

INTEGRATED 3D OBJECT TRANSFORMATION AND SIMULATION FOR TOWER CRANE OPERATIONS ON CONSTRUCTION SITES

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Abstract: This paper presents a methodology for integrating 3D (three-dimensional) object transformations with simulation in order to build a 4D model to aid practitioners to visualize tower crane operations on the computer screen. Since the detailed project schedule is already divided into work-packages, the proposed methodology will further divide each work-package into lift-packages. Each lift-package is geometrically designated for its source and final 3D-geometrical location in space. Additionally, the output of the simulation module will provide the simulated most probable time required to perform each lift. This paper focuses primarily on describing the 3D-geometrical transformation module and its integration with the simulated module.

Keywords: 3D Transformation, Tower Cranes, Simulation, 3D-animation.

1 INTRODUCTION

Tower cranes are the most expensive and frequently-shared resources on commercial building construction sites. Efficient utilization of tower cranes depends greatly on skilled judgments that account for a number of technical and schedule factors. As the number of work tasks and the demand for tower cranes increase, practitioners may require planners to make bold decisions on job conditions for a particular situation, potentially leading to unavoidable mistakes. A poor decision is likely to have significant effects, which will lead to additional costs and potential delays.

Computer simulation proved to be an effective tool for aiding practitioners in modeling complex construction operations. Substantial efforts in the domain of construction have been made after the development of the CYCLONE simulation language [1]. However, the use of simulation as a construction operations planning tool has fallen far below its maximum potential [2]. This unfortunate situation is due in part to the prevalent skepticism among potential practitioners—construction planners and analysts—who are typically well-versed in actual construction operations, to trust the credibility of the simulation analysis. Visualizing simulated construction operations can be of substantial help in communicating the authenticity of simulation analysis to construction decision-makers. In addition, visualization can provide valuable insight into the subtleties of modeled construction operations can thus provide more pragmatic and comprehensible

feedback from the simulation analysis to construction personnel as well as to simulation model developers [3].

This paper describes a methodology used to integrate simulation models with the concept of 3D (three-dimensional) object transformations. Objects are moved from their pick location (the material loading zone) by tower cranes to their destination location. Both geometrical locations are known and stored in the lifts database; however, the time needed to move these object is simulated using a priority rating Special Purpose Simulation (SPS) model built in a simulation model called *Simphony* [4]. The SPS model, which assists practitioners to schedule tower crane operations based on the priority rating concept, is described elsewhere ([5] and [6]) and is mentioned briefly in this paper to provide continuity. As illustrated in Figure 1, the proposed integrated methodology has been developed in a 3D Studio environment using a scripting programming language (MaxScript). The output of the simulation model is exported to an ASCII text file. 3D Studio Max is used as a platform for rendering the required frames and animation. The construction of the Natural Resources Engineering Facility (NREF) at the University of Alberta, Edmonton, Alberta, Canada is used as case study to demonstrate the effectiveness of this methodology.

2. SYSTEM COMPONENTS AND ARCHITECTURE

As illustrated in Figure 2, both the priority rating SPS module and the 3D visualization module share the information stored in two objects libraries, designated to 3D tower cranes and 3D project objects (lifts), and three databases comprising tower cranes load charts, site geometry characteristics, and lift packages, respectively.

Figure 3 shows the information dataflow diagram. In order to use the tower crane schedule efficiently, the priority rating SPS module evaluates each work package with respect to the site and tower crane characteristics. The output of the tower crane priority-rating SPS module includes the logic of the simulated lifts sequence and the time required to pick, hoist, and place each lift for a two or three week forecasting period. This output is exported using ASCII text file format for use by the 3D object transformation module, which is built in a 3D Studio environment for rendering and animation purposes. Rendering and animation will provide the user with 4D (3D plus time) short term schedules of two or three weeks worth of forecasted durations. The time limits are a result of the request made by the project manager and also to reduce the simulation module computing time.

3. COMPOSITION OF 3D TRANSFORMATIONS IN TOWER CRANE OPERATIONS

As illustrated in Figure 4, each lift is transformed from an initial location (position S) to a final location (position D), vertically by hoisting the lift up or down, horizontally by moving the trolley along the jib of the crane, and rotationally around the mast of the crane. The crane cycles its operations from one lift in the work-package to another as illustrated in Figure 5. Once all the lifts from a work-package are completed, the crane is expected to move to the next work-package with the highest priority. For each lift or work-package, the simulation module provides the information needed for the 3D-transformation module including the source and destination coordinates and the anticipated travel time, as shown in Figure 6. In this research, the 3D transportation follows the following three-step process:

3.1 Step 1: Hoist the lift from source position (S) to the desired height (S')

As can be seen in Figure 4, this transformation is expressed in Equation (1):

$$S' = T(d_{x1}, d_{y1}, d_{z1}) \cdot S = \begin{bmatrix} 1 & 0 & 0 & X_s - X_s \\ 0 & 1 & 0 & Y_s - Y_s \\ 0 & 0 & 1 & Z_s - Z_s \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_s \\ Y_s \\ Z_s \\ 1 \end{bmatrix} = \begin{bmatrix} X_s \\ Y_s \\ Z_s \\ 1 \end{bmatrix} \quad (1)$$

3.2 Step 2: Rotate lift around the mast or z-axis:

This transformation for the angle of rotation θ can be expressed in Equations (2) and (3):

$$\theta = \cos^{-1} \left[\frac{S^2 + D^2 - L^2}{2SD} \right] \quad (2)$$

$$D' = T(d_{x2}, d_{y2}, d_{z2}) \cdot S' = \begin{bmatrix} 1 & 0 & 0 & X_{D'} - X_{S'} \\ 0 & 1 & 0 & Y_{D'} - Y_{S'} \\ 0 & 0 & 1 & Z_{D'} - Z_{S'} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{S'} \\ Y_{S'} \\ Z_{S'} \\ 1 \end{bmatrix} = \begin{bmatrix} X_{D'} \\ Y_{D'} \\ Z_{D'} \\ 1 \end{bmatrix} \quad (3)$$

3.3 Step 3: Lowering the lift to its final destination from (D') to (D):

Similar to the hoisting of the lift, this step can be expressed in Equation (4):

$$D = T(d_{x3}, d_{y3}, d_{z3}) \cdot D' = \begin{bmatrix} 1 & 0 & 0 & X_D - X_{D'} \\ 0 & 1 & 0 & Y_D - Y_{D'} \\ 0 & 0 & 1 & Z_D - Z_{D'} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{D'} \\ Y_{D'} \\ Z_{D'} \\ 1 \end{bmatrix} = \begin{bmatrix} X_D \\ Y_D \\ Z_D \\ 1 \end{bmatrix} \quad (4)$$

The composite matrix of the three steps is expressed in Equation (5):

$$T(d_{x1}, d_{y1}, d_{z1}) \times (d_{x2}, d_{y2}, d_{z2}) \times R_z(\theta) \times T(d_{x3}, d_{y3}, d_{z3}) \quad (5)$$

However, this composite transformation matrix assumes a continuous operation, that is, no time delays. In real life, this assumption is impossible. To accommodate the time delay in the process, let t_1 , t_2 , t_3 represent the time delays between the three transformations. Equation (5), therefore, can be expressed in the following time-lapsed composition matrix, Equation (6):

$$T(X_1, Y_1, Z_1) \cdot t_1 \cdot T(X_2, Y_2, Z_2) \cdot t_2 \cdot R_z(\theta) \cdot t_3 \cdot T(X_3, Y_3, Z_3) \quad (6)$$

4. PROPOSED SPECIAL PURPOSE 3D VISUALIZATION SYSTEM FOR TOWER CRANES (SimAnim)

SimAnim has been developed using 3D Studio Max's scripting language, MaxScript, using 3D transformation concepts of 3D transformations. SimAnim provides practitioners with a powerful tool to animate modeled crane operations with sequential and spatial accuracy in 3D space. SimAnim input data files describe the spatial configuration of modeled systems over a period of time. Since the application is developed inside 3D Studio Max's scripting language, it inherits the strengths of 3D Studio Max. SimAnim is a "post-simulation" visualization application that possesses the following characteristics:

- It uses 3D Studio Max's clock, the speed of which can be controlled by the viewer depending on the desired animation speed.
- Navigation in 3D space is simplified and a desired view can be obtained by controlling the camera using the keyboard or the mouse.
- User can jump ahead or back to any desired location in the simulation by specifying a future or past time-value.
- Animation can be stopped and paused at any time to make static observations in the modeled system.

Simulated operations are visualized in 3D by processing sequential, time-ordered animation data. As shown in Figure 7, the animation data are retrieved from the simulation model in an ASCII text file format. Most of the simulation software is capable of writing custom text output automatically during a simulation run. These include most of the programmable generic and special-purpose simulation languages as well as high-level programming languages. Non-language-based simulation software may also be adapted to generate animation data files during a simulation run. Using an ASCII text file format provides SimAnim with the practical flexibility for use in combination with a wide range of different 3D-CAD models and simulation systems.

5. CASE STUDY

The proposed methodology has been tested in the case of the construction of the Natural Resources Engineering Facilities (NREF) at the University of Alberta, Edmonton, Alberta, Canada. The new building, which will house the Civil and Environmental Engineering Department, is a 28000 m² high-rise building consists of nine floors, two underground and seven above-ground level; 700-student classrooms; 78-research labs; and over a hundred offices. The building footprint is 60m by 80; the estimated construction cost of the building shell alone is \$56 million (CAN). The building being constructed is based on the design-build fast-track project delivery system, using two tower cranes (as shown in Figure 8). PCL-Max is the general contractor of the project, Cohos Evamy Partners are the design firm, and Stantec is the project consultant. Construction began on February 1st, 2003; substantial performance is expected to commence on October 1st, 2004; and construction is expected to be complete for December 1st.

The many different uses of the tower crane in each stage of construction made simulating the entire tower crane operation very difficult. This study focused on the construction of the second floor (L2) concrete section. The tower crane operations included the lifting of large formwork panels,

reinforcing bars and concrete buckets. For these three operations, a simulation model was built in *Simphony* as a SPS template [5] [6]. All related data, including source locations, destination locations, the number of lifts for each work package, hook up and unhook times, and the related distributions of parameters, were defined in the simulation model. The simulation model outputs, which included space- and time-related data, are stored sequentially in ASCII text file format. SimAnim uses this file format to implement the simulation results as a time-scaled 4D model in the 3D Studio Max environment, as illustrated in the screen snap-shots in Figure 8.

6. CONCLUSIONS

This paper presents a 4D-model incorporating a methodology that integrates the simulation models with 3D-transformation and animation tools. The proposed methodology has been implemented into a computer system, utilizing the simulated time and logic for tower crane operations in building construction. The methodology subsequently integrates a 3D transformation concept to simulate the forecasting of construction operations on the screen. The concept of 3D modeling and animation has also increased the efficiency of planners. Once the site is drawn in 3D and the crane and lift are placed, the planner can easily generate any number of views for evaluation and assessment prior to the approval of the plans for execution. In the case study, the client's engineers and safety representatives received a report of the planners' assessments along with nine different 2D and 3D drawings of the lift plan, as well as the 3D animation file displaying the entire crane operation. This information expedites the work of safety officers in order to facilitate the approval of lifting plans. The developed system, SimAnim, provides its users with a powerful, accurate, and instantaneous tool for evaluating and assessing tower crane utilization on construction sites. The case study was used to demonstrate the effectiveness of the developed integrated methodology. The methodology was developed within a 3D Studio Max environment coded in MaxScript language, which ensured the efficient utilization of 3D-object transformation code, as it was incorporated in the software.

Acknowledgments

The authors sincerely thank the organizations participating in this study. The continuous effort and contributions of Mr. Paul Knowles, Project Manager for NREF, are gratefully acknowledged. Special thanks are directed to the NSERC/Alberta Construction Industry Research Chair in Construction Engineering and Management for their technical and financial assistance and to PCL for their unbounded support.

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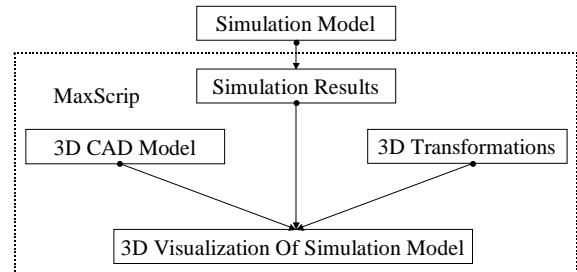


Figure 1: MaxScrip integration components

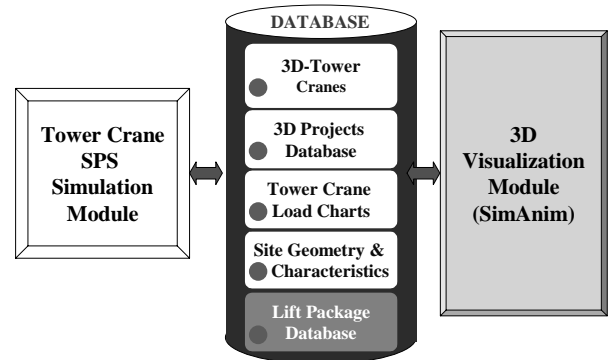


Figure 2: Proposed system components

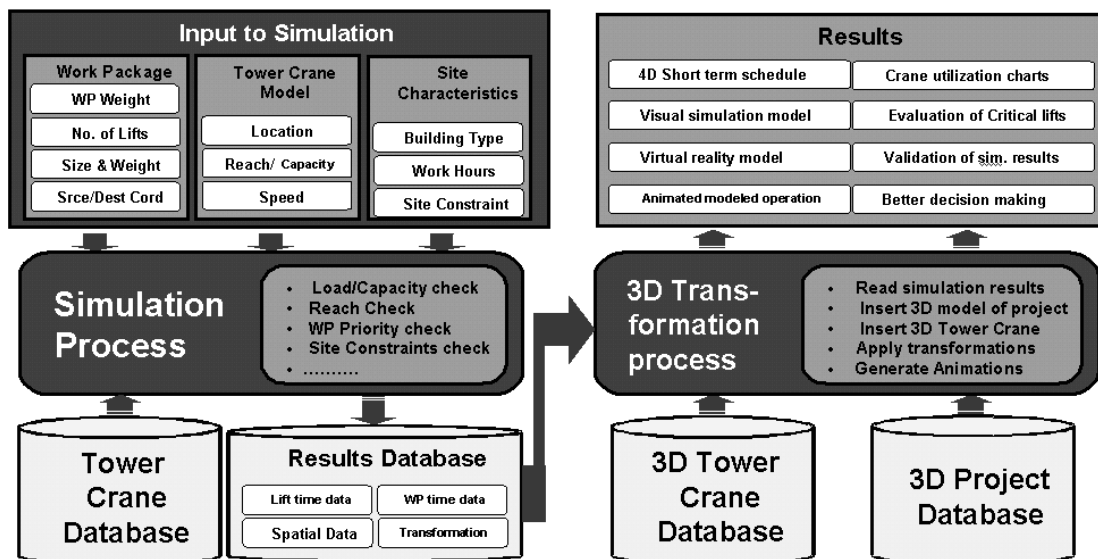


Figure 3: Information data-flow diagram

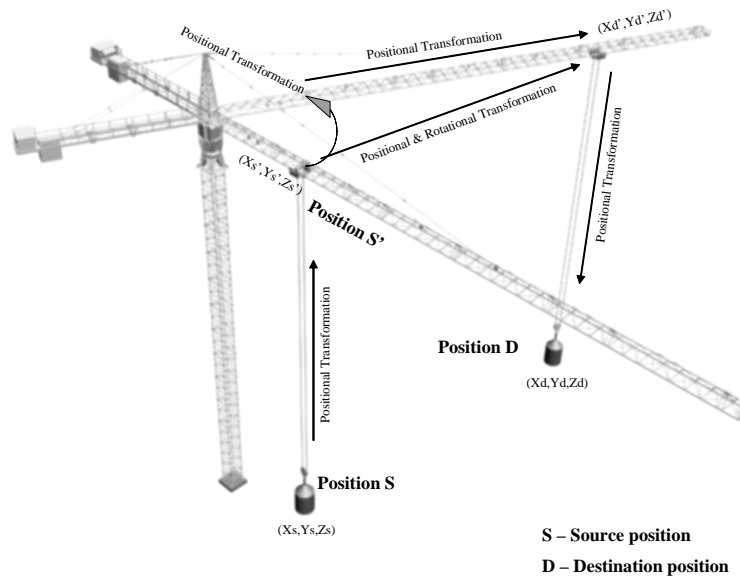


Figure 4: Illustration of objects transformation in space

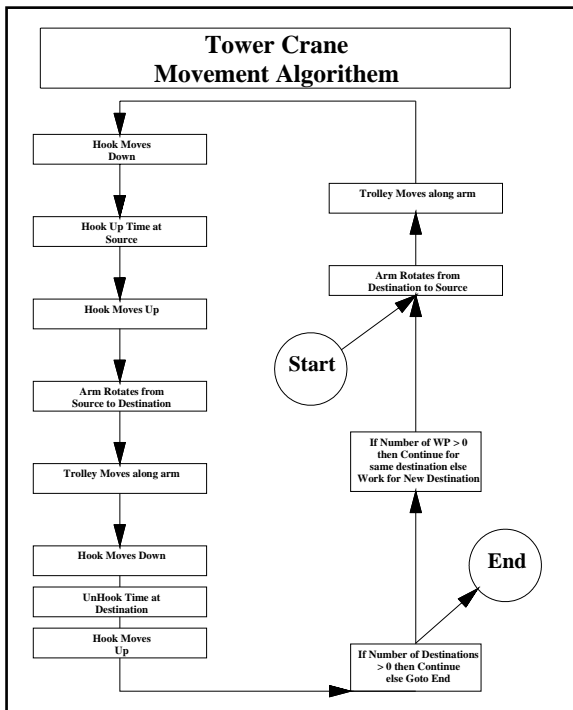


Figure 5: Tower crane cycle

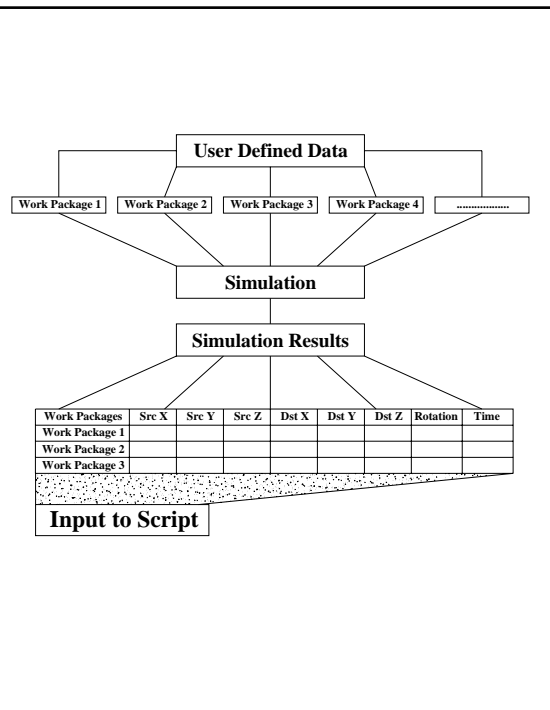


Figure 6: lifts detailed information

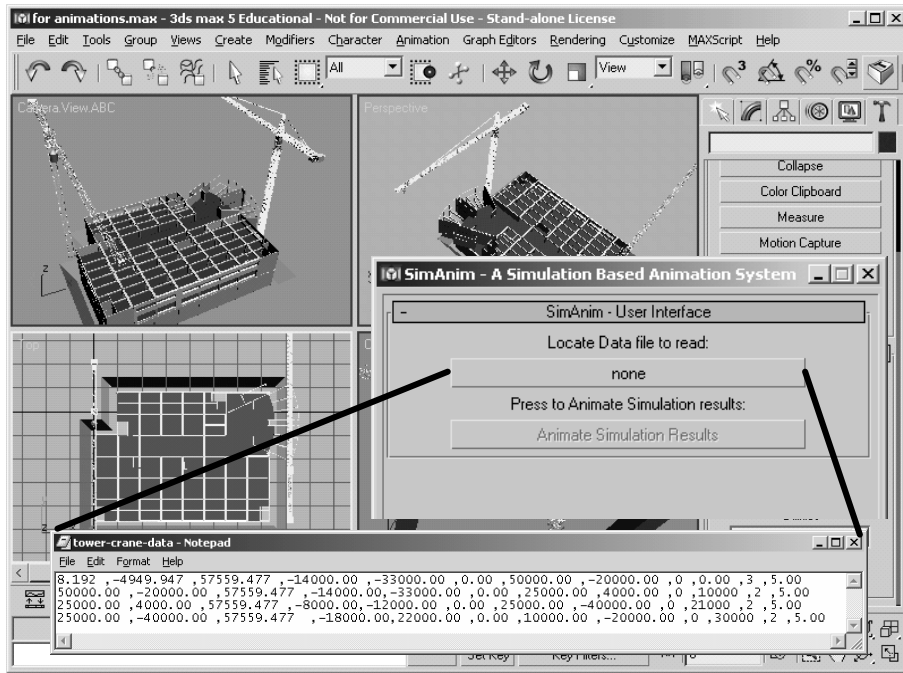


Figure 7: SimAnim process integration

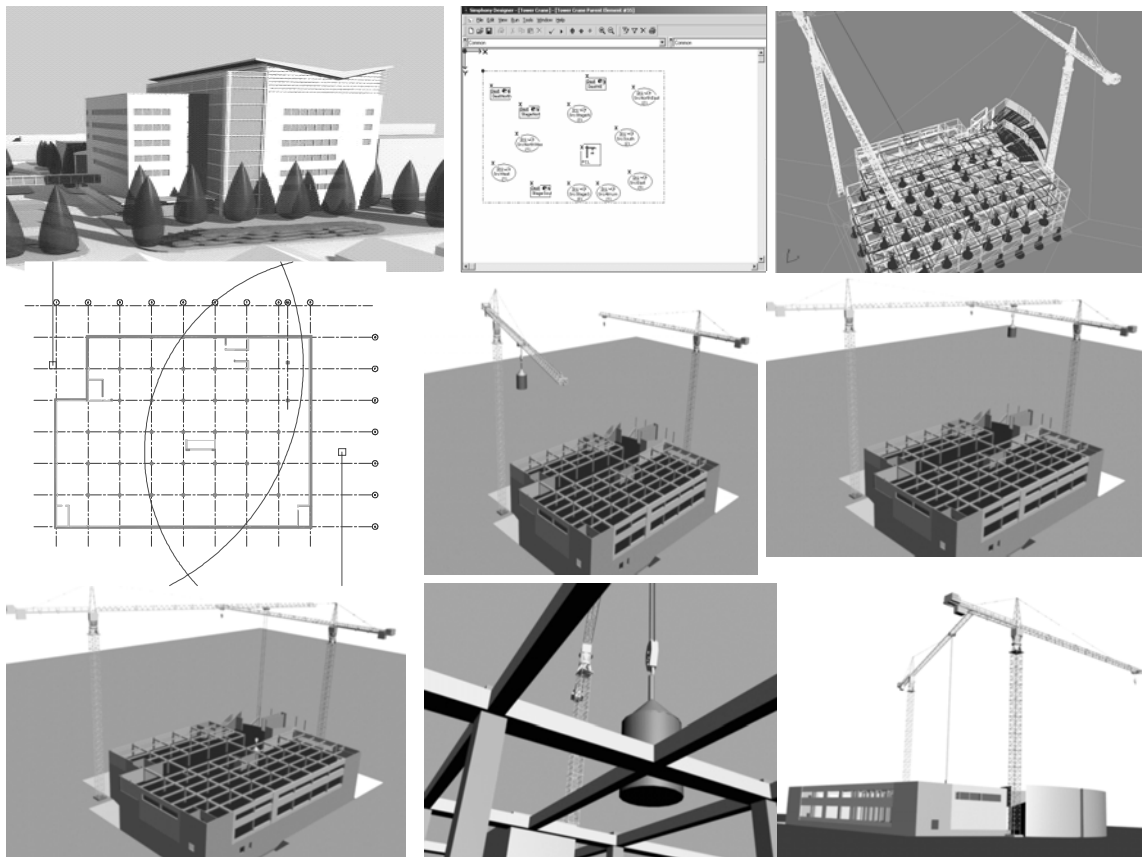


Figure 8: SimAnim screen snapshots of the case study