



**A SURVEY OF GRAPHICAL SIMULATION
IN CONSTRUCTION:
SOFTWARE, USAGE, & APPLICATIONS**

by

**David G. Alciatore
James T. O'Connor
Parmanand Dharwadkar**

**A Report to
The Construction Industry Institute
The University of Texas at Austin**

**Under the Guidance of the
The Advanced Technological Systems Task Force**

**from
The University of Texas at Austin
Austin, Texas**

**SD-68
September 1991**

© 1991 Construction Industry Institute™.

The University of Texas at Austin.

CII members may reproduce and distribute this work internally in any medium at no cost to internal recipients. CII members are permitted to revise and adapt this work for the internal use provided an informational copy is furnished to CII.

Available to non-members by purchase; however, no copies may be made or distributed and no modifications made without prior written permission from CII. Contact CII at <http://construction-institute.org/catalog.htm> to purchase copies. Volume discounts may be available.

All CII members, current students, and faculty at a college or university are eligible to purchase CII products at member prices. Faculty and students at a college or university may reproduce and distribute this work without modification for educational use.

Printed in the United States of America.

Table of Contents

1.0 – Introduction	page 1
2.0 – Graphical Simulation – What Is It ?	1
3.0 – Scope and Methodology of this Study	2
3.1 – Sources of Information	2
3.2 – Hardware for Graphical Simulation	3
4.0 – Construction Simulation Objectives and Benefits	3
4.1 – Application Objectives	3
4.2 – System Benefits & Costs	5
5.0 – Software Survey Results	6
5.1 – Software Evaluation	6
5.2 – Feature Descriptions	19
5.3 – Brief Software Descriptions	21
5.4 – Vendor Information	23
6.0 – Graphical Simulation Applications	25
7.0 – Industrial Plant Compressor Replacement: A Case Study	31
8.0 – Closure	36
9.0 – Bibliography	37
A.0 – Appendix	41
A.1 – Sample Phone Survey Forms	41
A.2 – Survey Project Schedule	43

1.0 Introduction

The purpose of this survey is to describe *graphical construction simulation* and to expose the benefits, methods, and tools of this type of simulation. There exist several classes of simulation but this survey is limited to 3-D (three-dimensional) computer graphical simulation or animation in the construction context. Some refer to this type of simulation as "real world" simulation. This report does *not* address non-simulation CAD developments.

This report begins with some background information, including a definition of simulation and a description of the broad classes or types of simulation practiced. The scope and study method of the survey are then presented, briefly addressing both information sources and system hardware. The range of objectives for applying simulation and an overview of potential benefits of graphical simulation are also addressed. After this background information, the survey of software packages and software attributes are presented. Descriptions of specific applications of simulation in both industry and research follow and an in-depth case study of a heavy-lift simulation is presented. The report concludes with a listing of software vendor information, a bibliography of the survey sources and useful references, sample phone survey forms used to obtain information on the software packages, and a listing of the schedule milestones followed in completing this study.

It is important to point out at this point that the two requirements for 3-D computer graphical simulation are a 3-D CAD model (of the facility or equipment of interest), and simulation/animation software running on a high-powered graphics workstation. If a construction firm uses 3-D CAD for modeling project designs, then construction simulation may require only a moderate amount of additional effort or investment. If 3-D CAD designs are not available, a modeling system must be used to create a 3-D model from 2-D (plan drawing) images. Some of the simulation software packages presented in this survey have this modeling capability built in, but others require additional software.

2.0 Graphical Simulation – What Is It?

In general, simulation refers to the approximation of a system with an abstract model in order to perform studies which will help predict the behavior of the actual system. There are several different types of simulation, three of which are listed and described below:

1) Physical Model Simulation

Plastic modeling in the plant engineering/construction context refers to the building of physical scale models of facilities and equipment, allowing for visualization of complex geometry, verification of clearances, and planning of routing and erection sequences of various components. Plastic modeling has been common and extremely useful in the petrochemical, process, and utility industries where facility designs and construction planning are difficult to visualize with only 2-D drawings. Disadvantages of plastic models are the cost involved with creating the model (it's not uncommon for the cost of a plastic model of a process facility to approach \$1,000,000), the immobility of large and bulky models, and the difficulty and expense involved with modifying the model.

2) Mathematical/Statistical Process Simulation

Mathematical/statistical process simulation in the construction context refers to the use of labor, material handling, and equipment performance variables and historical performance

statistical distributions to model complicated transport and/or erection processes involving uncertainty. This type of simulation is effective in providing insight into resource requirements or process design optimization (such as sequencing). One problem with this type of simulation is that it is often difficult and time-consuming to create an adequately complete and accurate representative model. There are often problems due to the lack of applicable statistical data or oversimplification of the process model.

A full description of mathematical and statistical process simulation can be found in Halpin [15] and Pritsker [22]. Various software packages that implement this type of simulation include SLAM, MICROCYCLONE, GPSS, and AUTOMOD.

3) 3-D (Computer) Graphical Simulation/Animation

Graphical simulation or animation refers to the use of high-powered computer graphics to visualize geometry and animate motion in order to simulate a dynamic process. The scope of the survey presented in this document is limited to this type of simulation.

Two requirements for this type of simulation are 1) a 3-D CAD geometric description of the model and 2) 3-D simulation or animation software running on high performance hardware. While the terms "simulation" and "animation" are often used interchangeably, a subtle distinction exists between the two. "Simulation" is used to refer to an interactive near real-time capability to depict motion. "Animation" refers to the ability to play back at a high speed pre-recorded images (in similar fashion to the production of cartoons). While these two different methods correspond to two very different approaches to image generation, and while the real-time response of "simulation" does offer significant advantages, both systems can generally achieve the same objectives and benefits. Accordingly, no further distinction between these two systems is discussed in this report.

If simulation or animation software is available, and if 3-D CAD is used in the design phase of a project, the amount of additional effort or expense required to perform this type of simulation can be significantly reduced. Various construction-related application objectives are discussed in Section 4.1.

3.0 Scope and Methodology of this Study

The scope of this survey is limited to the third type of simulation discussed in the previous section: 3-D Computer Graphical Simulation/Animation. Furthermore, the scope is limited within this category to simulation applicable to field construction activities. The 3-D CAD modeling packages associated with facility design are not addressed in this report. The types of applications suitable for this type of simulation are presented in the next section.

The review of simulation software presented here is limited to workstation level software (i.e., software that runs on high-powered engineering graphics workstations). There are many available engineering workstations which are suitable including Silicon Graphics Iris, SUN Sparcstations, IBM 6000 RISC, DEC Vaxstations, Intergraph, Hewlett Packard, Apollo, and Tektronix. Section 3.2 is a brief elaboration on hardware.

The sources of information for this survey are discussed in the following section. The schedule followed while conducting this study can be found at the end of this document (Section A.2).

3.1 – Sources of Information

The sources of information for this report included third-party software and hardware vendor catalogues, various published literature (papers, articles, and books) related to simulation, and personal contacts (such as engineering and construction company software users and developers). The vendor catalogues and other references used in this survey are listed in the Bibliography (Section 9.0).

The first step in the software survey was to assemble a list of software packages which seemed to be applicable to 3-D computer graphical construction simulation. Five comprehensive engineering workstation third-party software catalogues (see Bibliography) were reviewed to obtain a list of thirty-two software packages whose brief descriptions showed potential for construction simulation. A phone survey was conducted for each of these packages (see Appendix A.1) and further information (brochures, price lists, articles, video tapes, etc.) was requested from the vendors. After reviewing the phone survey information and the information received, the list of appropriate packages (i.e., those with capabilities for 3-D computer graphics construction simulation) was narrowed down to fifteen packages. The criteria used to compare the packages are listed and described in Section 5.2. A follow up phone/FAX survey (see Appendix A.1) was conducted for each package on this list of fifteen to verify the information and to obtain further descriptions. All of the information compiled is summarized in the Software Evaluation Table of Section 5.1.

3.2 – Hardware for Graphical Simulation

Hardware refers to the actual computer equipment used to run the simulation software and display graphics. Types of hardware available include personal computers, engineering workstations, and mainframes with multiple graphics terminals. The scope of this survey was limited to software running on high-powered engineering graphics workstations. This type of hardware is preferable due to performance (CPU speed and graphics capabilities) and software availability. The price range of engineering workstations is typically \$10,000 to \$100,000, though a \$30,000 workstation is certainly adequate for most applications.

Personal Computers (e.g., the IBM PC and Apple Macintosh) are much less expensive and more readily available but generally do not have the computing power or speed required for adequate simulation. Mainframes with graphics workstations can be powerful, but not all organizations have this type of hardware and it is quite expensive. Also, mainframes operate in a time-shared environment, so the number of users on the system affects the performance. Features (or attributes) to be considered when evaluating hardware for construction simulation potential include:

- CPU Speed
This refers to the speed of the computer's processor usually quoted in MIPS (million instructions per second) and MFLOPS (million floating point instructions per second). High MIPS and MFLOPS means high computational performance.
- Graphics Speed
This indicates how fast an image with a given number of surfaces can be redrawn. It is usually quoted in shaded polygons per second. This attribute is important for real-time animation. High shaded polygons per second implies high graphics performance.
- Operating System and User Interface
A window-based menu-based (Macintosh-like) system is preferable due to the ease of learning and use.
- Graphics Display Specifications
Built-in graphics features (such as geometric transformations, shading, z-buffering, and stereoscopic projection) and monitor resolution are important factors which affect graphics speed and image quality.

4.0 Construction Simulation Objectives and Benefits

4.1 – Application Objectives

Graphical simulation for construction may be pursued for a wide variety of reasons or may support a wide variety of objectives. These reasons or objectives are closely linked to the benefits accrued from such analyses, benefits which are often fairly apparent yet also difficult to quantify. Specific treatment of system benefit and costs follows in Section 4.2. An overview of the common objectives for construction graphical simulation is presented in the following listing.

The applications presented in Section 6.0 document examples of how these objectives have been applied in industry and research. (It should be noted that there are also some purely design-related applications of simulation. In general, these are not investigated in this study.)

- **Business Development and Project Bidding**
3-D computer graphics simulation provides a valuable communication tool by illustrating an understanding of difficult-to-visualize geometry or complex construction procedures. This capability is valuable for business development communications (video presentations) and for project proposal preparation.
- **Plant Walk-Throughs**
Complex facility layouts and designs can be easily visualized with the aid of a good 3-D graphics software package with walk-through capability. Walk-through refers to the ability to dynamically move the viewpoint through the model, simulating a walk through the actual facility. All three major project participants - the owner, designer, and constructor - can benefit from such familiarization walk-throughs.
- **Plant Operability/Maintainability/Constructability Analyses**
Construction simulations can be performed to help evaluate the operability, maintainability, and constructability of project designs. Operability simulations may model the movement of process raw materials or product. Maintainability simulations may investigate accessibility for switching out plant equipment. Constructability simulations may offer insight into crane boom swing accessibility or optimal design configurations based upon known construction equipment constraints or attributes. The results of simulation analyses can be fed back to designers, prompting design modifications before construction begins. Identifying, and improving the timeliness of such changes can have a dramatic effect on overall project cost and schedule performance.
- **Interference/Clearance Checking for Dynamic Elements**
Construction tasks involving the movement of equipment and material can be simulated and checked for physical interferences or clearance problems. If there are problems, design changes or alternative construction methods can be devised and re-evaluated through simulation. Erection of permanent equipment involving heavy lifts is particularly appropriate for simulation analyses, which can help ensure a timely and safe operation. Other benefits from this type of analysis include the determination of optimal equipment configurations, optimal lifting sequences, and optimal lifting points.
- **Construction Activity Sequence Visualization**
Simulation may be very useful in developing and reviewing construction schedules or sequences of activity. With the simulation tool, schedulers can visually model, review, refine, and optimize field sequences in a way never before possible. Without question, this is an advanced application of simulation which is not yet fully developed.
- **Construction Equipment Selection and Usage Planning**
Construction equipment selection, equipment site placement and orientation, and equipment operational usage can be simulated and experimented with in order to determine optimal approaches for a particular job. Collectively, such findings can have a significant impact on construction productivity, reducing both project cost and schedule.
- **Testing of Construction Equipment Control Systems/Operator Training**
In simulating construction equipment, manual operation controls can be interfaced to the simulation program resulting in a controller simulator (similar to a flight simulator). Such a system could be used to evaluate and train operators or to evaluate alternative controller designs for ergonomic effectiveness.
- **Pre-Planning and Pre-Programming of Automated Construction Tasks**
Automated equipment tasks can be simulated and even programmed for a completely automated operation. This is called off-line programming where a task is simulated and

planned and a program is used to duplicate the task on the actual equipment. In the manufacturing sector, it is done routinely with factory robotic equipment.

- **Construction Engineering/Project Management Research & Development**
Researchers have found graphical simulation a particularly effective tool for research and development into new construction engineering/project management systems. It may be particularly beneficial for studies into automated construction, automated project schedule development, and management information systems design.

An overview of these application objectives offers additional insights:

- There are currently two major types of graphical simulation in construction: 1) those applications where the focus is on the motion of physical parts (e.g., erection of vessels), and 2) those applications where it is the *viewer* that is in motion (e.g., "walk-throughs");
- Distinction should be drawn between those software systems which are limited to the modeling of objects and motion in space and those more advanced, "smart" systems which go beyond such modelling and also possess analytical capabilities (such as crane load analysis or project schedule analysis); and
- The timing of application of simulation appears particularly appropriate and beneficial during the conceptual planning, detailed design, and early construction planning phases of projects. Most benefits, however, are fully realized in the construction phase.

4.2 – System Benefits & Costs

As indicated in the above listing (as well as in the listing of applications in Section 6.0), application objectives and the benefits accrued from utilization of simulation can come in a variety of forms. While many analyses may lead to direct and visible savings or improvement in terms of overall project cost, schedule, or quality, many application objectives represent engineering analyses perhaps never before possible with only manual methods. Thus, effective application of computer graphical simulation can improve both bottom-line project performance and the efficiency with which that is achieved. Listed below are the various types of benefits and additional costs which may be associated with construction graphical simulation.

Benefits

- improved visualization of project design by client personnel and others
- improved design quality (operability, maintainability, and constructability)
- improved planning; optimization of construction process design, construction sequence, and/or resource allocation
- reduced manual planning efforts
- field labor savings
- construction equipment savings/reduced equipment cost
- savings in temporary structures or facilities
- effective communication of planned field operations to field personnel
- elimination or reduction in potentially costly risks, such as delays, accidents, equipment damage, or rework
- for testing new developments in construction materials, methods, and equipment

System Costs

- system computer hardware costs
- system computer software costs
- cost of system design and set-up
- cost of personnel training

Application Costs

- application set-up costs (excluding modeling of geometry)
- cost of modeling geometry and degrees of freedom
- cost of running simulation and conducting analyses

With the exception of hardware costs and software costs (the latter of which is treated briefly in Section 5.1), quantitative benefits and costs from construction graphical simulation can really only be determined on a case-by-case basis. This is due to the fact that project circumstances, system designs, system capabilities, and application set-up efforts can vary so widely. This matter is further complicated by the fact that few organizations apply strict, defensible accounting practices to such benefits and costs, and of those that may, few are willing to share such information. Accordingly, while it has been difficult to quantify such benefits and costs, an analysis of the benefits and costs of the compressor replacement simulation described in the case study in Section 7.0 is presented here:

Compressor Replacement Graphical Simulation

Estimated benefits:

Planning: 200 manhours of manual planning effort saved (a savings of \$4,000)

Execution: 1 day savings in schedule, crew, and equipment

Construction labor savings: \$1,000

Construction equipment savings: \$1,500

Construction schedule savings: \$2,000

Estimated costs:

First costs of system (to be distributed over several projects):

Hardware and software costs: \$57,000 (useful life: approximately 7 yrs)

System design, set-up, and training effort: approximately 75 manhours

System usage effort (this application): approximately 80 manhours

Bottom-Line: If manual planner and system user costs are \$20/manhour, if the system hardware, software, and set-up costs are distributed over 20 projects (approximately 3 projects/year for 7 years), and if both overhead costs and savings are ignored, then additional costs total approximately \$4,500 and benefits total approximately \$8,500. These figures are conservative and do not incorporate the benefits (expected values) from reduced risk. In addition, more complicated applications involving more pieces of equipment could offer substantially higher benefit/cost ratios.

5.0 Software Survey Results

5.1 – Software Evaluation

The following table provides a summary of features for each of the fifteen selected simulation software packages. Each feature listed in the table (i.e., each of the column headings) is briefly described in section 5.2. (An N/A in the software cost column indicates that no response to this particular question was provided.) Of particular relevance for construction simulation applications may be the features that pertain to real-time animation, walk-through capability, simultaneous views, and interference detection, in addition to the various analytical capabilities such as metrology and static force analysis. A brief description of each package and complete vendor information is provided in Sections 5.3 and 5.4 respectively.

Unfortunately, it is not fair to compare the packages solely by reviewing this table since they fall in slightly different application categories and because they vary in complexity. For example, GRASP, IGRIP, CIMSTATION, and ROBCAD are extremely sophisticated robot and automation system simulation systems; WALKTHRU, REVIEW, and DESIGN REVIEW are primarily plant design visualization and walk-through tools (with some added features); ALIAS and ADVANCED VISUALIZER are geometric modeling and advanced rendering tools for advanced visualization; AUTOMOD II is a statistical and mathematical process simulation tool with visualization and animation capabilities; and S1000 is an advanced rendering tool primarily for military battle and flight simulation. Despite the apparent diversity in the various packages, they all do have potential application in the simulation of construction.

Software Evaluation Table

Vendor Name	Software Name	Basic Description	Specific Application Domain	Compatible Hardware	Software Cost	Basic User Interface
Alias Research	ALIAS	modeling, animation, advanced rendering, visualization	industrial design, architectural rendering, scientific visualization	SG IRIS IBM RISC 6000	\$40,000	menus, pop-up menus
Animated Mathematical Technologies	OMEGA	modeling, animation, visualization	factory analysis, product visualization, mechanism animation	SG IRIS	\$20,000	menus, dials, on-line tutorials
AutoSimulations	AUTOMOD II	mat'l handling, scheduling, and process simulation	manufacturing facility design and analysis	SG IRIS 4D, 3000 Intergraph SUN SparcStation	\$51,000	menus, pop-up menus, keyboard
BBN Systems	S1000	advanced rendering, animation, flight simulation	terrain visualization, military simulation and training	SG IRIS	n/a	custom interfaces, control overlays
Bechtel Software	WALKTHRU	animation, visualization, plant walk-throughs	plant design review, construction planning	SG IRIS 25TG SG IRIS 85GT SG IRIS GTX SG IRIS VGX IBM RISC 6000	\$12,000 \$15,000 \$20,000 \$25,000 \$12,000	menus, pop-up menus, dial and button box, space ball
BYG Systems Limited	GRASP	3-D modeling, motion simulation, off-line programming	advanced manufacturing system planning, design, and programming	APOLLO, SUN TEKTRONIX, DEC IBM RISC 6000	\$20,000 to \$70,000	complete and hierarchical menu system, pull-down menus

Software Evaluation Table

Vendor Name	Software Name	Basic Description	Specific Application Domain	Compatible Hardware	Software Cost	Basic User Interface
CADCENTRE Inc.	REVIEW	model review, visualization	construction management, safety and maintenance checks	SD IRIS	n/a	menus, pop-up menus, function keys
Creative Visual Software	VOYAGER	modeling, visualization, motion simulation	conceptual design, product animation	SG IRIS SUN	\$14,900	menus
Deneb Robotics	IGRIP	robot simulation, off-line programming, visualization	robotics research, space, manufacturing, hazardous work automation studies	SG IRIS Intergraph SUN, HP, IBM Tektonix	\$50,000 \$10,000 (nonprofit)	complete and hierarchical menu system, dials, spaceball
Intergraph Corporation	Design Review	design visualization, plant walk-throughs	plant/facility/site model review	Intergraph	n/a	pop-up menus keypad, spaceball
SILMA	CIMSTATION	robot simulation and programming, workcell studies	robotics research, manufacturing equipment simulation	SG IRIS Intergraph APOLLO SUN others	n/a	hierarchical menu system, on-line help, dial and button box, space ball
SimGraphics	VR_Workbench	visualization, animation, simulation	product visualization and design review	SG IRIS 4D Hewlet Packard	\$2,500 + special fees	menus, pop-up menus, 3-D mouse, dataglove
Stephen Dedalus	METASITE	modeling, visualization, architecture	environmental planning, site development, roadway design	SG IRIS 4D	\$12,500	menus

Software Evaluation Table

[illegible]

Software Evaluation Table

Software Name	Customized User Interface	Real Time Animation	View Control & Walk-through Capability	Simultaneous Multiple Views	View Projections	ASCII File Interface	Object Oriented Database	Record/ Playback Capability
ALIAS	limited	yes	limited	yes	o, p, s	custom text filter, animation data	yes	yes
OMEGA	none	yes	limited	no	o, p	animation files	yes	yes
AUTOMOD II	none	yes	limited	no	o, p	non-graphic representation of model	yes	yes
S1000	service provided	yes	yes	yes	o, p, s	simulation scenarios	yes	yes
WALKTHRU	user-defined motion menus	yes	yes	no	o, p, s	object/view position control key frames	yes	yes
GRASP	screen layout and menus	yes	yes	yes	o, p	high level simulation instructions	yes	yes

Software Evaluation Table

Software Name	Customized User Interface	Real Time Animation	View Control and Walkthrough Capability	Simultaneous Multiple Views	Various View Projections	ASCII File Interface	Object Oriented Database	Record/ Playback Capability
REVIEW	no	yes	yes	no	o, p	no	yes	no
VOYAGER	no	yes	yes	yes	o, p	key frame animation	no	yes
IGRIP	menu and screen customization, commands/macros	yes	yes	yes	o, p	motion trajectories, robot programs	yes	yes
Design Review	limited	yes	yes	yes	p	database information only	yes	yes
CIMSTATION	yes	yes	yes	no	o, p	motion trajectories, robot programs	yes	yes
VR_Workbench	yes	yes	yes	no	o, p, s	no	yes	no
METASITE	user command procedures/menus	yes	yes	yes	o, p, s	object/view position control key frames	yes	yes

Software Evaluation Table

Software Name	Customized User Interface	Real Time Animation	View Control and Walkthrough Capability	Simultaneous Multiple Views	Various View Projections	ASCII File Interface	Object Oriented Database	Record/ Playback Capability
ROBCAD	yes	yes	yes		o, p			yes
ADVANCED VISUALIZER	yes	yes	yes	yes	o, p	yes	no	yes
Legend:					o:orthographic p:perspective s:stereographic			