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3D VISUALIZATION OF SIMULATED CONSTRUCTION OPERATIONS

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ABSTRACT

Significant advances have been made in the field of construction process modeling. However, no convenient graphical support tools exist that can depict the modeled operations in 3D. This results in the "black box" effect being experienced by many simulation output analysts who have reservations about the credibility of the analysis based solely on the text and chart based output provided by most simulation software. The process visualization/animation tools currently available commercially are restricted to two dimensions (e.g. PROOF™), inherently lacking in the real world 3D capabilities that are indispensable for the realistic visualization of many construction operations. This paper describes on-going research at Virginia Tech that focuses on the development of a general-purpose, 3D text file-driven visualization system. This system enables visualization of both the construction processes and the evolving products in 3D. The input to the program is an ASCII text file consisting of sequential animation commands. This file can be generated automatically by a variety of simulation software capable of writing formatted text during simulation runs. Due to the flexibility of the command set and the independence of the tool from any particular simulation modeling software, the system has numerous potential applications in fields other than construction, such as in the manufacturing and service industries.

1 INTRODUCTION

Discrete-event simulation has been used to model construction operations for many years (Martinez and Ioannou 1999, Tucker et al. 1998). Simulation is a powerful objective function evaluator that is well suited to the design of complex resource-driven construction processes. The current state-of-the-art in construction simulation systems allows the modeling of complex construction operations in great detail and with utmost flexibility (Martinez and Ioannou 1999). Simulation analysis reveals meticulous details about planned operations like resource utilization, resource idleness, operation bottlenecks, production rates, and the resulting cost before commencing the actual implementation in the field (Liu and Ioannou 1993).

Notwithstanding these facts, the use of simulation as a construction operations planning tool has been far below its maximum potential (Huang and Halpin 1994, Tucker et al. 1998). This is principally due to the prevalent skepticism among potential practitioners, i.e. construction planners and analysts, who are typically well versed with the actual construction operations, to trust the credibility of the simulation analysis. Decision makers are hesitant to base their decisions solely on the statistical text and graphical chart output provided by most simulation systems. In addition, typical simulation models do not provide sufficient insights pertaining to the requirements and/or limitations of working space needed to accomplish modeled construction operations unless the models are explicitly designed to do this.

The capability to visualize simulated construction operations can be of substantial help in communicating the authenticity of simulation analysis to construction decision makers. In addition, visualization can provide valuable insight into the subtleties of the modeled construction operations that cannot be otherwise quantified and presented. The ability to realistically visualize modeled construction operations can thus provide a more pragmatic and comprehensible feedback from the simulation analysis to construction personnel as well as simulation model developers.

2 VISUALIZING SIMULATED OPERATIONS

There are numerous ways to visualize modeled operations. The choice depends on the level-of-detail and realism, and on the information and insights to be gathered from the process. The insights gleaned by visualizing modeled construction operations should comprehensively establish the credibility of the simulation analysis by enabling the validation and verification of analytical models. In addition, otherwise non-quantifiable and presentable visual insights into the modeled system should be provided to the decision makers. This would allow them to make prudent decisions based on accurate and plausible simulation feedback without relying solely on their judgment and experience.

Schematic model representation overlaid by a dynamic display of runtime statistical data (Huang and Halpin 1994) and graphical iconic animation overlaying a schematic model (Liu and Ioannou 1993, Shi and Zhang 1999) have been used previously to provide an animated environment in construction simulation systems. This type of visualization can be of substantial help to simulation model developers in debugging models during the development stage and in verifying that the model accurately represents the modeled system, as the developer understands it. However, the capability of such systems to communicate modeled system configuration to persons who do not understand simulation is limited. This is partly due to their inability to realistically depict the complexities arising in the modeled operations due to the requirements, usage, possible shortage and conflicts in working space.

2D system animation tools like PROOF™ describe and depict smoothly moving animations of complex modeled systems whose states are constantly changing (Henriksen 1999). PROOF™ has been effectively used in the past to visualize modeled construction operations (Ioannou and Martinez 1996, Martinez 1998) and modeled mining operations (Sturgul and Seibt 1999). 2D visualization of construction operations, although effective in establishing the credibility of many simulation models, inherently lacks in the real-world 3D capabilities that are indispensable for the realistic visualization of some complex construction operations. In addition, due to the degrees of freedom exercised in accomplishing most construction operations, it is not possible to accurately depict entire system configuration in two-dimensional space alone.

Simulation systems possessing inbuilt 3D graphical output capability enable real-time 3D animation of the modeled operations during a simulation run. These 3D visualization-enabled simulation systems, although capable of modeling and visually depicting some construction operations (Tucker et al. 1998), are tied to their own simulation engines based on process interaction. This makes them quite effective for modeling manufacturing systems but not a clear choice for construction. In addition, the use of these systems to model and animate construction operations requires a radical change in the frame of thought in construction model developers due to the stringent coupling between the simulation engines and the in-built visualizers (Aloufa 1993, Tucker et al. 1998).

3 GENERAL-PURPOSE 3D VISUALIZATION SYSTEM

The remainder of this paper describes ongoing research at Virginia Tech that focuses on the development of a general-purpose 3D visualization system. This system, tentatively named the Dynamic Construction Visualizer (DCV) allows the visualization of modeled construction operations and the evolving products in 3D virtual space after each simulation run.

3.1 Salient Features

The DCV is implemented as a Microsoft Windows application that can process ASCII text files written in the DCV language to unambiguously describe the visual configuration of modeled systems with the passage of time.

The DCV is a post-simulation visualization engine that possesses the following characteristics:

- Maintains an independent, user-controllable simulation clock.
- Allows the user to navigate easily in the 3D virtual space.
- Allows the user to jump ahead or back to any desired point in the simulation by specifying a time value.
- Permits the user to start and pause the animation at any time to make static observations.

3.2 Description

The DCV is an ASCII text file driven visualization engine capable of visualizing modeled operations with spatial and chronological accuracy after each simulation run. The DCV is designed to work in conjunction with process modeling software, but at the same time is entirely independent of the simulation system that is used to model the operations of interest.

The text-file driven nature of the system allows its seamless integration with numerous process modeling software that are capable of generating text output during a simulation run. The required input text file consists of sequential animation command statements such as CREATE, DESTROY, PLACE, and MOVE. In addition, the input text file also contains statements such as PATH and NONDIRECPATH that define resource movement paths during the animation. The statements in the input file are then processed sequentially to visually simulate the modeled operations in 3D virtual space.

This is accomplished by using 3D CAD models of the involved system resources and other model entities. The result is in essence a “motion picture” of the actual operations being carried out in the virtual environment. This “motion picture” can be replayed at varying speeds depending on the viewer's preferences. In addition, the system also allows users to jump ahead or back to any point in simulation time which is fairly analogous to being able to instantaneously rewind and fast forward a motion picture tape to a desired location. The user is able to navigate easily in the 3D virtual space and hence can position himself/herself at any vantage position he/she desires at any time during the visualization process.

Realistic animations can be created using 3D CAD models from supported data file formats. The VRML data file format is directly supported by the DCV. VRML was enabled as a supported CAD file format since it is steadily emerging as the de facto standard for extremely lightweight and portable computer graphics applications. In addition, practically every CAD modelling software program can export their data files in VRML format. As a result, the DCV visualization system is practically independent of any CAD modelling software as well.

Figure 1 shows an animation snapshot of a modelled earthmoving operation that was used in the initial testing of the visualization system. In this animation, the viewer is able to realistically observe the accumulating trucks waiting to be loaded, the trucks manoeuvring to get into position under the excavator, the excavator digging the earth and loading the trucks until they are full, the trucks travelling to the dumpsite, accumulating occasionally to enter the dump area, backing up and tipping their load, and then returning to the loading site to begin another cycle.

3.3 Current Visualization Capabilities

Thus far, the focus of the research has been to develop a methodology to realistically define and depict construction processes. This includes the ability to accurately portray the motion of complex construction equipment such as excavators, dumptrucks, and forklifts.

Figure 2 presents an animation snapshot of a modelled block-laying operation that shows a mason and his assistant working on a wall section. The depiction of the constructed facility i.e. the product at various stages of completion as the construction progresses is currently accomplished by "assembling" the facility from CAD models of discrete components such as blocks and gypsum boards. Therefore, at the current stage of development, it is fairly impractical to model and visualize all the operations for an entire construction project.

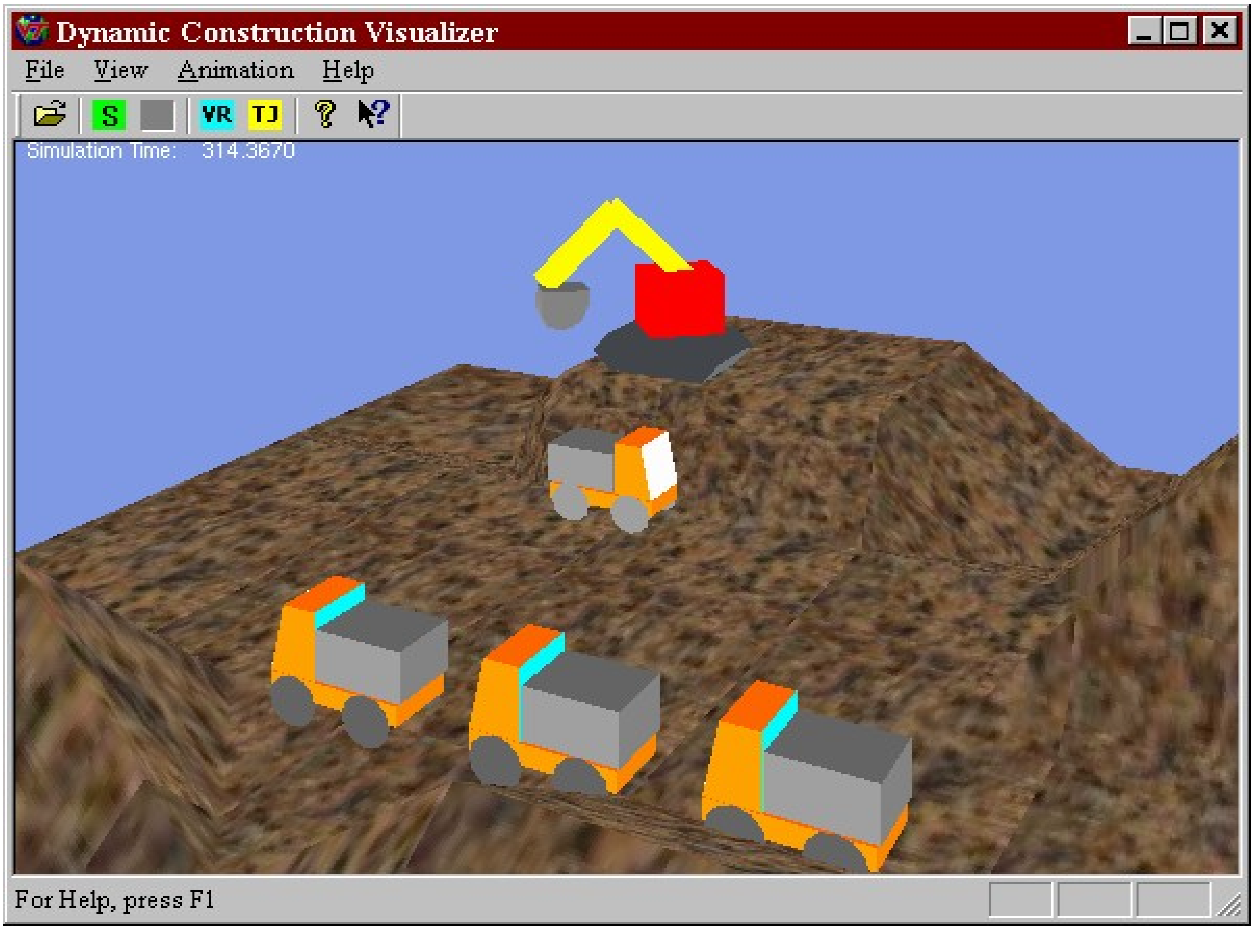

Figure 1: Animation Snapshot of the Loading Area in an Earthmoving Operation

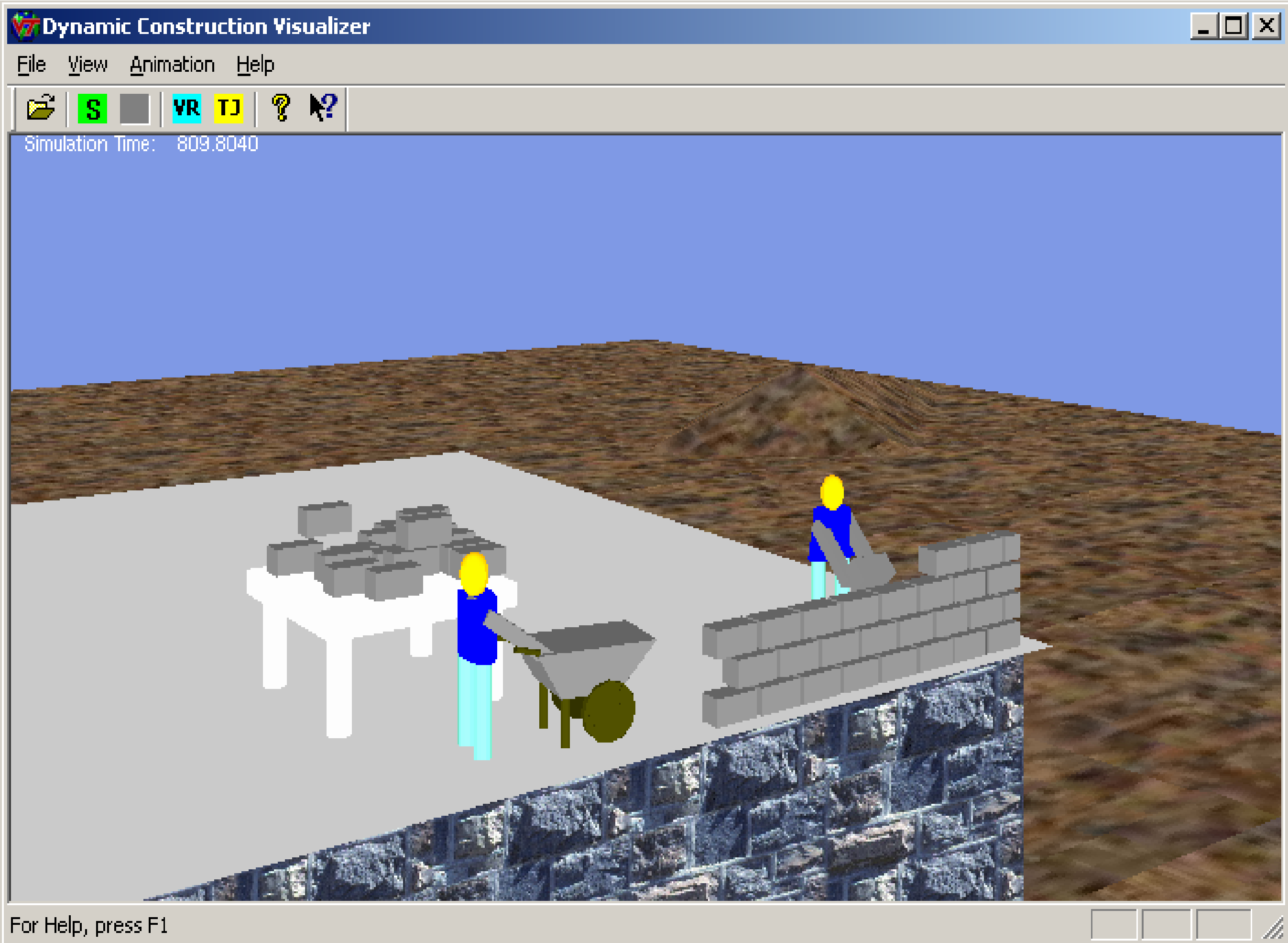

Figure 2: Animation Snapshot of a Block laying Operation

3.4 Applicability

Due to its capability of running on standard desktop PCs and laptops, the DCV has numerous potential applications not only in the planning office, but also on the actual construction site. The capability to realistically visualize future planned construction operations in 3D will facilitate greater awareness and understanding about the project among the management and site personnel alike by providing them with a virtual experience of how and what should be constructed. Modelling and subsequently visualizing a construction scenario will provide in-depth insights into the planned operations. The operations can thus be effectively designed, planned, and scheduled without relying solely on the planner's judgment, imagination, intuition, and experience.

Due to the flexibility of the command set and the independence of the system from any particular simulation modelling software as well as from any particular CAD modelling program, the DCV visualization system has numerous potential applications in fields other than construction, such as in the manufacturing and service industries.

4 CONCLUSION

The essence of using simulation to model construction operations is to obtain insights into the consequences of using different techniques and strategies and thus helping the planner in making the most advantageous decisions. Construction simulation systems provide users with detailed information such as statistical production charts, resource usability, and breakdown times in the modelled system. However, there are no supporting tools that can illustrate the simulated operations in 3D. This results in the experiencing of the "black box" effect by many simulation output analysts and decision makers.

The capability to visualize the geometrical characteristics of the modelled system and the dynamic nature of all the entities involved in the construction process will greatly improve the accessibility of simulation as an operation-level planning tool in the construction industry. The DCV visualization system will provide numerous simulation languages and packages with the support necessary to enable construction planners and designers to obtain a more realistic and comprehensible feedback from simulation analysis.

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