Chapter 8

Research Conclusions and Recommendations

8.1 Conclusions of Overall Research

At present the processes of decision-making and planning in construction processes are fragmented. Construction methods are assigned by expert planners, while construction times are calculated by scheduling tools, and operation cost is determined by cost estimators. In addition, human ability for decision-making in several dimensions simultaneously is limited. Existing simulation modelings are useful but limited to non-graphical output and emphasis on a certain aspect, consequently, an integrated system of 3D construction processes, time, and cost will enhance effective decision-making in construction planning. Virtual Reality (VR) technologies: CAD, database, and programming language are appropriate technologies for developing the system because of its ability to visualize the virtual construction processes.

In this research, factory construction was selected as an appropriate construction operation to be simulated using 3D visualization because there are large volumes of work involved. There are also a lot of structure members to be fabricated in each activity such as, piling work, column installation and roof truss installation. Furthermore, factory construction activities are complex and involve with various resources and their inter action.

Walkthroughs of construction sites, direct interviews, and expert's questionnaires were selected as the approach for construction site surveys to find out the current practices, problems, and limitation of construction participants' decision-making. According to the site survey responses, construction managers usually prepare construction plans by using their experience. 2D drawings, BOQ, and construction contracts are commonly used as tools in construction planning, and sometimes, planning software is used as a tool in construction scheduling. The activities involved in construction-site planning usually consist of construction-site layout, space conflict and safely analysis, and construction activity time and cost analysis. The problems of construction-site planning that commonly occurred in construction planning involve a lack of planning experience of the personal, lack of data, and limited ability to make decisions in several dimensions especially the dimension of dimension of time.

The well-known CAD software called "AutoCAD version 2000" was used as a tool for creating the 3D static models. Three types of 3D models were created using this CAD software, which are 1) main construction machine models, 2) models of factory building components, and 3) facilities and temporary work models. These 3D models have been used as the important inputs of the Integrated System.

After 3D static models were created by CAD, they were developed to be 3D dynamic models that simulate their actions or movements. The methodology of characteristics and mechanisms assignment to the models consists of: 1) importing the components of the 3D models and assign names; 2) assigning the pivot points to the components; 3) assigning the relationship and building hierarchical structures; and, 4) linking the components of the models. The 3D models of construction machine such as the excavator, pile-driving machine and mobile-crane were used as examples for characteristics and mechanisms assignment. After that, these 3D models were verified by examining their actions and movements, which are similar to the actions and movements of the real machines.

In order to ensure that the actions of the main components (materials and equipment) of construction activities is correct, visualizing controllers called "controlling parameters" are assigned to the components of the 3D models. Those controlling parameters consist of 1) the transformation parameters for position, rotation and shape-transformation, 2) the visibility parameter, and 3) the linking parameter. In order to illustrate the visualizing construction activities according to the simulation time, the frame update technique is applied in two categories: 1) key-frame and 2) frame rate.

Basic simulation techniques and methods were also used for developing the Integrated System. Discrete-event simulation is an appropriate simulation method for simulating construction operation. The time advance mechanism called "next-time event time advance" is an appropriate approach to simulate construction activity. The Monte Carlo technique is a simulation technique, which was employed to simulate the productivity of construction activities such as productivity of pile driving. The random numbers and accumulated probability of requirement data are key parts of the Monte Carlo simulation technique. In this research, random numbers were generated by computer programming, and factory construction data that involved construction time and productivities were converted to accumulate probability.

One very important input component of the Integrated System is the system database. The methods used to develop the database of Integrated System were divided into as follows: data classification, data identification, data acquisition and collection, and database development and implementation.

Scripts language in visualizer software and methods of programming were used to develop the components of the Integrated System such as input component, processing components, and output components. The methods for programming the controlling of construction activities using visualizer scripts commands and syntaxes are explained using an example of earth excavating by an excavator in Chapter 5.

The accuracy of the system is tested in two ways: 1) system verification, and 2) system validation. In order to verify the accuracy of the system development, points of time and actions of 3D models of the construction activities generated using visualizer scripts programming were tested. Earth excavation activity by an excavator was used as a case study for system validation. The results of the validation show that all points of time are able to generate the correct action of construction activities.

The Integrated System was validated by comparing the productivity of construction activities generated by the system and the actual productivity rates recorded from the field. Pile driving activity was used as a case study to validate the system. The results of system validation showed that the productivity of the pile-driving machine according to the system simulation is higher than the productivity of pile-driving machine in actual construction due to 1) unforeseen condition such as machine down, accident, worker's delay, and rainfall, which are not included in the system simulation, and 2) the productivity of each construction machine changes due to quality of personal.

8.2 Applications and Benefits of the Integrated System

The Integrated System can support integrated decision-making of construction managers in a main application and two by-product applications. Time-motion and cost analysis is a main application of the system. By-product applications involve construction space management that can be divided into two applications: 1) construction-site layout, and 2) space conflict and safety analysis.

8.2.1 Time-Motion and Cost Analysis

The Integrated System can be used to experiment with different construction methods that generate different construction durations, and construction process cost in a virtual environment. Time-motion and cost of construction processes were analyzed using what-if analysis in the system. A factory building construction was selected as a case study. The proposed system can assist the construction manager to analyze and select the appropriate construction method, equipment set, operation time and cost of the construction process by simulating the construction process in virtual space. The virtual reality approach can enhance effectiveness of construction managers' decision-making by enabling them to visualize several dimensions in the virtual construction site generated in the Integrated System.

8.2.2 Construction-Site Layout

Virtual reality approach of the Integrated System can be applied to illustrate the virtual construction site. The 3D CAD was used to create 3D static models of facilities and resources. Those 3D models were then imported into the virtual construction site. In order to generate a realistic construction site layout, the construction managers can alter the layout by moving or changing the positions of the 3D models for determining the appropriate position of all facilities and resources within the limited boundaries.

8.2.3 Space Conflicts and Safety Analysis

The Integrated System is applied to analyze space conflicts and safety in the construction site. Because of the potential of the virtual reality approach to display the virtual construction site in four dimensions (x, y, z, and time), the project managers can walk through the virtual construction site to observe space conflicts, unsafe areas and dangerous events. Project managers can investigate unforeseen problems and take preventative measures before the conflicts and hazards can occur in real construction.

8.3 Research Contributions

This research contributes a new innovation of construction planning that consists of:

1) The new innovation of construction planning that is able to display construction processes and resources used in virtual space and also calculate the construction operation time and cost of construction processes.

2) The product of this research is a prototype of the Integrated System that is designed for realistic visualization of factory construction. It is a tool for assisting project planners in making decisions includes selecting appropriate equipment set, operating logic, construction method, time, and cost in the dynamic environment.

8.4 Recommendations and Limitations

1) The prototype of the Integrated System in this research is developed based on factory-construction activities only. Some unforeseen conditions, e.g., rainfall, construction machine breakdowns, and lack of labor that may occur and affect construction method, time, and cost are not incorporated in this research.

2) In the proposed prototype system, the construction method and processes must be pre-defined by users. The system cannot automatically simulate all details of construction processes.

3) The cost of construction in the prototype system is limited to construction process costs, which consist of cost of equipment operation and some of cost of construction site overhead.

8.5 Future Research

Future research should involve the detailed study of each component of the Integrated System. The Integrated System database should be developed to cover more details of construction resources. Unforeseen conditions such as rainfall and construction machine breakdowns that are excluded in this research should be integrated to the system to allow project managers to explore closer to the real site conditions. Moreover, the simulated motions or movements of the construction machines should be developed to be more realistic, such as ability to identify the collision of machines.

The system should be developed to cover other aspects so the planners can simulate only once but they can get more information of different scenarios such as operation expense of resources, safety measures required, and experts' suggestions.