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AUTOMATING THE PROCESS OF BUILDING SIMULATION MODELS

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ABSTRACT

This paper presents concepts and implementations for automated construction simulation modeling for aggregate crushing plant operations (CRUISER) and for earthmoving operations (AP2_EARTH). In the automated modeling environment, the user can specify a real world construction system: physical components, required resources and other system information. A simulation model is automatically constructed, and the experimentation can then be performed using the generated model. One of the major advantages of an automated modeling process is that it allows a user to build and experiment with a simulation model for a real world system without being proficient in simulation as required by current simulation packages.

1 INTRODUCTION

Construction operations are characterized by the random nature involved in construction processes and by the dynamic interactions between resources and processes (Paulson et al. 1987, Shi and AbouRizk 1994). Many traditional analytic methods (e.g., CPM) fail to address these key issues and have shown various limitations in planning and scheduling construction projects. Computer simulation provides advantages in modeling uncertainties and dynamics, and has been proven to be an effective tool for planning and scheduling construction projects (Halpin 1977, Vanegas et al. 1993).

Computer simulation is defined as the process of designing a mathematical-logical model of a real world system and experimenting with the model on a computer (Pritsker 1986). From the user's prospective, three major phases can be identified in simulation to resolve a real world problem as shown in Figure 1: modeling, experimentation and optimization.

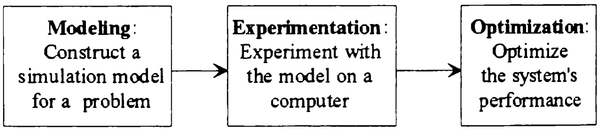

Figure 1: Three Phases of Computer Simulation

A model is a description of a system. The modeling process involves describing the stated problem in terms acceptable to a computing system (Pritsker 1986). During this stage, the modeler is required to understand the real world problem, construct a model for it, collect data for running the model, and finally verify and validate the model. The experimentation phase involves executing the simulation model so that operations of the system can be duplicated on a computer and its dynamic behaviors can be observed. By analyzing the operation of a system, its performance (e.g., production rate, or operating cost) can usually be improved. This is one of the major purposes and motivations for a user to simulate a system. Optimization is the process of analyzing simulation outputs and improving the system's performance.

Construction simulation has been successful in academic research with limited successful applications in industry. Modeling is the hardest and the most time-consuming process of simulation because it requires a level of knowledge in both simulation and real world problems. The major obstacles to its use by the construction industry are the complexities involved in constructing a model and the resultant time requirement—the technique is not yet cost effective (Shi and AbouRizk 1994). A simulation workshop of National Science Foundation concluded that seven of the eleven future research issues must deal with simplifying simulation and making it an operational tool for the construction site (Ibbs 1987).

Paul (1992) noted that "it is impossible to produce an all purpose simulation modeling system that can handle any problem that one might wish to model. The analyst is restricted to what a simulation system can handle, or the simulation system must provide programming code that can be modified to do the task that has been set."

This paper will only address automated modeling portion of two automated simulation processes. First CRUISER, an automated aggregate crushing plant simulation model will be discussed. The simulation model is created from the plant layout as it is drawn on the screen by the user and from other information supplied, such as raw material gradation.

Second, AP2_EARTH, an automated earth-moving simulation model is discussed. It is based on a fully automated simulation process that was presented by Shi (1995). In this process, with the user specifying project and resource information, a simulation model can be automatically constructed. A simulation language is then called to experiment with the model. After experimentation, the system is able to analyze the simulation results, and to search for the optimal solution for the system by modifying resource configurations or other parameters.

2 CRUISER

CRUISER (CRUshIng Simulation EnviRonment) is an evaluation and optimization software for aggregate crushing plants being developed by Construction Engineering & Management at University of Alberta. CRUISER can be used to experiment with equipment variables for the purpose of optimizing the production of the plant. For example, it takes, on average, one hour to shut down a small plant, change the deck screens and start it up again. Along with the cost of lost production, there is a cost associated with the risk of actually achieving the expected productivity increase. By doing the experimentation on the computer, the change can be tested in the simulation model without losing production time. As well, the predicted increase in production can be evaluated against the shutdown time in a cost/benefit analysis.

CRUISER may also be used to evaluate various plant configurations for productivity, cost-effectiveness of new equipment, and the best raw material source for a desired product.

CRUISER was designed for users who are not familiar with simulation. The motivation for this was twofold. First, the majority of managers in the aggregate industry started their careers in the field and rose through the ranks to their present position. This provided them with a very clear understanding of the aggregate business, but not well-developed computer simulation skills.

The second reason is that the program is also intended to be used on site. Therefore, the program must be robust and quick to learn. Without these features, CRUISER will not be accepted by the targeted users.

2.1 Review of Crushing Plant Operations

Crushing plants perform three main functions: material crushing, size separation, and transportation. These functions are executed, respectively, by crushers, screens, and conveyors. (While some plants also have washing facilities, they were not considered in this model.)

2.2 Model Overview

CRUISER is based on a static simulation model by Hancher and Havers (1972). In brief, their model uses subroutines for each plant component. The subroutines for crushers and screens analyze the input material stream, make the appropriate changes, and pass the output information back to the main program. Aggregate gradations are tracked and stored in arrays at each conveyor.

While the original model was written in FORTRAN, our programming has been done in C++, enabling a very intuitive graphical user interface (GUI).

2.3 CRUISER Components

CRUISER provides the user with a wide range of components that are used to represent an actual crushing operation. Each component holds graphical properties used for display purposes and specification data that defines how it behaves during analysis.

There are nine different components: raw material feed, conveyors, screens, crushers, add joints, split joints, waste material, product material and counters.

Each new component comes with default specifications and a default "name". To change this information, the user double clicks on the component (or selects "Properties" from the "Edit" menu) to display a dialog box specific to the node selected. Here, the user is able to change the default name to something more illustrative, as this name is used on the computer screen and in the analysis results. Information which can be input for crushers includes the crusher type (cone, impactor, roller, or jaw) and opening settings. Screens require data on their inclination, number of decks (up to 4), screen opening sizes, and vibration amplitude.

Creating the site layout can be done using simple click and drag mouse operations or by using the "Create" menu. To start, the raw material icon is placed on the screen. A conveyor is then placed to take the raw aggregate to the next component, either a crusher or a screen. To ensure the components are correctly joined, a solid red circle appears when the connection is made.

All components must be joined by conveyors as they serve as the linking structures for the automated model. They also serve to track the material gradation throughout the system.

Conveyors taking material from screens must know to which deck they are connected. This is done by attaching the conveyor to the appropriate connection circle on the right side of the screen. There is one circle for each screen deck specified and one at the bottom for 'throughs' (material which has fallen through all of the screens).

The remainder of the plant is drawn with the stream end points being either waste material or product. All components may be moved around by clicking and dragging either alone or with the connecting components still attached. The model can be as large as necessary since CRUISER supports screen scrolling and zooming.

2.4 The Automated Model

Once the plant design is complete, the analysis can be initiated by selecting "Analyze Streams" from the "Model" menu. This will start the integrity checker to ensure there are not any errors. For example, an error would occur if the raw feed supply is not defined. Alternately, a screen must have an output conveyor for each deck it has specified.

As mentioned earlier, the model uses subroutines to process the simulation. At present, the subroutines rely on empirical data from Cedarapids Pocket Reference

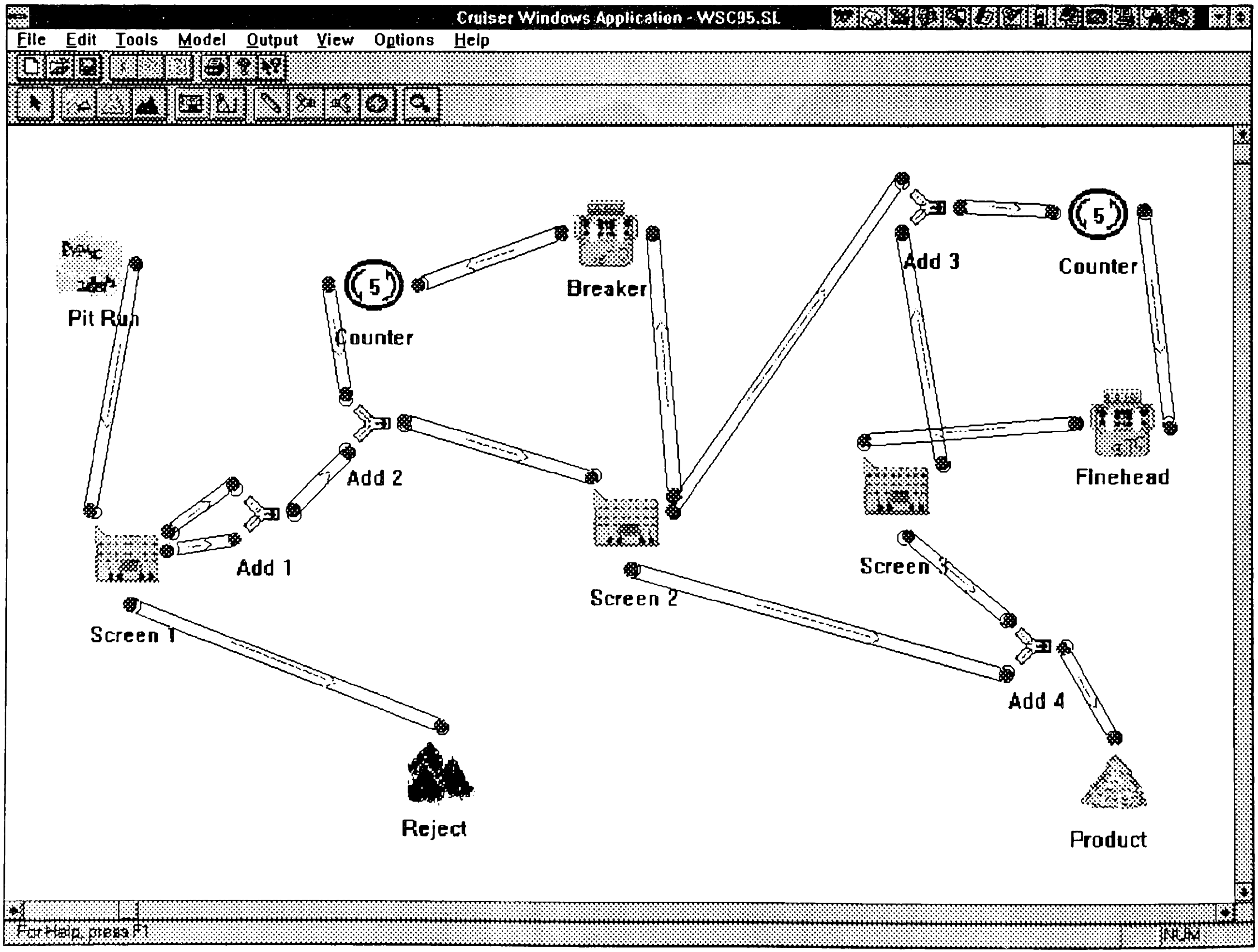

Figure 2 Sample Application of CRUISER

Book. In the sample application shown in Figure 2 the gradation of the material in the first conveyor is the same as the raw material or pit run. The material then passes through the screen, where the gradation will change. A call to the screen subroutine is made and the new gradation is determined.

CRUISER has the ability to analyze both open and closed-circuit models. Open-circuit models involve straight-forward non-looping analysis where each component is analyzed once. Closed-circuit models however involve special considerations.

Closed-circuit models contain loops where some of the crushed material is recycled back to a previous stage of analysis. The two main components used in this case are Add Joints and Counters. Add Joints are used to combine two streams into one, which is required when a recycling stream reenters the main stream. Counters are used to control the number of iterations through the cycle independent of the other cycles. The number of cycles should be just high enough to reach a steady state, but not so high as to increase processing time.

CRUISER uses a "Call Queue" to perform the analysis. This queue stores the id of the conveyers that should be called. When a conveyer is called, it dispatches a message to its destination (a component other than a conveyer. Let's call it MACHINE) which has the effect of calling one of the analysis subroutines. The analysis is done on the stream from the input conveyer and the results is stored in the conveyers that follows MACHINE. After that is done the id of the conveyers that follow MACHINE are added to the Call Queue for future analysis. If MACHINE doesn't have any succeeding conveyers (such as in the case of a Stock Pile) or doesn't wish the analysis to continue at this branch (such as a Counter with cycles=0) , no conveyer id's are added to the Call Queue.

The analysis is started by initially adding the id of the conveyer that follows the Raw pile to the Call Queue, and then calling the conveyers at the top of the queue one at a time until the Call Queue is empty (which happens when all the components stop adding conveyer ids to the queue).

Analysis results may be shown to the screen only or also put in a text file. Each component contains an option in their dialog box to have that particular stream gradation included in the output report. However, even if the option is set to 'No', the gradation at any point may be viewed on screen be clicking the conveyor with the right mouse button.

2.5 Sample Application

CRUISER was tested at one of Lafarge Construction Materials' gravel crushing plants. The layout is shown in Figure 2. Lafarge provided gradation test results at various points throughout the plant, including raw material input, waste material and product. Screen and crusher settings were obtained during interviews of the plant operators. The complete model was prepared in about 40 minutes and saved for future experimentation. The analysis results vs. the actual test results are shown in Figure 3.

In Figure 3, the heavy solid line shows the actual gradation test of the plant product. The dashed line is the result of CRUISER analysis.

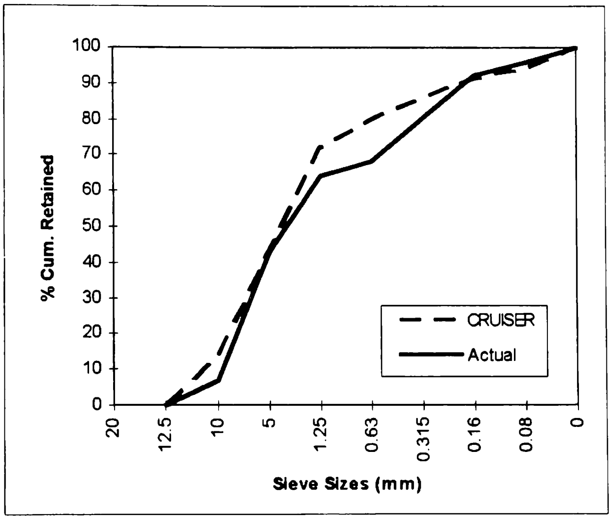

Figure 3 CRUISER Results Comparison

The crusher results are within 13% of the actual. One of the obvious sources of this variability is the sampling of the input aggregate. In gravel pits, material gradation is quite variable. The input material samples, therefore, are equally variable, which affects the outcome of the analysis. During operation, skilled loader operators usually try to lessen the bulk effects of this variability by mixing aggregate from various sections of the pit. As well, the empirical tables used in the analysis have not been calibrated to the specific plant components. Once this is done, the program would be customized for the plant operation and allow more accurate results.

3 AP2_EARTH

AP2_EARTH is a simulation-based tool for analyzing earthmoving operations. The objective to develop this tool was to provide a powerful but user-friendly computer-based simulation program for practitioners to analyze the operations of an earthmoving system. By experimenting with different scenarios, the user will be able to locate the optimum equipment allocation for minimizing the production cost of a project.

3.1 The Graphical User Interface (GUI)

The implemented graphical user interface allows the user to construct the site layout of an earthmoving site using physical components including “source area”, “placement area”, “road”, “intersection”. There are corresponding properties to be attached to each component. For instance, the properties for “road” are: one way traffic or two way traffic, grade, surface condition, length, allowed maximal speed, etc.

The user can connect a “source area” with a “placement area” with “roads” and “intersections”. The user may also allocate construction equipment to specific components. A backhoe, for instance, is allocated at the “source area” for loading. Figure 4 illustrates the GUI screen. This GUI was implemented using Microsoft Visual C++.

3.2 Modeling Methodology

Shi (1995) presented Resource-Base Modeling Methodology (RBM) to automate the modeling process for resource intensive construction projects. An automated modeling environment for earthmoving operations was implemented using RBM. In RBM, the operating processes of earthwork equipment including tractors, excavators, scrapers, loaders, trucks, compactors, and graders are defined as the resource atomic models in the atomic model library. A resource library was also implemented to provide default attributes for resources (e.g., operation costs).

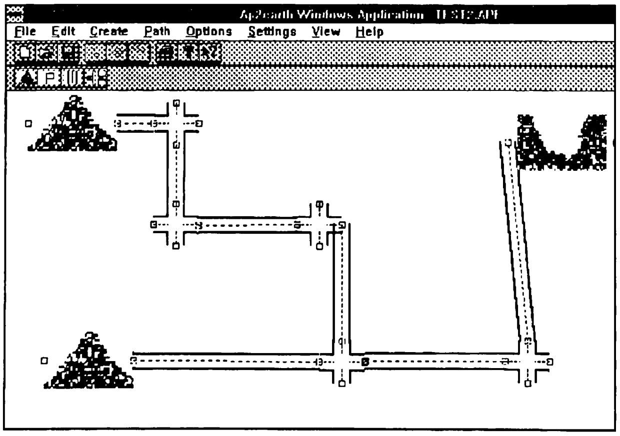

Figure 4 User Interface For AP2_EARTH

When RBM is used to construct a simulation model, the modeler needs to specify project-required equipment, and project information through the provided user interface.

The modeling process is divided into two stages: project-specific atomic model generation and entire model generation. In stage one, the user-specified equipment and project information will be automatically integrated with corresponding atomic models to generate project-specific atomic models. In stage two, all the project-specific atomic models will be combined into one working model by identifying required linking structures. Miscellaneous linking structures for coupling earthmoving atomic models have been defined (AbouRizk and Shi 1995, Shi 1995).

Model Initialization

1. Set up road and intersection data structures based on the user interface definition.
2. Create facilities for intersections.
3. Initialize truck entities at the loading facility.

Sequence of truck events

1) Wait for a loader facility to become available.
2) Load material and schedule the release of the facility
3) Release the loader and prepare to follow user defined travel path.
4) Travel the first road segment and wait for the succeeding intersection to become available. (Time needed to traverse the road segment is calculated using both road and truck properties.)
5) Release intersection, traverse the succeeding road.
6) Repeat steps 4,5 until dump location is reached.
7) Wait for dump facility to become available.
8) Dump material, and traverse path back to loader facility. (as in steps 4,5)
9) Procedure from steps 1 through 8 is repeated until desired production is reached.

Figure 5: A Truck Hauling Module

In the previous work, SLAM II was used as the external simulation engine for the constructed simulation model. In AP2_EARTH implementation, RBM is the modeling methodology while the event-driven discrete modeling and simulation function is accomplished using SimPack (Fishwick 1992).

In SimPack, a simulation model is represented in a main module in which simulation entities (tokens), facilities (servers), events and event sequence are to be defined. Resource atomic models (Shi 1995) are to be defined according to their occurring events in subroutines of the main module. Various linking structures are also defined as subroutines. The main simulation module will get information from the GUI.

It will be tailored to form a specific main module for a project according to the user specified project and equipment information. SimPack main module has to be coded in C or C++ language. Figure 5 illustrates the

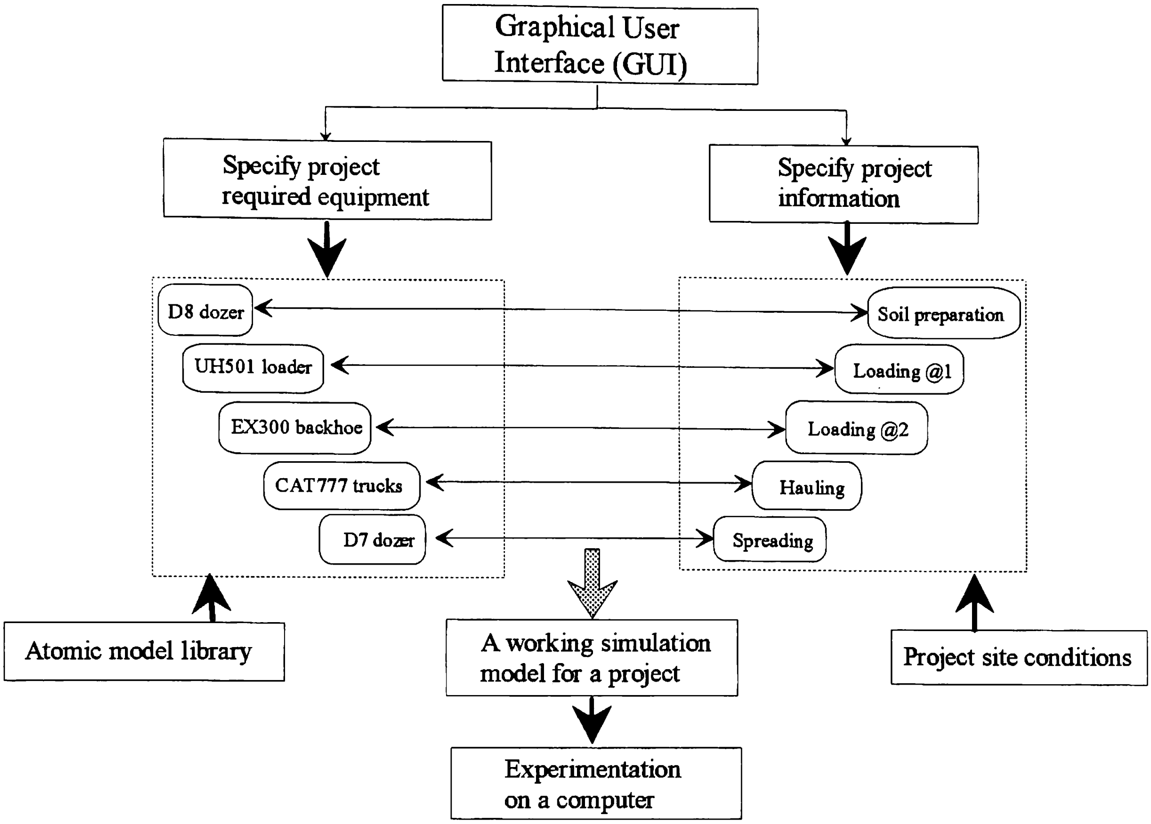

Figure 6: An Example Modeling Process

module of a truck hauling atomic model.

This part of work is still under implementation during the writing of this paper

3.3 A Modeling Example

To illustrate the modeling concept, consider an earthmoving operation with five processes: soil preparation, loading at location 1, loading at location 2, hauling, and spreading. Five resources have been specified: a CAT-D8 dozer, a UH-501 backhoe excavator, CAT-777 trucks, and a CAT-D7 dozer. The *resource assignments* are: CAT-D8 for soil preparation, UH-501 for loading at location 1 ; EX-300 for loading at location 2, CAT-777 trucks for hauling, and CAT-D7 for spreading. *Local site conditions* are: hard clay ground for CAT-D8 (hard pushing), loose stockpiled clay (easy cut) for UH-501 and EX-300; a haul route consisting of a section of 10% inclining grade and a section of busy traffic for the trucks, and loose stockpiled clay (easy pushing) for CAT-D7. *The project objective* is to spread 100,000 m^3 of excavated soil at the dump area.

The information integration and the main module generation are schematically illustrated in Figure 6. Information specified by the user through GUI, will be incorporated into corresponding atomic models to generate project-specific atomic models. One soil preparation process, one hauling process, one spreading process, and two loading models are to be generated for this sample project. The linking structures are then identified as required to assemble the five process models: one-multiple indirect link between soil preparation and loading, multiple-one indirect link between loading and hauling, and one-one indirect link between hauling and spreading. The entire project simulation model is constructed by assembling these atomic models.

A simulation engine is then called to experiment with the generated model. After experimentation and optimization process, eleven trucks have been found to result in the minimal unit cost for this sample project.

4 SUMMARY

An automated modeling process can significantly simplify construction analysis, reduce the time requirement for the modeling process, and improve the cost-effectiveness of construction simulation. The two automated modeling systems (CRUISER and AP2_EARTH) presented in this paper have substantiated these.

CRUISER is an easy, effective, and efficient way of examining the production and gradation results of crushing operations. The graphical user interface and limited computer skills required to run the program has been an asset toward encouraging managers and operators to try it.

Improvements planned for CRUISER include a metric option, an interactive way of defining the performance of "Custom" crusher or screen types and an automated optimization module.

AP2_EARTH utilizes generic programming tools which, with input provided from a user specification interface, automatically constructs a simulation model for a given project. The user needs to be familiar with the construction operations, project site conditions, and resources that are used in the project, but no simulation language expertise is required in this modeling process.

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