VIRCON: Interactive System for Teaching Construction Management

By Ali Jaafari,[1] Kitsana K. Manivong,[2] and Michel Chaaya[3]

Abstract: The focus in this paper is on a system, developed by the writers, called VIRCON (short for VIRtual CONstruction), in which the traditional construction planning is combined with 3D/4D models of the project. To facilitate current best practices with 3D/4D models of the project, VIRCON has been implemented using object-oriented programming, client/server configuration, database management information, and CAD systems. The real innovation in the design of VIRCON is associated with the unique scheduling and simulation engine developed to integrate cost planning and scheduling and accommodate integrated cross-impact analysis. VIRCON has been validated by means of student group projects on a course where many of the project management techniques are being taught. The teaching approach conducted with the utilization of VIRCON has shown the way forward in creating a dynamic and interactive learning atmosphere. This paper also outlines the experience gained from teaching construction planning fundamentals by means of the VIRCON system.

INTRODUCTION AND BACKGROUND

To provide an effective dynamic planning environment for construction project managers and students, an interactive program is needed. Continual advances in computer technology have created a potential for the construction industry to vastly improve its techniques, processes, and managerial decision-making capabilities. Some areas where computing and information technologies can help the industry are networking multidiscipline teams, planning construction activities, cost management of the project, visualizing the finished product, reporting the status of the project, and assisting the project transaction and communication processes. Integrated visualization systems such as Jacobus Technology's Schedule Simulator and Intergraph's Schedule Review, have paved the way for development of smarter (IT) information technology based techniques, providing managers with a new generation of tools for effective decision making (Parfitt et al. 1993; Kartam 1994; Chin et al. 1995).

Visualization of construction plans enables planners to share complex ideas. It encourages them to be more creative in providing and testing solutions by means of viewing the simulated time-lapse representation of corresponding construction sequences (McKinney and Fischer 1997).

VIRCON has been designed and developed as a facility for integrated planning and visualization of construction plans. In VIRCON the construction management information system (CMIS) is a continuation of the work developed by Jaafari and Wong (1994). The original CMIS was written to operate within a relational database, using the database's built-in programming environment. However, the current version (embodied in VIRCON) has been rewritten in C++/Visual C++ and integrated with an object-oriented database (ObjectStore) for data modeling and management. The shift to C++ has resulted in flexibility in system design and integration with other systems, particularly linking with CAD. The quality and range of graphics have also shown marked improvements compared to the original version. As stated, the system is based on a client-server configuration to permit sharing and integration of information for project team members.

The visualization capability in VIRCON has been created using the programming facility offered by AutoCAD R14. AutoCAD's approach is similar to C++ and fully compatible with the object database used in VIRCON. When coupled with the schedule simulation facility within VIRCON, it is possible to view a time-lapse presentation of the construction sequence in 3D and see details for clashes and other inconsistencies.

Therefore, VIRCON has been researched and developed as both a planning tool and a teaching tool. It has the following aims:

- To act as an interactive system for information manipulation and decision modeling of the construction phase
- To run case projects that can act as the basis for setting student assignments/exercises, enabling them to respond to diverse learning challenges
- To offer Intranet and Internet access for self-paced learning of construction planning fundamentals

In this paper a select number of project manager (PM) systems are briefly discussed. Then significant details of the VIRCON system will be summarized, outlining the underlying innovations and application to specific modules and functions developed and performed by the system. A point comparison of the systems reviewed, including VIRCON, will then be made showing the main differences of each system. Furthermore, validating VIRCON in the classroom will be presented, outlining the experiences gained. Finally, recommendations and future work on the program and the overall teaching methodology will be discussed.

REVIEW OF TYPICAL ADVANCED SYSTEMS

This section provides a short review of a number of advanced systems selected for comparative studies. The intention is to shed light on the types of integrated systems in use or developed in institutions.

Intergraph's Schedule Review

This software uses data from existing project planning software such as Primavera Project Planner, Open Plan, and Microsoft Project. Schedule Review helps analyze the construction process to avoid problems, show the construction sequence of specific units in the context of the overall project schedule, display the project as it should appear on a certain day, or fly through the model while displaying the construction sequence. Querying capabilities are also available to search the

[1]Assoc. Prof., Dept. of Civ. Engrg., Univ. of Sydney, Sydney, New South Wales 2006, Australia. E-mail: a.jaafari@civil.usyd.edu.au

[2]Doctoral Student, Dept. of Civ. Engrg., Univ. of Sydney, Sydney, New South Wales 2006, Australia.

[3]Doctoral Student, Dept. of Civ. Engrg., Univ. of Sydney, Sydney, New South Wales 2006, Australia.

Note. Discussion open until July 1, 2001. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on September 13, 1999. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 127, No. 1, January/February, 2001. ©ASCE, ISSN 0733-9634/01/0001-0066–0075/$8.00 + $.50 per page. Paper No. 21872.

J. Constr. Eng. Manage., 2001, 127(1): 66-75

model for elements that match criteria in the project plan, such as Critical Path or Percent Complete. The results of the query would then be graphically displayed (''Intergraph's'' 1999).

Jacobus Technology's Schedule Simulator

This 4D (3D plus time) system provides an easy-to-use, dynamic environment for visually simulating the sequence of construction based on project scheduling information. Jacobus's Schedule Simulator has the power to integrate project schedules, 3D CAD models, and real-time animation to visually simulate the project according to schedule dates. The software works hand in hand with leading project planning/scheduling tools, databases, and 3D modeling applications in multiple formats. The user can ''play'' the schedule and watch the logic and sequences of activities progressively unfold. Users can also clearly visualize planned activities as they see the project being built in a computer simulation (''PlantSpace'' 1997).

Primavera's Project Planner P3e

P3e is a multiproject planning and control software, built on Oracle and Microsoft SQL Server relational databases for enterprisewide project management. P3e can stand alone for project and resource management, or it can be used in conjunction with other Primavera products, such as P3 and SureTrak, to consolidate decentralized project plans for ongoing cross-project analysis and insight. Summary cost accounts and global resource breakdown structures are just a few of the many features in P3e to anticipate control of project issues and risks. P3e has a straightforward interface that ensures an easy to learn and use software. P3e's capabilities are complemented by an extensive project Web site and companion products for making visible the progress made on projects (''Primavera'' 1999).

OPIS

OPIS (Object model-based Project Information System) is a prototype integrated system that uses a shared object-oriented database as the central unifying core of an integrated project planning system. It includes an interface to an intelligent CAD and drafting program, plan-generation expert system, estimating application, and scheduling application. Integration is achieved by establishing standard models that all applications can adapt and share. This requires a standard data model that specifies the general data-representation approach, standard domain model that provides a language for representing construction information, and project database for information about a specific project that can be shared among multiple computer applications (Froese and Paulson 1994). This prototype system uses standard object-oriented project models to achieve computer-aided project management system integration.

ISICAD

ISICAD (Interactive System for Integrating CAD and computer-based construction systems) captures selected design data and represents these data in an object-oriented project model. Throughout this system, design-related data are captured and stored within construction drawings and reasoning about these data is made possible. The object-oriented model provides computer-based construction systems (e.g., database management and knowledge-base expert systems) performing estimating, scheduling, cost control, etc. with necessary data input. Hence, it serves as a unified medium for integrating design and construction (Kartam 1994).

Summary

As noted from the short description of the systems reviewed, there is great emphasis in integrating construction planning information with 3D CAD models of the project. The most popular computing technologies appled to develop such systems are object-oriented techniques, databases, knowledge-base systems, and CAD systems.

In addition, the prototype systems, such as OPIS and ISICAD, have been developed as an extension to CAD, knowledge-base, and PM software. As seen, most systems primarily interface with popular PM software, such as Primavera's Project Planner and Microsoft's Project.

The researchers of OPIS and ISICAD acknowledge that these prototype systems are for demonstration and research purposes, for the time being, because it requires an enormous amount of resources to push such systems toward commercialization. Most commercial systems have evolved using low-level programming techniques. The prototypes, on the other hand, have been built using high-level programming techniques. Thus, system performance differences stem from the different development techniques used.

VIRCON SYSTEM

The following sections summarize VIRCON and highlight the underlying innovations incorporated in this system. VIRCON consists mainly of two modules (Fig. 1): CMIS and Visualization.

CMIS

CMIS is a Windows-based program written in MS Visual C++/C++ that provides an interface for data input as well as analysis and reporting. The user builds up a dedicated shared databank for each project within the CMIS shell by entering the relevant data interactively into specific fields provided by a series of dialog windows. Once a project is created within CMIS, the data are automatically stored in the object-oriented database. In the design of CMIS, the database management functions have been separated from data processing and reporting functions. The separation allows maintenance of data in real time and sharing of the information among all processing functions. Fig. 1 shows the processing functions incorporated within CMIS, they are (1) cost/budget management; (2) time management; (3) resource management; (4) risk management; (5) earned value analysis; (6) reporting; (7) cash flow analysis; and (8) alternative scenario analysis.

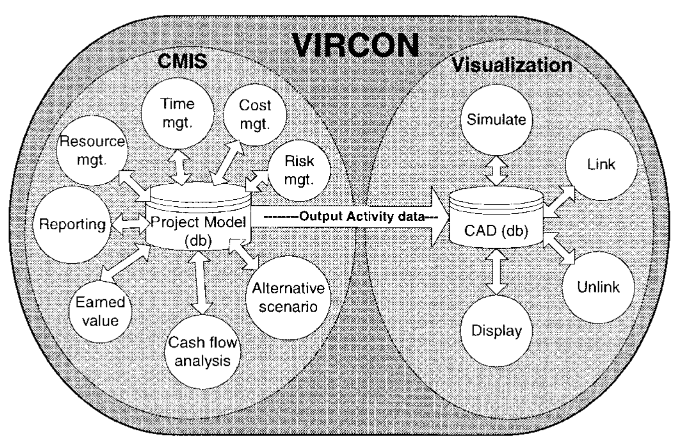

FIG. 1. Broad Architecture of VIRCON

J. Constr. Eng. Manage., 2001, 127(1): 66-75

CMIS—SPECIAL FEATURES

Although the general approach followed in the development of CMIS is based on current best practices in the construction industry [i.e., Barrie and Paulson (1992), Harrison (1985), and Gould (1997)], there are a number of innovations that make it different from similar systems that are commercially available:

- It embodies a novel dynamic scheduling approach, which is far more adaptable to accommodating changes than a critical path method or program evaluation and review technique, so impacts of delay or acceleration on cost, for example, can be forecasted [see Jaafari (1996) for more details].
- It provides a basis for integration of schedule and cost (Fig. 2), as well as a more accurate basis for earned value and risk analysis functions.
- It provides a facility for the stochastic analysis of the schedule; i.e. it will accept stochastic input data and generate a distribution for the project duration from which mean and variance or characteristic values can be estimated.
- It enables derivation of a distribution for the total cost estimate, which will reflect the uncertainties associated with the project duration, thus enabling multiple scenarios to be analyzed for locating the optimum plan.
- It allows conducting the stochastic analysis at the activity or work package level as part of isolating high risk areas of the project.
- It provides for monitoring of risks at each update interval by plotting the time and cost risk bands (defined as 90% characteristic-value−mean-value of the respective time or cost function) against time.
- It is possible to track transactions and changes over time or produce special reports based on specific information requirements.
- It provides a common project model [generic work breakdown structure of the project components (Fig. 3)] for sharing of program module data and multiuser access.

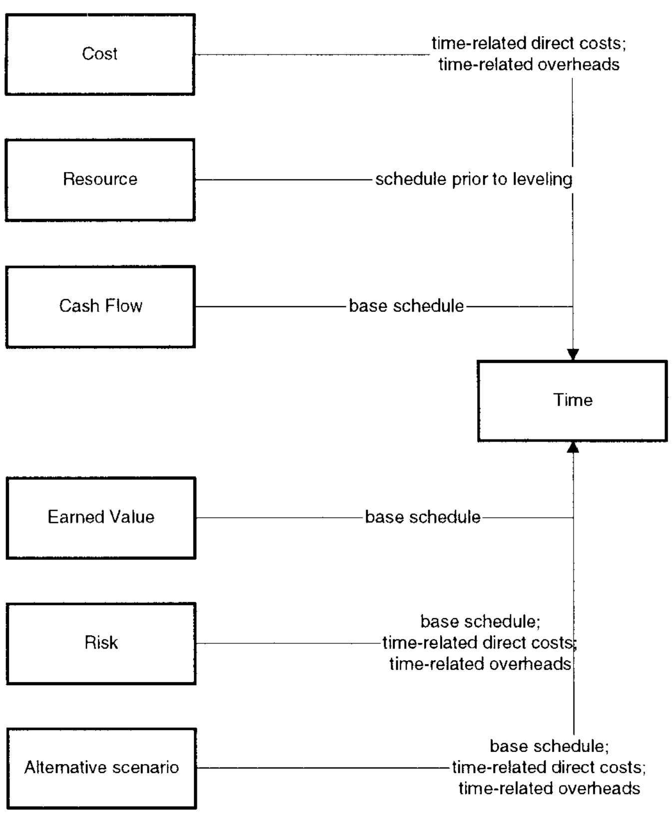

FIG. 2. Interrelationships to Time Function

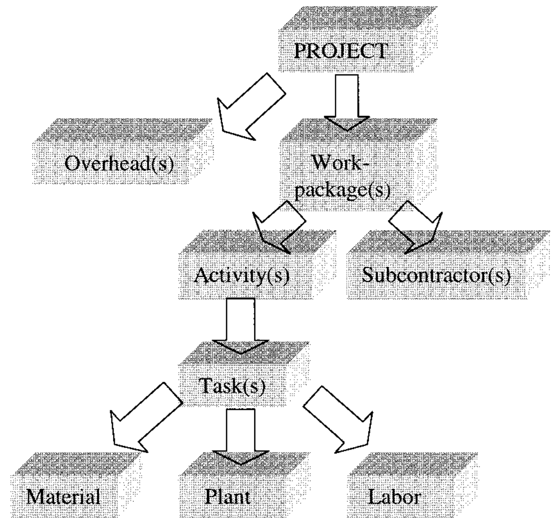

FIG. 3. Work Breakdown Structure

As CMIS was designed and developed in-house, the opportunity to take advantage of the latest advances in system design and integration of functions was fully exploited. In-house design offers flexibility in that it does not require approval from owners of commercial systems. It is not dependent on connecting different systems together for a particular purpose. The processing functions have been designed as separate program modules held within a dynamic library linked to the project database. These programs access the same data sets for each project and exchange information among themselves. This design is well suited to a client/server setup in the sense that the database holding the project data is placed on a server and program modules will be located on client machines accessing the data via a local area network or even the Internet. But more importantly, the functions designed in CMIS are flexible in that new research can be readily incorporated into the system for practice enhancements or teaching purposes. Therefore, this configuration allows a much easier accommodation of future improvements to functions or changes in technology (with no need to wait for the next commercial release).

VISUALIZATION MODULE

The concept of visualization (creating a virtual reality model of a project) has been applied in most fields, such as architecture, biology, and arts, providing 3D graphics and animation to aid spatial interpretation of complex objects, creatures, or their movements. Visualization will reveal details normally beyond ordinary perception. There are basically two types of virtual reality (VR) models: immersive and nonimmersive. In immersive models the subject wears cyber headgear and gloves that will have the effect of the user feeling located within the VR environment of the model and interacting with its elements. Nonimmersive models display objects on computer screens. Manipulation of models can be achieved using normal input devices such as a mouse or keyboard. The VR environment selected for VIRCON is that of the nonimmersive type, as this facilitates a collaborative planning approach as well as sharing of information.

Construction planning lends itself well to the application of visualization, due to its complexity and the multiple ways in which it can be approached. For an experienced planner, the mental framework to visualize construction operations is generally well developed. This ability is acquired through years of practice and experience of the actual projects in the field.

J. Constr. Eng. Manage., 2001, 127(1): 66-75

However, even experienced planners often fail to think of all aspects of their plans and having a VR model of the project will prompt them to consider all missing details (e.g., safety and access) (Barsoum et al. 1996; Soedarmono et al. 1996; Wakefield 1999). But more importantly, VR conveys the right messages to a client, government agency, or public group (Eberhard 1996) on the subject project.

The ability to visualize the physical dimension and thus determine the feasibility of the decisions made is not generally well developed in students. They have insufficient mental references to visualize the size of the task to be undertaken on a construction site. For this reason a tool that can assist in visualizing construction plans and sequences is considered helpful and engaging, although not a substitute for ''real'' world experience. As stated already, construction is a complex process and the schedule simulator facility within VIRCON is intended to improve the planner's or student's understanding of how a construction sequence will turn out in the real world, by means of a simulated time-lapse assembly of the components within a 3D VR environment.

The visualization module provides the following tools in VIRCON:

- A ''schedule simulator'' facility that compresses activity durations into seconds and ''constructs'' a time-lapsed 3D representation of the constructed facility/plant according to the schedule
- A ''3D WalkThrough'' tool that allows the planner to zoom and view details of the project

The module was developed as part of an existing CAD system, which has in-built object-oriented programming capabilities. The 3D WalkThrough tool was provided via the 3D model of the project held within the CAD system. In essence, VIRCON is a hybrid system where half of the visualization module's functionality is derived from the CAD system's functionality.

In short, the visualization module imports the construction planning data from CMIS. The walk-through and schedule simulation functions of VIRCON are performed within the CAD environment according to the program extensions.

VISUALIZATION MODULE—SPECIAL FEATURES

The visualization module's Schedule Simulator is worthy of note because it utilizes an existing CAD system's (AutoCAD R14's ObjectARX) application programming interface environment, without the need to develop a CAD environment system. This feature was customized to provide Schedule Simulator's functionality.

Fig. 4 depicts the flowchart of the methodology embodied within VIRCON for creating a simulated construction sequence by means of the schedule simulator. Prior to the start of the simulator, the 3D CAD model of the project needs to be broken into components. The division will correspond to the relevant activities in the construction plan. In this manner it will be possible to establish a link (manually or automatically) between the 3D image of a component and its corresponding activity object. At present linkages are created man-

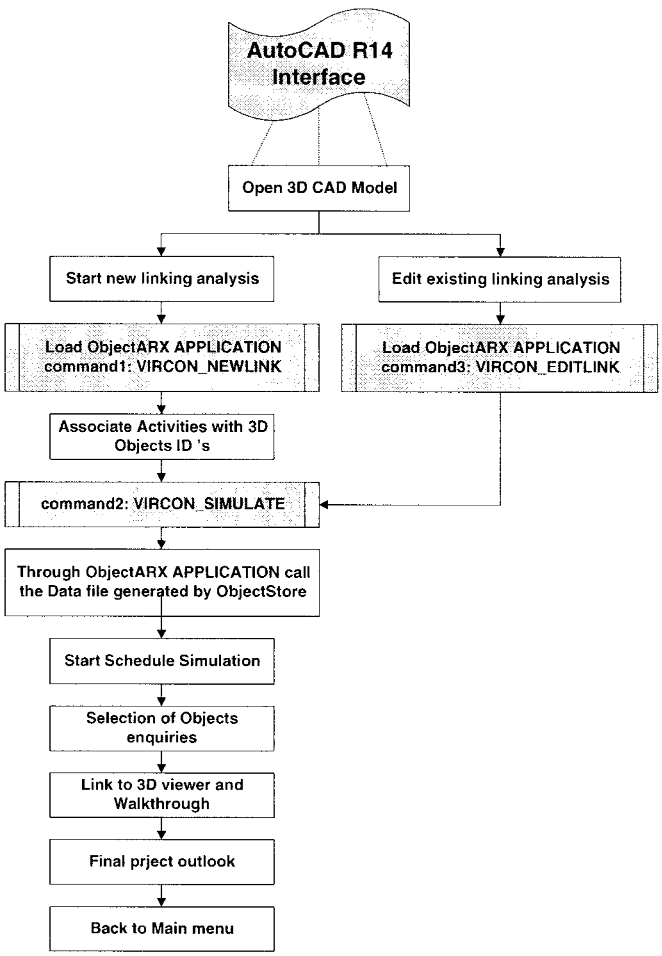

FIG. 4. Flowchart of Schedule Simulator

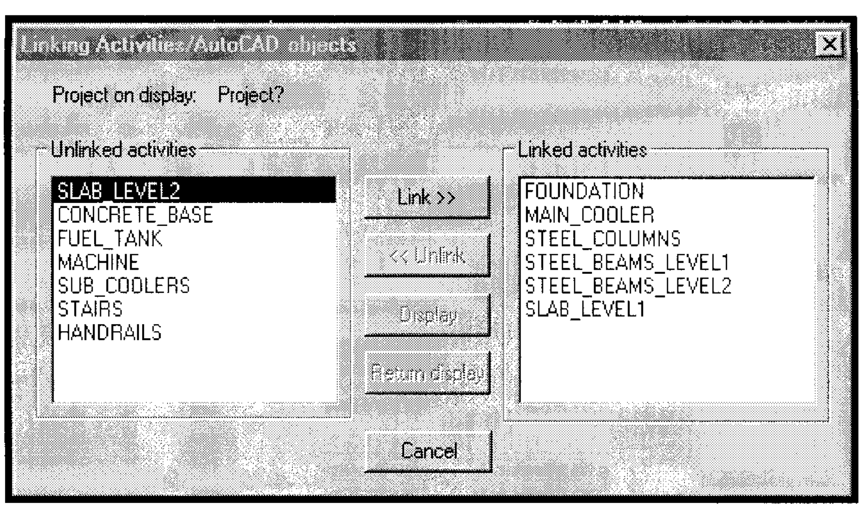

FIG. 5. Typical Interface for Manipulating CAD Objects and Activities

J. Constr. Eng. Manage., 2001, 127(1): 66-75

ually by invoking the VIRCON_NEWLINK command in the system. An interface window to create or manipulate the connections between the activities and their respective 3D CAD objects will then be displayed (Fig. 5). Links can be released at any time with the ''Unlink'' button. Verifying an activity-to-3D object link is provided using the ''Display'' button. The ''Return display'' button shows the original 3D CAD model. To start the simulation, the VIRCON_SIMULATE command is invoked. After simulation, it is possible to save the linking details as files, if desired, for future use or editing. The saved linked files are available by means of the VIRCON_EDITLINK command. Thus, editing of previous links can be made. The suitability of a new construction plan can then be tested by invoking the schedule simulator function.

VIRCON ADVANTAGES

VIRCON has a number of key advantages, chief among which the following can be noted:

- It integrates construction-planning information under a single shared database, utilizing an object structure.
- It supports scenario analysis and provides a capability to apply ''what-if'' questions effectively and interactively.
- It provides a graphical simulation of the proposed work plan and helps constructibility analysis and optimization of work plans.
- It provides a means for interdisciplinary communication and teamwork.
- It provides an effective means for conveying the planning results.
- It allows early problem detection, including clashes in design and overall construction sequencing.
- It provides a means for better interfacing of design with construction plans.
- It allows querying of 3D model objects using the CAD environment.

POINT COMPARISON

Table 1 shows the comparison of the selected systems including VIRCON. As seen, key characteristics have been selected to compare the systems. They are functional features, support systems, development technology, special functions/techniques, and system status. Note that the systems selected and characteristics chosen are not intended to create any bias in the systems toward the VIRCON system but are merely to show the varying features that these types of systems can encompass. The results of the comparison can be summarized as follows.

Intergraph's Schedule Review and **Jacobus Technology's Schedule Simulator** are very similar systems, although the latter system provides more features in animation and, more importantly, in integration with other compatible systems, such as PM software, databases using ODBC (Open Database Connectivity), and OLE (Object Linking Embedding).

Primavera's P3e is a PM software that provides the most important features needed by a PM firm. From the senior management level to the project and resource management levels, this system modifies the fundamental PM functions, such as the management of risk, schedule, cost/budgeting, and resources, for a PM firm. Also, the important features of client-server and Internet configurations (facilitated by the project Web site) allows multiuser access.

OPIS and **ISICAD** are research prototype systems, which utilize other applications, such as CAD, PM software, knowledge bases, and databases, for the AEC industry participants to share and integrate information. The research on these systems concentrates on a project model created to facilitate the integration of application systems to exchange, store, and process common data. These project models have been specifically designed and developed using the object technology.

VIRCON facilitates some aspects of the features described in the selected systems. For example, under functional features, VIRCON's Visualization module allows the user to prepare and see the 3D model simulated on the screen. Under support systems, CMIS provides as many PM functions as Primavera's P3e. However, CMIS does not provide different levels of reporting for management and does not manage multiple projects. Also CMIS cannot be applied over the Internet but can be applied over a local area network. In development technology, CMIS compares well with others as it uses an integrated project model for the execution and analyses of its PM functions, as well as utilizing an object-oriented model and a database management system. Hence, all PM program modules in CMIS use the same project data that are held within a shared database. In addition, CMIS and VIRCON do not utilize knowledge bases or expert systems to aid in planning and control of projects. The planning and monitoring of projects should be an ''art,'' and a computer program should not dictate how one plans a project. Such expert systems should only facilitate in systematic information management (such as managing historical project data). But in the case of visualization, expert systems would be useful and can automatically link 3D model components to the construction activity or activities using rules and similar processes. Jacobus's Schedule Simulator uses this technique effectively.

SUMMARY

As shown from the point comparison, VIRCON compares favorably with the advanced systems for educational and practical uses. As will be described, from the evaluation and tests conducted, VIRCON has proven to have the potential to facilitate many of the features offered by the advanced systems.

TESTING AND VALIDATING THE SYSTEM

To verify and validate the VIRCON system, it was applied as a client-server system established in 1999 as part of a course module in the undergraduate construction and project management program at the University of Sydney, Australia. Ninety students were enrolled in this module, who were then divided into nine groups of 10 students.

TEACHING AIMS AND OBJECTIVES

The aim of the above course module is to impart knowledge and skills in integrated IT-supported planning, scheduling, and cost estimation of capital projects, including formal documentation and submission of a report, to be known as the ''prebid'' report. Each group was required to competitively bid for a case project. The entire project planning, scheduling, cost estimation, and documentation were required to be done using the VIRCON system provided on-line. This enabled students to view the relevant design details, plan the construction of works based on resources needed, estimate and evaluate activity duration, simulate the construction sequences, and assess the project as a whole, including evaluation of changes, risks, and uncertainties.

Thus, the learning objectives were as follows:

- To introduce a ''real-life'' case project to the groups for competitive bidding
- To create a collaborative learning environment by setting up client-server applications
- To set up and customize VIRCON for secure group work application (Fig. 6)

J. Constr. Eng. Manage., 2001, 127(1): 66-75

TABLE 1. Point Comparison of Selected Systems

Selected systems (1)	Functional features (2)	Support systems (3)	Development technology (4)	Special functions/techniques (5)	System status (6)
Intergraph's Schedule Review	Integrates with project schedules and 3D CAD models Graphical simulations and animation	Intergraph's DesignReview Adobe Premiere Primavera's Project Planner Welcome Software Technology Open Plan Microsoft Project	N/A	Query functions to search model for criteria asked (for example, search for model elements that fall within critical path) Reviews schedule sequences in stationary and animated mode Associates tasks from schedule with element models automatically or manually	Commercial
Jacobus Technology's Schedule Simulator	Integrates with project schedules, 3D CAD models, real-time animation, and databases Graphical simulations and animation (similar to Intergraph's Schedule Review	PlantSpace DesignSeries Intergraph PDS Rebis OMNI-series, AutoPlant, and Pro-series Primavera's Project Planner (P3) and SureTrak Project Manager PlantSpace Enterprise Navigator PlantSpace Integration Tools	C++ programming language	Relate physical model elements with schedule activity relationship links Queries can be performed under certain rules and results shown graphically Use of animation to control construction sequence Simulate different aspects of same schedule side by side in multiple windows and multiple views Data connectivity using ODBC and OLE2	Commercial
Primavera's Project Planner P3e	Hierarchical PM consisting of WBSs, OBSs, centralized resource pools, cost account hierarchy, and custom activity coding structures Tracking and analysis (e.g., compares baseline, planned, and actual and remaining values) Proactive control of project issues (e.g., impact calculated based on probability for costs, resources, and schedule Resource and cost management Performance measurement Project documents and steps Project reporting and communication Project Web site (e.g., wizard to publish complete project Web site including activities, resources, and documents)	Portfolio analyst groups together any number of projects for comparison and analysis (for information at any level of detail for clear presentation and discussion) Progress reporter provides full work-group support and coordination of project resources; each member uses progress reporter to communicate time sheet and activity status feedback directly to PM and project database via local area network, e-mail, or Internet	N/A	Scalable PM utilizing Oracle and Microsoft SQL server relational databases Simultaneously manages multiple projects and supports-multiuser access across department or entire enterprise Supports unlimited number of projects, project groups or programs, activities, baselines, resources, and user-defined WBS and activity codes	Commercial
OPIS	Approach uses integrated systems by establishing standard models that applications can adopt and share Features are essentially integrated application systems (i.e., CIFECAD is prototype CAD and drafting system used to create 3D models of project; AutoPlan is expert system that creates construction plan using knowledge bases; InCost is integrated estimating module; and InTime estimates schedule dates for activities)	CIFECAD AutoPlan InCost InTime	Object—C object-oriented programming language (for database project model)	Standard domain data project model used for integration of systems AEC industry can then adopt this approach for integration between many application systems	Prototype
ISICAD	Features from AutoCAD and knowledge-base construction systems Design-related data to be stored within construction drawings so that reasoning about data is possible	AutoCAD Construction knowledge bases Databases	C++, C programming language AutoCAD R12	Approach allows for sharing of engineering and construction knowledge by multiple people facilitated by object-oriented project model	Prototype
VIRCON	Scheduling and time management Cost/budgeting Performance monitoring (earned value) Risk management Resource management Cash flow analysis Reporting Alternative scenario analysis Project archiving 3D project modeling Schedule simulator Animation	ObjectStore (object-oriented database) CMIS Visualization module AutoDesk WalkThrough	C++/C Visual C++ AutoCAD R14 ObjectARX	Dynamic scheduling technique Integrated function modules Schedule simulator (graphical animated construction sequence)	Prototype

Note: N/A = does not apply

J. Constr. Eng. Manage., 2001, 127(1): 66-75

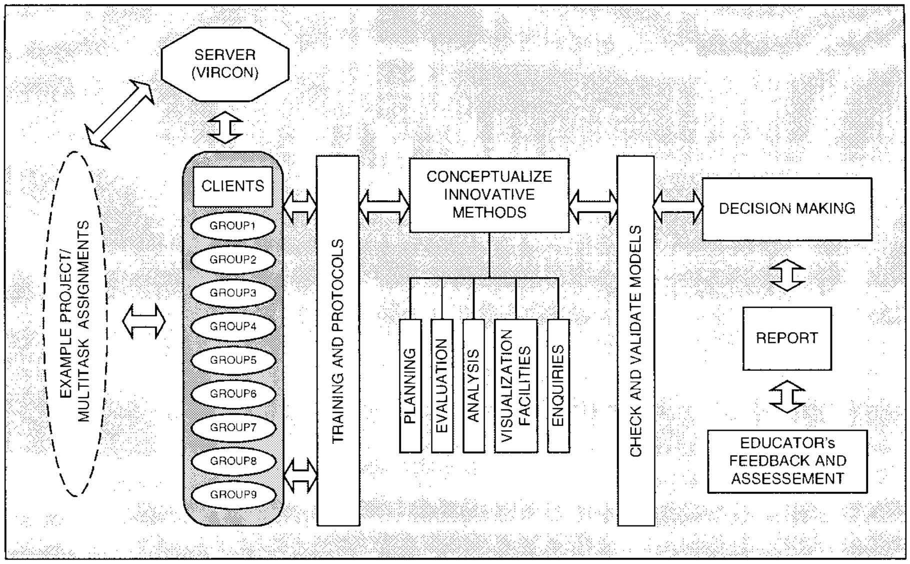

FIG. 6. Educational Process Using VIRCON

TABLE 2. Key Dates for Submissions

Milestone (1)	Date (2)	Marks (3)
Group assignment definition and briefing	Monday, April 12	N/A
Completed WBS and quantity estimation	Monday, April 27	4
Construction plan and estimates of resources	Monday, May 10	4
Complete plan, schedule, and estimate	Monday, May 17	4
Submission of draft report	Monday, May 24	4
Final report deadline	Monday, May 31	16
Presentation to board of review	Thursday, June 3	8
Total		40

Note: N/A = does not apply.

- Establish milestone dates for performance monitoring, feedback on intermediate submissions, and formative assessment (Table 2)
- Provide timely assistance and tutorials for each group to facilitate experiential learning and interaction with the system.

Case Project

The project introduced for this assignment was the proposed new Economics Building at the University of Sydney, which is currently under development. The building comprises approximately 7,200 m^2 and is scheduled for completion in mid-2001.

The proposed building has five floors; the two lower floors are fully air-conditioned to house computing systems and graduate research areas, and the top three floors will be naturally ventilated and will house lecture halls and departmental offices. The building is based on a conventional design, using masonry up to the lower two floors, and a ''high-tech'' design for the three top floors. That is, the design is based on prefinished metal cladding panels, an innovative approach to the roof design, and a complex metal/plastic sun screening to the north elevation.

There is also an open atrium space to the three upper floors, which serves two purposes:

- Provision of natural ventilation of the building
- Spatial relief to enhance the whole of the three top floors

At the time of writing, the project is proceeding, pending the local authority permit.

Assignment

Each group had to submit electronically, in designated directories (as well as a formatted hard-copy document), an overall prebid report on the case project. The report had to include the following:

- An executive summary
- Description of any construction planning and method innovations and how these affect the competitiveness of the formulated plans
- Identification of the top 20% of items making up >80% of the contract sum
- Alternative construction methods and selection of the preferred method for each major (top 20%) item, as well as development of a proper method statement
- Construction plans and schedule, and overall staging of the works
- Cost estimate for the entire project (the bottom 80% items were to be estimated using an adjusted published schedule of rates, but the risk of cost overrun on such estimates was required to be evaluated and included using the VIRCON system)
- An overall plan for the management of construction OH&S, environmental impacts, and quality assurance, including a responsibility allocation chart, resources, and cost.
- An estimate of the indirect costs and preliminaries that must also include provision of welfare and site amenities and an allowance for contractual liabilities on this project, such as security (surety), workers' compensation insurance, and third party indemnity
- An analysis of the expected competition and how confident a particular group is of winning against the competition

To accomplish the tasks stated above in a reasonable time frame, key submission dates were set (Table 2). Groups were required (in formal attire) to present their winning prebid reports to a board of review. The board would then evaluate and select the winning group. Both quality of submission and conformity with the brief (terms of reference) were the basis of assessing the work done by students.

J. Constr. Eng. Manage., 2001, 127(1): 66-75

SYSTEMS' SETUP

Method of Approach

To provide uniformity of approach and test VIRCON, there was a ban on the use of any other system for planning and cost estimation on the case project. However, word processors were permitted to consolidate reports. In addition to providing tutorial and laboratory sessions, to further assist students using VIRCON, a manual was provided on-line. Also, examples of data input and report generation facilities were provided to facilitate self-learning as far as possible.

Location of Programs and Files

Each group was given access to an NT workstation as well as a user name and password. To access and store group files and documents, the NT server was connected to the workstations to serve as a central data repository, as well as providing administration facilities, but most importantly it facilitated multiusers in a collaborative environment required by VIRCON.

Peer Evaluation

To further improve the VIRCON system and student learning, each group member submitted an evaluation form on the VIRCON system, the teaching method, and peer evaluation of other group members.

TEACHING RESULTS

Progress Experiences

During the course of the assignment, due emphasis was placed on students acquiring the necessary background knowledge on construction planning techniques. Each group was to nominate a group leader or coordinator to coordinate and direct other members in the group. The group divided the tasks among members in accordance with a work plan. The group leaders would then consult the writers, who acted as module coordinators, on any problems they faced (e.g., tasks, terminology, and system interface).

It was found that most students were capable of operating and using computer programs, in particular Microsoft products. Understandably the use of the Windows-based applications, CMIS and VIRCON, posed no real problem in student interaction.

Construction Management Fundamentals

As mentioned already, parallel with learning how to use VIRCON, students had to acquire knowledge about the fundamentals of construction project planning and management. The nominated textbooks and reference material were helpful, although many students had gained some knowledge during their work experience conducted earlier (i.e., 13 weeks minimum practical experience after completion of the third year and before commencement of the fourth year). They had also completed construction engineering courses during their second and third years. In addition, several tutorial sessions were held with the competing groups to assist them in proper understanding and applications of the relevant fundamentals, formulation, and evaluation of construction plans and related studies. CMIS also helped students in their endeavor by means of on-line provision of sample tutorials and information contained in the manual.

VIRCON System Use

During the process of entering data into the system, a minority of students thought that CMIS would plan their project for them. Clearly it was found that CMIS did not have ''wizard'' functions because it was up to the users to come up with their own WBS and associated input data. A few minor bugs were reported by students, who also made some useful suggestions that were implemented to improve the VIRCON system performance and facilitate teaching. For example, most data that were computed automatically by the system would have been well known to an experienced construction planner. However, novice students learning construction planning fundamentals blindly entered data into the computational fields. Thus, the relevant fields had to be disabled.

Student groups preferred more graphical images or help functions. For example, when students or novice users begin to create their project databanks, an ''agent'' or wizard would direct the user to the definition or processes that are involved in inputting or obtaining a value for some data field or function. Applications of this sort are now widespread. Microsoft agents from the Microsoft Corporation allow such applications to be created. This feature will be implemented in due course.

Finally, network system administrators have to acknowledge that the network will break down once in a while. In VIRCON's case, delays occurred and consequently an extension to the assignment dates had to be given. From an administrator's point of view, this was not a major concern, however, it was more of an educator's nightmare, because this interrupted the overall schedule of the submissions students had to adhere to.

Group Reports

Table 3 shows a summary of the groups' results (cost and duration estimates) generated using the VIRCON system. Note that the budget allocated for the same scope of works by the client was approximately $13,250,000 for a duration of about 52 weeks. Note also that the bid packages in the assignment given to the students do not contain all packages that the client

TABLE 3. Group Bid Results

Group (1)	Bid cost (2)	Duration (weeks) (3)	Rank (4)
Client	$13,250,000	52	N/A
1	$11,324,000	50	5
2	$10,240,000	46	3
3	$10,597,000	44	2
4	$11,695,000	50	6
5	$10,785,000	48	4
6	$11,729,000	37	7
7	$10,800,000	35	8
8	$9,068,000	35	9
9	$12,403,000	39	1

N/A = does not apply.

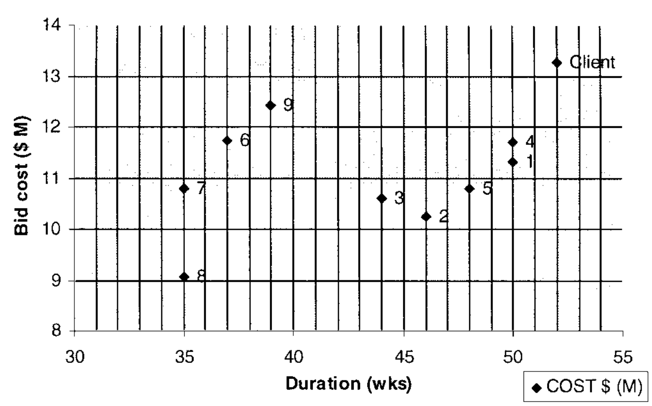

FIG. 7. Distribution of Prebid Results

J. Constr. Eng. Manage., 2001, 127(1): 66-75

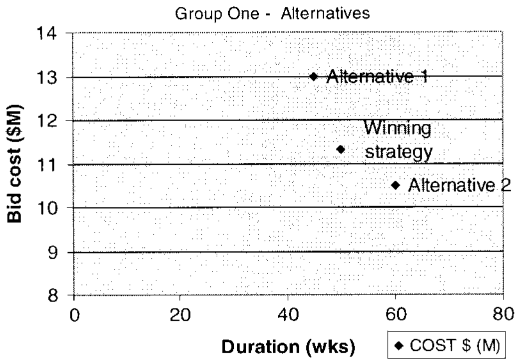

FIG. 8. Sample Cost and Schedule Trade-Off

estimated. Fig. 7 also indicates the distributions of these results. As can be seen from this figure, ''bid'' points are widely distributed. Some are close to the client's budget and others are not. In practice, because this project is heading for a traditional head contracting and fully documented contract, Group 9 (Table 3) was selected as the winner in terms of meeting budget and schedule targets. Its prebid estimate was $12,403,000, and it had a duration of about 39 weeks. For brevity, this ranking was not based on other aspects of the prebid report, such as management of quality and safety. Only time and cost estimates were used to rank the groups' bids.

Although Group 9's bid was underbudget and came close to the client's estimate, so too was their target schedule, which was earlier than the client's duration of 52 weeks. The duration was set as the criteria (minimum duration) in the selection process because it was one of the client requirements. Note that Groups 6–8 were not considered because their bids were not logical and contained errors. These groups were missing certain cost items, activities, tasks, and so on.

The use of VIRCON enabled the groups to learn the trade-off that exists between the project's objectives of total cost and construction duration. The groups were required to plot cost against different durations to locate the optimum duration (defined as a duration at which the estimated total cost is minimal). This type of analysis would not have been possible in such a short period of time had it not been for the availability of VIRCON. Fig. 8 shows an example of a group's trade-off between total cost and duration.

Future Teaching

Based on the success of the first trial use of VIRCON for teaching, a new course called Project Planning and Tendering has been planned. It will be an entirely problem-centered, computer-mediated course integrating IT skills with project planning and estimating competencies. The assignments will be customized to fit the purpose of the course.

Advantages of Teaching VIRCON

There are many different ways VIRCON can be utilized for teaching construction management. The following are some of the ways that VIRCON can be taught for the new course:

- Student groups can be asked to plan a project (scheduling only) for meeting a contractual completion date.
- An estimation of the total cost of the above can then be made.
- The duration at which the total cost will be minimum can be found.
- The cost penalty associated with the contractual completion date can be established.
- The stochastic analysis can be used to perform and estimate variances for both cost and time for formulating contingency provisions.
- Students can be given simulated progress data and asked to locate major deviations and come up with recovery plans.
- Students could be asked to redesign parts of the project to minimize total cost or cut delivery time, or both.
- Students could be asked to reflect on the above and come up with suggestions to improve the data (case project), thus working backward on better planning and controlling of projects.

CONCLUSIONS AND FUTURE WORK

This paper described VIRCON, an integrated planning and educational system researched and developed for teaching and learning construction planning fundamentals. The basic system design philosophy embraced is that of intuitive user interaction with VIRCON supported by on-line help and guidance. The system capabilities extended to interactive planning of construction activities and tasks, risk analysis, alternative construction method investigation, cash flow plotting, and preparing various reports.

VIRCON's modules were described briefly, highlighting the innovative methods developed and technologies used. The paper described the CMIS module that was developed in-house using object-oriented techniques. The visualization module in VIRCON was programmed to operate within the general environment of a CAD system. It was found to be a cost-effective way to respond to the visualization needs in VIRCON, without having to develop complex computer programs. One advantage of this approach is that future 3D capabilities provided by major CAD systems will be on tap by substituting the new release for the present version of the CAD system used.

The teaching environment provided an opportunity to test VIRCON and assess the feasibility of conducting fully integrated computer-based experiential learning. VIRCON provided flexibility in implementation, which consequently enabled quick fixes and improvements based on the suggestions received from students during their project work. It was found that, due to its modular (object-based) structure, VIRCON could be customized to fit the requirements in a relatively short period of time. Therefore, the experience gained from teaching, implementing, and developing VIRCON set a precedent for future module improvements and additions.

ACKNOWLEDGMENTS

VIRCON was initially planned as a joint project of the Departments of Civil Engineering at Sydney University and Stanford University, Stanford, Calif. The writers gratefully acknowledge the advice and input provided by Dr. Martin Fisher of CIFE at Stanford University. VIRCON was financially supported by a grant from the Department of Employment, Education, and Training of Youth Affairs. A project reference group, comprising a panel of academics and practitioners, oversaw the conduct of research and development work leading to this present version of VIRCON. The writers would like to thank them for their guidance and expertise. Also the support and facilities provided by the Department of Civil Engineering of the University of Sydney are acknowledged with gratitude. Special thanks go to John Krey, senior PM, Facility Management Office, University of Sydney, for facilitating the use of the proposed Economics Building project as a student project.

APPENDIX. REFERENCES

Barrie, D. S., and Paulson, B. C. (1992). *Professional construction management: Including C.M., design-construct, and general contracting*, 3rd Ed., McGraw-Hill, New York.

Barsoum, A. S., Hadipriono, F. C., and Larew, R. E. (1996). ''Avoiding falls from scaffolding in virtual world.'' *Proc., 3rd Conf.—Computing in Civ. Engrg.*, ASCE, New York, 906–912.

J. Constr. Eng. Manage., 2001, 127(1): 66-75

Chin, S., Liu, L. Y., Stumpf, A. L., Ganeshan, R., and Hicks, D. K. (1995). ''CADD-based construction information management for corps of engineers projects.'' *Proc., 2nd Conf.—Computing in Civ. Engrg.*, vol. 1, ASCE, New York, 187–194.

Eberhard, D. D. (1996). ''Quicktime VR and interactive CD-ROM applications for communicating project alternatives.'' *Proc., 3rd Conf.—Computing in Civ. Engrg.*, ASCE, New York, 806–811.

Froese, T. M., and Paulson, B. C., Jr. (1994). ''OPIS: An object model-based project information system.'' *Microcomputers in Civ. Engrg.*, 9, 13–28.

Gould, F. E. (1997). *Managing the construction process: Estimating, scheduling, and project control*, New Jersey, Prentice-Hall, Upper Saddle River, N.J.

Harrison, F. L. (1985). *Advanced project management*, 2nd Ed., Aldershot, Gower.

''Intergraph's Schedule Review.'' (1999). ⟨http://www.intergraph.com/visualization/schedrev.asp⟩.

Jaafari, A. (1996). ''Time and priority allocation scheduling technique for projects.'' *Int. J. Project Mgmt.*, 14(5), 289–299.

Jaafari, A., and Wong, K. H. K. (1994). ''Advanced construction management information systems.'' *Proc., Nat. Constr. and Mgmt. Conf.*, Institution of Engineers, Australia, and School of Civil Engineering, University of New South Wales.

Kartam, N. A. (1994). ''ISICAD: Interactive System for Integrating CAD and computer-based construction systems.'' *Microcomputers in Civ. Engrg.*, 9, 41–51.

McKinney, K., and Fischer, M. (1997). ''4D analysis of temporary support.'' *Proc., 1997 4th Congr. on Computing in Civ. Engrg.*, ASCE, New York, 470–476.

Parfitt, M. K., Syal, M. G., Khalvati, M., and Bhatia, S. (1993). ''Computer-integrated design drawings and construction project plans.'' *J. Constr. Engrg. and Mgmt.*, ASCE, 119(4), 729–242.

''PlantSpace schedule simulator.'' (1997). ⟨http://www.bentley.com/products/peproducts/pdfs/schsim.pdf⟩.

''Primavera project planner for the Enterprise P3e.'' (1999). ⟨http://www.primavera.com/products/p3e.html⟩.

Soedarmono, D. R., Hadipriono, F. C., and Larew, R. E. (1996). ''Using virtual reality to avoid construction falls.'' *Proc., 3rd Conf.—Computing in Civ. Engrg.*, ASCE, New York, 899–905.

Wakefield, R. R. (1999). ''Computer modeling and simulation for construction.'' *Engrg. Trans.*, Thailand, May–August, 87–98.

J. Constr. Eng. Manage., 2001, 127(1): 66-75