3D VISUALIZATION OF CONSTRUCTION PROCESSES AND PRODUCTS

Vineet R. Kamat[1], Julio C. Martinez[2]
1 Graduate Student, Virginia Tech, Blacksburg, VA 24061, USA
2 Assistant Professor, Virginia Tech, Blacksburg, VA 24061, USA

ABSTRACT: Construction processes range from the relatively simple to the most complex. In the construction industry, complex decisions yielding maximum benefit are an essential component of process design and planning. Simulation modelling and Visualization are thus being increasingly used to help decision-makers make economically optimal decisions.

Although many advances have been recently made in the area of construction process modelling (e.g. STROBOSCOPE), the Visualization/Animation aspect has mainly focused on the finished product (3D CAD) or on the product as it evolves through construction (4D CAD). Very little attention has been given to visualizing the construction process that leads to the end product, which includes temporary structures and materials, equipment and labor as they create the product. The process visualization/animation tools currently available commercially are restricted to two dimensions (e.g., Proof Animation), 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 and trace-driven visualization/animation system. This system enables visualization of both the construction process and the resulting product in 3D. The tool enables the easy creation of realistic 3D animations using CAD models from supported data file formats. The core of the work is a simple yet extremely robust set of animation commands, the capability to process sequences of these commands, and the ability to navigate effortlessly in 3-D space. The input to the program is an ASCII text file consisting of sequential command statements. This file can be generated automatically by a variety of simulation software tools such as STROBOSCOPE, which is currently being used to test the system.

Due to the flexibility of the command set and the independence of the tool from any particular simulation modelling software, the system has numerous potential applications in fields other than construction, such as in the manufacturing and service industries. Construction simulation model developers will find this tool useful for debugging their model and verifying that analytical models indeed behave correctly.

KEYWORDS: Construction operations, 3D Visualization, Simulation.

1. INTRODUCTION

Construction operations range from the relatively simple to the most complex. They involve multiple pieces of equipment, labor trades, and materials that can interact in complex ways. Traditional methods used to design them prove ineffective in many cases where simulation modeling and visualization can be of substantial help.

Significant advances have been made in the area of construction process modelling. The current state-of-the-art in construction simulation systems allow the modelling of complex construction processes in great detail and with utmost flexibility (Martinez & Ioannou, 1999). Such systems provide the user with abundant detailed information such as statistical production charts, resource usability, and breakdown times in the processes being modelled. There are however, no supporting tools that can illustrate the modelled processes graphically in 3D. As a result, there is a prevalent scepticism among the 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 and to base their decisions on the statistical text output.

The currently available commercial visualization/animation tools capable of visualizing modelled construction operations are restricted to two dimensions (e.g., Proof Animation). Such a tool inherently lacks in the real world 3D capabilities that are indispensable for the realistic visualization of the complex dynamic interaction among resources and the ongoing concurrent processes that are typical of many construction operations.

2. VISUALIZATION IN CONSTRUCTION ENGINEERING

In the construction industry, the Visualization/Animation aspect has thus far mainly focused on the finished product (3D CAD) or on the product as it evolves through construction (4D CAD). 3D CAD systems are used extensively in the design phases of many projects. On the other hand, 4D CAD (3D CAD plus Time) has steadily emerged as a project management tool capable of providing visualization support to construction managers and schedulers at a schedule level of detail. These systems fragment the 3D CAD model of a facility into manageable parts such that each part thereof can be suitably assigned or linked to a distinct activity in the construction schedule. The result is a visual simulation of the transformation of space over time (McKinney et al, 1996).

In all these systems, very little attention has been given to visualizing the modelled construction processes that lead to the completion of the constructed facility. Visualizing the construction process involves being able to view in a virtual environment, the interaction of the various resources as they build the facility with the passage of time. These resources include, but are not limited to temporary structures, materials, equipment, and labor as they create the product. Such a system would essentially be a 4D CAD system, but with a construction process level of detail rather than a schedule level of detail.

2.1 Advantages Of Enabling Construction Process Visualization

Effective planning and scheduling of construction operations is critical for the success of any construction project, irrespective of its magnitude. Simulation modelling is a valuable construction management tool that is well suited to the analysis of construction processes, the majority of which are resource driven. Simulation allows construction planners and analysts to experiment with and evaluate different scenarios during the planning phase.

The capability to pictorially visualize in 3D space the planned construction processes is necessary to facilitate the usability of construction process simulation as an operations management tool in the construction industry. 3D visualization of the planned construction operations will provide easier accessibility for the planners by graphically conveying the physical configuration of the system of interest in a very realistic but virtual format, thus

allowing the user to easily and clearly comprehend the dynamic and interrelated behavior of the system model after each simulation run. 3D visualization will thus establish the credibility of the analysis by facilitating the validation and verification of complex simulation models. This will provide an opportunity to convince all the parties involved that the model indeed reflects the reality, thus favoring the reaching of a common ground.

Planning, scheduling, and controlling complex construction projects can thus benefit greatly by integrating traditional project management techniques with construction process simulation and visualization. It is to be noted that 3D visualization of construction processes and the resulting products intrinsically affords most of the advantages realized by incorporating a purely schedule level detail based 4D CAD system in addition to a host of other exclusive benefits. A few specific advantages realized by visualizing the planned and simulated construction operations are enumerated below.

- Construction Personnel, management and workers alike, are able to comprehend the construction process better by visualizing precisely how activities relate to one another, thus reducing conflicting interpretations and communication problems.
- Sequencing of interrelated activities in an operation can be better planned by organizing the resources for maximum productivity.
- Problems with equipment positioning and manpower congestion in certain areas can be visualized prior to the actual operation, thus preventing accidents and safety problems such as collision between two machines and losses in productivity.
- Construction operation designers and planners can take full advantage of advanced process simulation capabilities by first simulating and then visualizing numerous possible "what if" scenarios, thus eliminating costly and risky trial and error techniques.
- 3D visualization can be used very effectively as a medium for educational training in construction process design and execution.
- Visualization is essential to simulation model developers for debugging their model and verifying that analytical models indeed behave correctly.

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 that is being specifically designed to meet the unique requirements of visualizing construction processes and the resulting products in 3D virtual space.

3.1 Description Of The System

The system being designed is a post-simulation 3D visualization engine capable of visualizing modeled construction operations and scenarios with spatial and chronological accuracy after each simulation run. The system is being designed to work in conjunction with a process modeling simulation system, but at the same time would be entirely independent of the simulation software being used to model the scenario of interest.

The visualization tool is a Trace-File driven system thus allowing its seamless integration with numerous process modelling software capable of generating text output during a simulation run. A Trace File is an ASCII text file consisting of sequential animation command statements. These statements are then processed by the system to visually simulate the modelled operations in 3D virtual space. This is being accomplished by using 3D CAD

models of the involved resources and entities and the constructed facility at various levels of completion. The result is in essence a “motion picture” of the actual processes being carried out in the virtual environment. This “motion picture” can be replayed at varying speeds depending on the viewer’s preferences and also allows the user 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. In addition, a significant advantage that is afforded to the user is that he/she is able to navigate easily in 3D space and hence can position himself/herself at any convenient position he/she desires at any time during the visualization process.

The system enables easy creation of realistic 3D animations using 3D CAD models from supported data file formats. The VRML data file format is directly supported by the system. VRML was incorporated as a supported CAD file format since it is steadily emerging as the de facto standard for extremely lightweight and portable computer graphics applications. Also, practically every CAD modelling software program can export their data files in VRML format thus making this visualization system independent of any CAD modelling software as well. Figure 1 shows a snapshot of the loading area in the visualization of an earthmoving operation being used in the initial testing of the system.

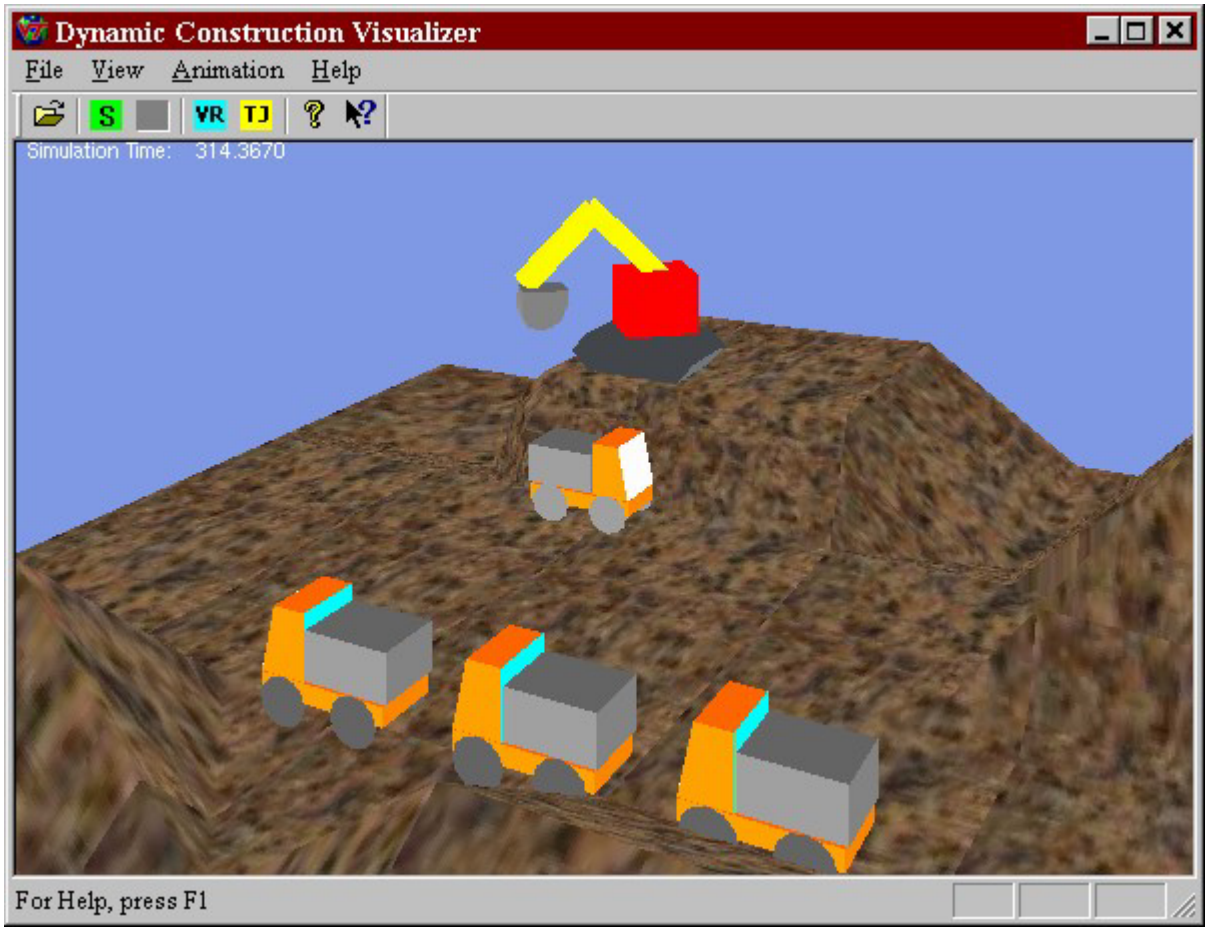

Figure 1. Animation snapshot of a loading area in an earthmoving operation showing one truck being loaded and three trucks waiting to be loaded

The system is designed to work on the Microsoft Windows NT platform. This platform was chosen because of its stability, portability, and popularity.

3.2 Current Capabilities Of The System

The core of the research as far as implementation of the visualization system is concerned is the development of a fairly simple yet robust set of animation commands, and the capability to process sequences of these commands adhering to spatial and chronological accuracy. Table 1 lists a few key commands incorporated in the designed animation language and provides a concise explanation of their functionality. In addition, the system provides the user with a capability to navigate effortlessly in 3D virtual space, so that he/she does not get "lost" in the virtual world.

STATEMENT	***FUCTIONALITY***
TIME	*Maintains a simulation time clock during visualization.*
CLASS	*Associates a class of simulation entities with their geometric description contained in a CAD file.*
CREATE	*Creates specific simulation objects by instantiating predefined classes.*
PLACE	*Places simulation objects at particular locations or at the beginning of predefined resource movement paths.*
MOVE	*Moves simulation objects on predefined resource movement paths.*

Table 1 – Selected DCV Animation Language Commands And Their Functionality

Thus far, the methodology to define and depict the realistic motion of complex construction equipment such as dumptrucks and forklifts, as well as that of complex hierarchical assemblies such as cranes, backhoes etc. has been developed and is currently being tested. Figure 2 shows a snapshot of the dump area in the visualization of an earthmoving operation being used in the initial testing of the system. The depiction of the transformation of space as the construction operations are completed i.e. the representation of the evolving construction products at various stages of completion is currently being accomplished by "assembling" the facility from CAD models of discrete units such as blocks and gypsum boards. This procedure makes it impractical to visualize all the operations for an entire construction project.

The system is being used to visualize several actual construction site scenarios as well as numerous pseudo scenarios so that its capability to visualize any possible configuration that might be encountered in real life can be tested. The STROBOSCOPE Simulation System (Martinez, 1996) is being used to generate all the required input trace files during the testing of the visualization system. STROBOSCOPE is a programmable and extensible simulation system designed for modelling complex construction operations in detail and for the development of special-purpose simulation tools (Martinez & Ioannou, 1999).

3.3 Applicability

Due to its capability of running on standard desktop PCs and laptops, the visualization system has numerous potential applications not only in the planning office, but also on the actual construction site. The capability to visualize the future planned construction operations in 3D will facilitate greater awareness and understanding about the project among the management

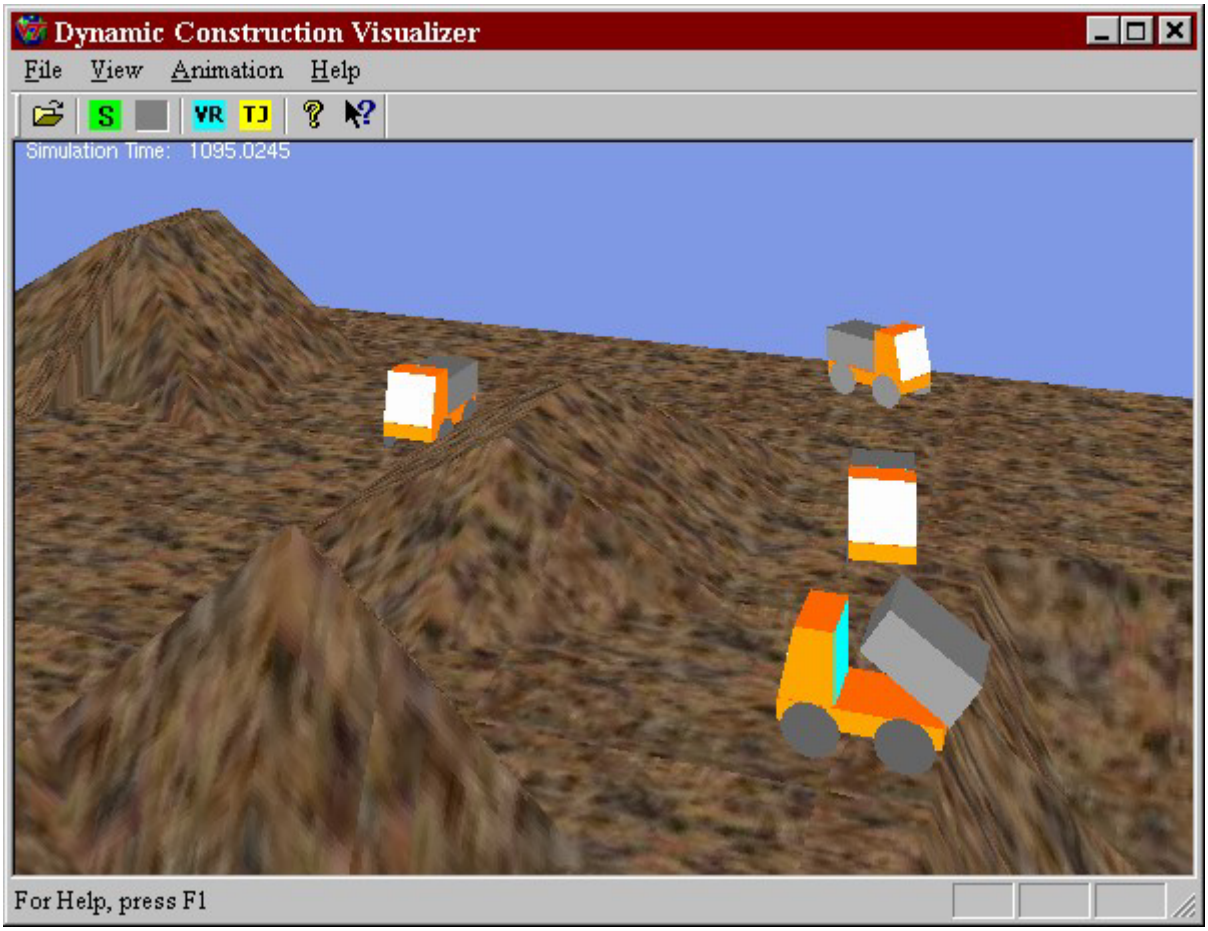

Figure 2. Animation snapshot of a dumping area in an earthmoving operation showing one truck dumping in a fill and another waiting to dump

and the site personnel by providing them with a virtual experience of how and what should be constructed. Modelling and subsequently visualizing a construction scenario is capable of providing in-depth insight necessary to effectively plan and schedule construction operations by revealing the dynamic interaction among various involved resources and concurrent processes without relying on the planner's judgement, imagination, intuition, and experience.

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

4. CONCLUSION

The sole purpose of using simulation as a project management tool in construction is to obtain insights into the consequences of using different techniques and strategies and thus helping the planner in making the most advantageous decisions. Although simulation modelling software systems have advanced considerably in recent times, there are no supporting tools that can illustrate the processes that are being simulated in 3D, resulting in the "black box" effect being experienced by many simulation output analysts.

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 provide the necessary momentum to the use of simulation modelling as an indispensable process-level planning tool in the construction industry. The 3D 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 form the simulation analysis.

REFERENCES

Martinez J.C. (1996). STROBOSCOPE: State and Resource Based Simulation of Construction Processes, Dissertation submitted to the University of Michigan for the Degree of Doctor of Philosophy in Civil Engineering.

Martinez J.C., and Ioannou P.G. (1999). General Purpose Systems for Effective Construction Simulation, Journal of Construction Engineering and Management, Vol. 125, No. 4, ASCE

McKinney K., Kim J., Fischer M., and Howard C. (1996). Interactive 4D-CAD, Proceedings of the Third Congress on Computing in Civil Engineering.

Wolverine Software Corporation (1995). Using Proof Animation, 2nd Edition.