be based solely on capacity and reach appropriate for pile driving, however, the optimal crane for the project may be one large enough to accommodate setting the precast concrete beams later in the project. If the smaller unit is selected there could be additional mobilization and demobilization costs associated with this decision.

VICE requires manipulation of geometric information from actual projects to create animations and simulations from a BIM or other modeling software like Sketchup. The cost, schedule and project data are used to develop realistic scenario modeling loaded with any number of management issues arising during actual construction. Most of the necessary project information is available in a thorough BIM. Scenario building is driven by daily progress reports, photos and other data like weather reports. Delays due to unforeseen conditions or other unplanned events are built into the more advanced features for experienced constructors.

3.2 Graphics and Database Exchange

There are two projects currently under development: a small residential house and a single span bridge. REVIT was used to model the residential project and project data was collected during the construction of an actual energy efficient house. The geometric model for the bridge was developed in Sketch-up while the cost, quantity and schedule data was collected from the department of roads database. The transfer of geometric data from Sketch-up and REVIT to Autodesk 3DS Max was indirect.

The Google Sketch Up file was transferred to Autodesk 3DS Max. using a .skp version7 file format. Version 8, the most current version is currently incompatible and attempts to save will result in a prompt to save to the compatible version. Once 3DS Max 2011 is open, the upper case logo in the upper left corner which is the “File” tab can be expanded. The SketchUp file is opened by selecting “Import” from the drop down menu. A dialog box will allows you to select the appropriate model. A smaller dialog box asks you to check any or all of the following options: “skip hidden objects”, “cameras”,” daylight system”, and “split objects by layer”. It will

also prompt you to determine a location to extract hidden textures. Selecting the default option is normally most desirable. If you interrupt the time it takes to execute the command your changes may not be saved. Once the file has been successfully imported into 3DS Max, modifications may be necessary before developing animations. Modification may include: assigning materials to imported objects, adjusting lighting and light fixtures, moving / modifying objects, and placing cameras to the newly created scene.

The Revit file must be exported into Autodesk 3DS Max in an .fbx file format using the Reload feature. Other file formats may not accurately transfer objects, textures, day lighting or colors correctly. There are some interoperability issues that must be considered when transferring information using the file link manager. A three-dimensional design can be graphically rendered as points, lines and polygons if necessary. However, any number of attributes may not transfer accurately.

3.3 Platform, Interface and Interactions

The final platform of the VICE project will be Adobe Director 11.5. The other option was to use Adobe flash CS5.5. Both tools can be used to create powerful, rich applications. But Flash is less capable of handling 3D models compared to Adobe Director. Flash does not have a built-in 3D engine. Therefore, it handles 3D through other third party 3D engines like Papervision 3D, Away 3D, etc. All these external 3D engines have issues in importing 3D models created using other 3D modeling software (e.g. Google SketchUp) into Flash. One of the main issues is that the texture and lightning does not get imported with the model. On the other hand Adobe Director 11.5 has native 3D rendering including openGL and DirectX9. The main advantage of using Adobe director as the main platform for the VICE project is that the included NVIDIA® PhysX™ engine that can be used to add advanced dynamic motion and realistic interaction to the game. Another advantage is the availability of Google SketchUp importer in the version 11.5 to import the 3D models from SketchUp. In addition, version 11.5 supports more than 40 image formats that include most of the video formats available today that may be incorporated as learning segments or animations.

Game-based training systems, such as VICE, usually support a number of game stories with varying game objectives. For example, an objective of the game story in VICE Residential is to construct a house with a given set of requirements while making optimal use of available resources such as cost and time. One objective of VICE Bridge, another game story described in this paper, is to construct a single-span bridge making optimal use of available resources while working within constraints like safety standards and remote locations. Players can customize the game objectives in these systems for a more targeted training experience.

In each play session of a game-story, a player (or a team) chooses roles (e.g.: laborer, construction supervisor, project manager, etc.), selects degree of difficulty (e.g.: novice, medium, expert), learning modes (e.g.: supervised, unsupervised) to start playing. Each play session consists of players interacting with a sequence of visual media-rich scenarios to achieve the chosen objectives. Similar to other popular video games, there is no explicit adversary in these game stories. The player's response to each scenario is scored based on the contribution towards achieving the objective at hand. Cumulative scores obtained at the end of a play session rates a player's performance in that session.

VICE codifies domain knowledge in a knowledge base consisting of i) a set of knowledge components with enabling pre-conditions and effects specified by post-conditions, and ii) a knowledge map describing the interdependency between the knowledge components.

Each game story is modeled as a problem solving activity. The feasible solutions to each problem are limited to those that can be built using the available knowledge components. These solutions are stored in the form of a template called a **solution plan**, a sequence of play situations. User responses are used to move from one play situation to the next. In each play session, based on parameters, a solution plan is first extracted from the knowledge base by identifying the initial and final situations for the problem at hand. Each extracted plan is customized based on values of the parameters such as the learning modes, player roles, to create what is called an **actionable solution plan** (s). An actionable solution plan annotates the solution plan with all possible responses that a player may provide to move from one situation to the next one in the plan. Each path in the actionable solution plan from the initial to the final situation denotes one feasible solution to the problem. All the possible responses connecting any two situations are ranked in terms of their contribution to the game objectives.

During play, the media-rich scenarios are generated for each play situation, the player responds to the scenario reaching the next play situation, obtains a score computed based on the rank assigned to that response in the actionable solution plan. The play session ends upon reaching the final situation with the final score. To obtain the highest score, a player (team) must choose the top ranked response in every situation starting from the initial to the final one in the actionable solution plan.

Note that in systems, such as VICE, that model complex construction projects, the solution space is too large to obtain the complete solution plan at any single step. Therefore, incremental planning is accomplished by extracting a partial plan to a certain depth and then extracting the next plan based on the situation reached at the conclusion of the first plan and so on. Re-planning is performed whenever user actions deviate from the existing solution plans. This can happen in certain learning modes wherever user interactions are totally unconstrained.

3. RESULTS

The long term objective of this research program is to replace the subject-based pedagogical model with a project-based model that puts students in the full contexts of construction project management throughout their degree. Typically topics are covered in a subject-based construction curriculum. This proposal is to deliver via a project-based curriculum. The bridge module will be the first complete module. It will undergo beta testing with a group of students within six months. Players will make decisions reflecting the actual construction process including cost and schedule. The geometric and project data are derived from the Department of Roads database and a SketchUp model. It will be beta tested using a convenience sample of undergraduate construction students, industry experts, and a group of high school students. The module will be evaluated on its effect on learning and the potential for implementation in a post-secondary curriculum.

The geometric information was developed for the residential module in RIVET. This module will be more extensive evaluated than the bridge module. A single project module cannot be readily compared with a four year curriculum with any degree of accuracy or reliability. The residential module can be compared with the full curriculum of a residential program of community colleges.

BIMs can be very useful in developing the optimal path and scenario modeling in the VICE modules. However, neither the geometry nor the project data are directly transferable. There are several issues that prevent the direct transfer of BIM information into VICE including software compatibility, consistency of data between projects, and the context of information

needed to build the scenarios. The compatibility and consistency issues could, presumably, be resolved and allow data to transfer directly to simulations. However, the format for scenario modeling will always be an issue because of the difference in scope between VICE and BIMs. Scenario modeling has a number of issues that need further development for realistic animations. Second life was considered but didn't have realistic physical rules to constrain the construction processes. Olive is currently under consideration with robust physical rules. It appears to have the functionality needed to develop life-like construction animations. The disadvantage is that it is not open source and the animations would still have to be captured in a format that could be manipulated within a readily available program.

Another issue is the need for a library of construction equipment animations. In order to create realistic animations, heavy construction equipment animations must not only move around the jobsite but also function in a realistic manner. For example, it is fairly easy to show a load moving vertically as if moved by a crane but more difficult to have a crane swing on its carriage or the boom to pivot on the crane connection to boom out.

5. CONCLUSION

VICE is in the early stages of development with two of six modules under construction. The bridge module is the subject of this paper and is scheduled for beta testing in six months for level of student engagement and levels of learning acquired. The residential module requires substantial development and will be tested against a full curriculum at the community college level. BIMs will provide the geometric and project information to develop realistic scenarios and solution sets that place students in the full context of construction project management. These project-based modules eliminate the need for traditional subject-based pedagogical model. Instead, subjects will be introduced as needed to a project-based curriculum. Much work is still needed for both the curriculum development and module development. Curriculum mapping will ensure that all topics are covered to meet accreditation requirements. In addition, methodologies will need to be developed to animate construction equipment and export these animations to the simulations.

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