Chapter 2
Literature Reviews

2.1 Introduction

This chapter presents literature reviews of related research. First, the state of the art of integrated systems in construction is described. Second, definitions and applications of virtual reality in construction are presented. Next, definitions and the state of the art of simulation modeling are explained. Finally, the issues of integrated systems, virtual reality, and simulation modeling in construction are discussed.

2.2 State of the Art of Integrated Systems in Construction

Retik (1997) presented an approach, which aims to develop a computer-based system for planning and monitoring of the construction process. The system allows creation of a virtual construction project from a schedule and subsequent visual monitoring of, and interaction with, the progress of the simulated project.

Marir et al. (1998) presented an interactive system called "OSCONCAD" for integrating CAD and construction related applications to address the problems of design fragmentation and the gap that exists between construction and design processes. It provides a vehicle for storing architectural design information in an integrated construction object-oriented database that can be shared by a range of computer applications such as AutoCAD application, web-base application using VRML, and OSCON construction applications.

Mather (1998) presented a method of analyzing construction operations by using an integrated CAD-base simulation system, which incorporates the site and design information from CAD and other data. While the project structure and site have been defined in CAD, the simulation models can be used to analyze construction operations, different construction methods, site conditions and system productivity. It was implemented in an earthmoving operation.

Fischer et al (2000) described the research that was to test 4D Planning and Scheduling (4D-PS) to demonstrate its benefits as a CAVT (Computer Advance Visualization Tool) applied to the case study. The objective was to find out how 4D model reviews can help generate more constructable projects by assisting construction planners in optimizing construction sequences, identifying and resolving schedule conflicts and providing feedback from the construction team to the design team.

Ma et al. (2000) have developed a prototype integrated planning system for building construction of reinforced concrete high-rise building by using object-oriented technology. An integrated approach was adopted. Namely, subsystems, i.e., the subsystems for selection of construction method, for scheduling and for making site layout, were developed respectively. These subsystems are being integrated based on the central database, where the functions of the subsystems take the form of menu items and can be used as tools in arbitrary sequence. As a result, the system makes it possible for engineers to carry out construction planning more naturally and efficiently by using the powerful tools.

Mahashi (2000) reported on a study that integrates a virtual reality (VR) environment with a critical time-space scheduling analytical tool. The technique is based on a genetic algorithm, which is read by an interactive virtual environment and displayed as 2D and 3D intelligent objects. This technique was applied to solve construction site problems such as low productivity and construction accidents due to poor site logistics, and inefficient space planning for resources and space conflicts among sub-contractors.

Sriprasert and Dawood (2002) described a system framework and a methodology to integrate information and constraint management with 4D planning and control system. An implementation of this vision has been resulted in a prototype called "LEWIS-Lean Enterprise Web-base Information System for Construction". The system enabled the generation of a reliable plan to construction work that can reduce production wastes and improve on-site productivity.

Sulaiman (2001) presented an approach and benefits of integrating CAD with other construction planning. The main benefit is the sharing of data at real time, which can help the planners to improve decision-making in the early stages of construction. In his project, users can generate the virtual building elements using the traditional CAD system and can walk through and navigate in the virtual building and interact with the individual virtual objects similar to moving through the real building.

Ho and Liu (2002) presented a prototype of a virtual reality system that allows the participants in a construction project to be immersed in a 3D environment via the Internet and to review alternative building models. Engineers, architects and other participants in construction can exchange project information. The construction sequence and schedule can be integrated into the 3D model. The model can visually simulate construction process with respect to different alternatives. The system can effectively improve the construction pre-planning process.

2.3 Virtual Reality (VR) in Construction

2.3.1 Definitions of Virtual Reality

There is no standard definition to the term Virtual reality (VR). (Ayman H. M., 2001). However, virtual reality can be defined as one or combinations of the following:

1) Virtual reality is the term used to describe advanced methods of involvement and interaction for humans with computer generated graphical (usually 3D) environment. (Barnes, 1996)

2) Virtual reality is a breakthrough technology that allows a person to step through the computer screen into a 3D simulation world. (Pimental and Teixeira, 1995)

3) Virtual reality has been defined as " ...the computer of communication which takes place in a computer generated synthetic space and embeds human as an integral part of the system..." (Regenbrench and Donath, 1997)

2.3.2 State of the Art of Virtual Reality in Construction

Wichard et al. (1989) presented a tool that integrated the CAD system with Construction CAE, a simulation, planning, scheduling, and cost controlling. The simulation plan is graphically defined within CAD and output is presented as real-time animation, which is replayed graphically on the screen.

Feghhi et al. (1990) presented an object-oriented kernel that integrated design and process planning of mechanical parts. It can be customized to wide range of environments and be used as a rapid prototyping tool.

Cherneff et al. (1991) integrated CAD with construction schedule generation through knowledge-based programming and database techniques.

Tumay (1992) described the process of integrating simulation models with CAD for facility layouts and highlights the implementation issues such as file formats, scaling, model resolution, and dynamic depiction. The users can reduce the time to create animation and reduce the time to incorporate frequent layout changes into a simulation during the design phase of project.

Beliveau et al. (1993) described a method for controlling material handling on site by using CAD.

Koved and Wooten (1993) presented an Object-Oriented Programming called GROOP (Graphics using Object-Oriented Programming). It is a toolkit for animation of 3D computer generated graphics, and it is designed to be portable across graphics system. It is divided into two major components: scene construction and animation and rendering. GROOP can be applied for both discrete and continuous systems.

Vanegas et al. (1993) described a methodology that provides a way of running an interactive and real-time simulation of construction operations in virtual environment. It is a new methodology for simulating construction operations, which strengthens the design/construction interface and brings the user closer to the real world than ever before. One important component of this methodology is a new technique called CADA (Computer Aided Design and Assembly).

OpdenBosch (1994) studied a new methodology, which was designed to simulate construction operation in a real-time virtual interactive environment created by using object-oriented language C++. This environment called Interactive Visualize Plus Plus (IV++). It provides the users with the choices of virtual construction equipment that can perform the tasks needed to assemble building. He also developed a new technique called Computer Aided Design and Assembly (CADA) conceived to simplify the process of defining simulation goals by using CAD. This approach uses a combination of technique from different areas to allow the designers, construction managers, and other users to share ideas and experiences.

Huang and Halpin (1995) used computer simulation techniques and a graphic method, DISCO (Dynamic Interface for Simulation of Construction Operations), for the evaluation of the transient effects of construction caused by the process mobilization of construction operations.

McKinney et al. (1998) presented a construction example (roof construction) that illustrates how 3D CAD modeling can help identify construction problems and evaluate the quality of the construction plan through 4D analysis. He also discussed a method of generating, visualizing, and evaluating planning information with CAD.

Sly (1998) presented a new object-oriented approach (Visfactory), which allows users to create 2D and 3D models of the factory layouts by using AutoCAD. It can reduce the time and effort for creating current 2D drawings and can communicate to simulation packages.

Rauterberg et al. (1998) described a planning tool for construction and design called BUILD-IT. It was designed for supporting providers of assembly lines and plants in early design processes. It can read and render an arbitrary CAD model of the virtual objects, which are realized by connecting BUILD-IT with the CAD system. .

Kwaw and Gorny (1999) presented the highly interactive 3D geometric modeling system (VCAD). It is used to communicate between all persons during the construction process that could reduce a significant amount of cost caused by misunderstandings. VCAD is developed to a CAD-system prototype, which simplifies the existing design procedures in structural engineering.

Retik and Shapira (1999) presented an approach system to integrate site-related activities into the planning and scheduling of construction project. The system is based on the creation of realistic 3D images of the project's building structure and site, and subsequent visual simulation of the construction process. The prototype system was developed to serve as an environment for the planning of multiple residential units in low-rise and multi-story building. The system applied Superscape's Shape Editor to create a library of graphic elements and applied Superscape VRT to provide dynamic interaction with a virtual project.

Yoshihiko et al. (1999) introduced the application of Frame Accurate Animation (FAA) as an important implementation for construction management. It can help to visualize clearly the sequence of the construction process, simulate and make it possible to be carried out smoothly before the construction begins. AutoCAD r14J and 3D studioVIZ 1.0J were used for the modeling and each FAA's frame from Autodesk Inc. Director 5.0J was used to script each command of action. Case studies of Sashiki Bridge construction were presented as simulation of re-bar arrangements of a pier, overall construction schedule, simulation of cantilever erection system and change order approval for the main tower.

AbouRizk and Mather (2000) integrated a simulation model with 3D CAD for earthmoving operation. Simulation models are automatically generated from high-level descriptions in CAD by making use of add-on tools to capture key information.

Whyte and Bouchlaghem (2000) presented virtual reality techniques for housing developers to plan marketing and improve the quality of new houses. Planners can model urban environments in 3D electronic space by using CAD and visualization techniques.

Lipman and Reed (2000) described initial research using the Virtual Reality Modeling Language (VRML) in construction industry applications. The research was focused on the modeling of steel structures and construction equipment. A VRML prototype was used to create a beam object that provided a simple way to specify thousands of different types of beam with only a beam designation and position. Construction equipment such as excavator was also studied.

Maruyama et al. (2000) developed virtual and real-field construction management systems called "VR-Coms" that is integrated with virtual construction simulation, planning and scheduling, and real-time based construction management functions. "What-if" analysis can be carried out to explore what happens in the construction site, as well as when and where the events occur. The virtual simulation was combined with the scheduling system. It was used to monitor and study the status of the project and the work performed at a specific time and specific location.

Ovararin (2001) presented output of his research to be displayed in the animation of the real-time 3D model to plan, assess and communication construction project. This computer program was created by using the Visual Basic 5.0, which operated on Windows 95 and active automation in AutoCAD release 14. The advantage of this computer application was to display a time-base window, a 3D model window and a schedule window in the same time.

OpdenBosch (2001) presented a system adapted for construction process simulations. The construction planners and designers can create and run the simulation in real-time while interactively participating in process while the simulation is running.

Kamat and Martinez (2001) developed 3D visualizing simulated construction operation called "DCV (Dynamic Construction Visualizer)". It was the first version of a general-purpose visualization system that was specifically designed for earthwork operations, which involved excavation, transportation, and placement or disposal of materials. DCV was developed from computer graphics programming libraries called "Cosmo3D and OpenGL Optimizer", which were distributed by Silicon Graphics Inc.

Dawood, et al. (2002) reported the development of an integrated database to act as an information resource base for 4D/VR construction process simulation. It is a part of the research project, the Virtual Construction Site: A Decision Support System for Construction Planning (VIRCON). The core database was designed using standard classification methods. It is a new classification scheme for the construction industry and follows the international work set out by ISO technical report.

2.4 Simulation Modeling in Construction

2.4.1 The Meanings of Simulation Modeling in Construction

The meanings of the simulation modeling and computer simulation are defined as one or combinations of the following meanings:

1) 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 (Pristker, 1986).

2) Computer simulation is a tool that has been used in construction planning. Simulation can be beneficial to construction planning and analysis because some construction processes are repetitive. Cycle duration significantly contributes to the total operation cost and duration times are random variables (Touran, 1990).

3) Computer simulation is a tool available for users in planning and estimating by using simulated construction process to establish the anticipated level of production. It is used for solving some of the problems related to the random of construction operations (AbouRizk et al. 1992).

4) Computer simulation is an effective tool for designing construction processes. (By changing initial conditions and resources specification, different system responses results that the user can select the mix of resources, work sequences, and technology to best achieve objectives) (Gonzalez and AbouRizk, 1993).

5) Computer simulation is an effective tool for analyzing the difficulties of scheduling and making parts of many different specifications (Vern and Gunal, 1998).

6) Computer simulation is a tool that can simulate a construction process on the operational level by addressing the random nature, resource-driven characteristics and dynamic interaction during operation (Shi, 1999).

7) Simulation is the process of building a mathematical or logical model of system or a decision problem, and experimenting with the model to obtain insight into the system's behavior or to assist in solving the decision problems (Evans, 1998).

2.4.2 State of the Art of Construction Simulation

2.4.2.1 General-Propose of Simulation Modeling in Construction

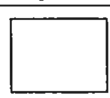
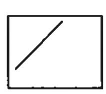
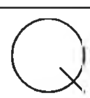
Jensen (1992) presented a discrete-event simulation modeling system called "*Petri Nets*" (Petri, 1962). It is a formal graphical representation for analysis of a system. Petri Net theory provides formal methods of analysis to determine a specific configuration of a system that can be reached from another configuration. The system is reversible and a complex system can be simplified.

Hajjar and AbouRizk (1996) presented a system called "CYCLONE" or CYCLic Operation NEtwork (Halpin, 1977) that popularized the use of simulation in construction. CYCLONE became the basis for a wide range of construction simulation research. But it proved practical only for small-scale application, and its used in the industry was limited to simple construction. Llunch and Halpin (1981) developed simulation program called "MicroCYCLONE". It is a microcomputer version of CYCLONE, which can be run on microcomputer desktop or workstation.

A CYCLONE or (Cyclic Operation Network) was developed as a tool for modeling construction operation by Halpin (1976). The ACD (Activity Cycle Diagram) of CYCLONE consists of several different elements connected by arrows. Table 2.1 illustrates the symbols, their names and definitions of the CYCLONE elements. In addition, Figure 2.1 presents a CYCLONE network diagram for earth excavating and hauling.

Several construction operations have been modeled by using CYCLONE; including, concrete placement operation, mixing plant operation and mud-hauling operations in tunnel excavation (Vanegas et al., 1993). There are three limitations of CYCLONE: 1) the inability to recognize difference between similar resources; 2) the inability to recognize the state of simulated process; and 3) the inability to make dynamic use of resource property and the state of the simulation to define model behavior (Martinez, 1996).

Tables 2.1: Names, symbols and definitions of CYCLONE's elements. (Source: Gonzalez and AbouRizk, 1993)

Name	Symbol	Definition
NORMAL		The normal task element is unconstrained in its logic. NORMAL will start immediately after its predecessor finishes
COMBI		The combi task element is logically constrained in its start logic. COMBI will start when none of preceding queue is empty.
QUEUE		Queue is the idle state of a resource entity. It represents a queuing or waiting for use passive state of resources.
FUNCTION		This element is inserted into the model to consolidate or multiply flow units.
ACCUMULATOR		This element is used to measure system productivity and used to define the number of times of system cycles.
ARROW		This element is used to present direction of flow of resource entity

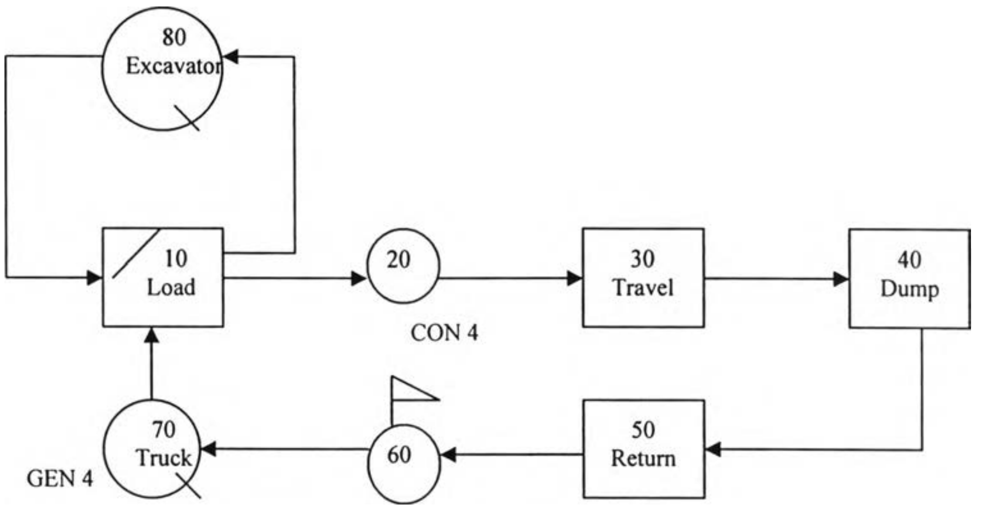


Figure 2.1: CYCLONE network diagram for earth excavating and hauling (Adapted from Martinez, 1996)

Chang (1986) developed a simulation program by incorporating the concepts of CYCLONE and functional extensions called “RESQUE” (Resource Based Queuing network simulation system). It could define resource distinctions and increase simulation control. It is more flexible than simulation using CYCLONE.

Touran (1990) investigated the integration of simulation with an expert system. This system was called “SIMEX”. He showed that expert system could provide a front end to the simulation package that enables the user to perform simulation analysis without having to be an expert in simulation modeling. The user can perform simulation analysis of a number of simple earth-moving operations.

Liu (1991) developed an object-oriented system called “COOPS” (Construction Object-Oriented Process Simulation System). He used concept of CYCLONE and added some node rules. COOPS was a discrete-event simulation system and was developed for graphic user interface. The users can use COOPS to track and capture resources, define difference resource requirements and link to other planning system.

Odeh (1992) developed a simulation tool called “CIPROS”, which integrates process-level and project level planning by containing a knowledge base of construction techniques and methods, and making use of a hierarchical object-oriented representation for resources and their properties.

Martinez (1996) developed a simulation-programming language called “STROBOSCOPE” (State and Resource Based Simulation of Construction Process).

It could be used for general purpose, which the details of model were specified with other mechanisms. Each modeling element has methods that define the element's behavior. And each method has a default implementation that reflects the element's most common behavior.

In order to reduce the above limitations and problems of CYCLONE, Martinez (1996) developed the new simulation tool called "STROBOSCOPE" in his doctoral study. He still used the ACD for developing this simulation tool. Figure 2.2 presents the STROBOSCOPE network diagram for earth excavating and hauling, which was modeled by the above CYCLONE network.

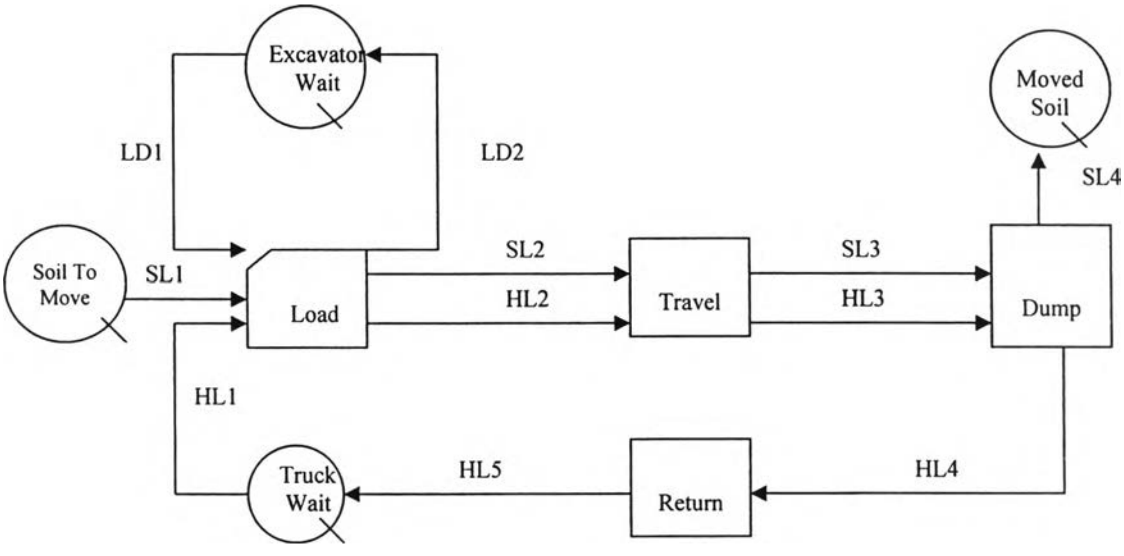


Figure 2.2: STROBOSCOPE ACD for earth excavation and hauling (Adapted from Martinez, 1996)

The STROBOSCOPE can be programmed and an extended simulation system designed for modeling complex construction operations in details. In an ACD of STROBOSCOPE, there are methods or attributes that define the behavior of element. Each method has a default implementation that reflects the most common behavior of element, which can be redefined to achieve the desired effect. Therefore, the functional details of a model are specified by redefining these methods. The modelers can use code to redefine a method. Not only it can be a simple number, but also it can consist of a complex expression or function. The naming convention adopted in the STROBOSCOPE network also indicates the relative order in which the different types of resources traverse the links. The STROBOSCOPE has been used for modeling many construction operations; e.g., tunneling operation, paving operation and lean construction processes (Martinez and Ioannou, 1999).

2.4.2.2 Specific-Purpose of Simulation Modeling in Construction

Carr (1979) developed a system called "MUD" (Model for Uncertainly Determination) which uses a simulation-network scheduling methodology to provide a sampling of unbalance estimate activity duration, a critical index, and expected duration. It was modeled with CPM network software system and CYCLONE simulation methodology. It was an effective tool for the improvement of estimating activity duration.

Farid (1994) developed a simulation program for constriction equipment selection called "FLEET". The MicroCYCLONE computer simulation package is used to verify FLEET. The research showed that FLEET could yield substantial saving in time and cost in equipment selection.

Hajjar and AbouRizk (1996) developed a tool called "AP2-Earth" that can be used in large earthmoving projects. It can help contractors to automate the traditionally time-consuming and manual process of preparing earthmoving estimates for large and complex projects.

Hajjar et al. (1998) constructed a tool called "CRUISER" that can be used for modeling aggregate production plans. Users can define the plant layout and create the crushing components and visually connect them with conveyers.

2.4.2.3 Other Case-Studies of Simulation Modeling in Construction

Riggs (1980) showed that resource allocation could be enhanced when a simulation model was applied. He used CYCLONE to address the issue of sensitivity analysis.

Gonzalez and AbouRizk (1993) compared the two simulation methodologies of MicroCYCLONE and SLAM II, which were used for simulating a horizontal earth-moving operation. This research showed that MicroCYCLONE and SLAM II yielded effectively the same results for the deterministic simulation.

Hajjar and AbouRizk (2000) applied the application of objected-oriented application framework concepts to the construction simulation domain. It was found that an application framework approach greatly reduced the development effort and allowed for the standardization of the generated tools.

Senior (1995) introduced an algorithm that used CYCLONE, a discrete-event simulation method oriented to construction applications, to compute task late-time and float information that were used for project planning.

Vanegas et al. (1993) described the implementation of the MicroCYCLONE, microcomputer-based simulation system within the firm, to effectively design and evaluate construction processes and achieve improved cost and scheduling efficiency. The system was applied for concrete placement operation, batch plant analysis and muck-hauling operation in tunnel excavation.

AbouRizk and Dozzi (1993) discussed the uses of simulation model (CYCLONE) to analyze parts of claim between the public owner and steel contractors. Simulation models are also developed to estimate the cost of operation at the time of bidding and to estimate the cost of the operation after change order.

AbouRizk and Wales (1997) presented a model, which a project schedule prepared using the critical path method (CPM) is transferred into a process interaction-discrete event simulation model and combined with a continuous change weather process in the same model. It is more effective than deterministically adding the expected delay due to weather to expected duration of project estimated from CPM.

Shi (1995) presented the automated modeling process and optimization technique for simulating construction projects in order to simplify simulation. He developed Resource-Based Modeling (RBM) as an automate-modeling tool mainly for resource-intensive construction projects and used the REM methodology for modeling earthmoving operations. It is a prototype environment with user-friendly interface and requires little time to construct a simulation model for a project.

Shi et al. (1998) presented the application of simulation technique for modeling and simulating public housing construction in Hong Kong with the intention to conclude the appropriate floor cycle construction time and necessary resource combination.

2.5 Discussion

Simulation modeling can assist in designing complex construction operations and making optimal decisions where traditional methods prove ineffective or are unfeasible. However, there have been limited uses of simulation in planning construction operations due to the unavailability of appropriate support tools that can provide users with more realistic and comprehensible feedback from simulation analysis.

Due to the limitations of traditional simulation modeling, Virtual Reality (VR) and 3D technology have been applied to integrate with other planning tools, e.g., scheduling software, in order to improve the effectiveness of communication among construction project participants and improve the traditional planning and monitoring of construction project. However, the VR and 3D technology have been used only as tools to visualize construction processes according to scheduling.

In traditional planning, construction methods are selected based on expert planners' experience while construction time or durations are calculated by scheduling tools and construction cost is determined by a cost estimator. Furthermore, human managers have limitation of their thinking to generate integrated planning. Because of this fragmentation of traditional planning method and the limitations of human thinking, the construction planners need a tool or an integrated system, which is able to visualize the construction process, calculate time and estimate operation cost simultaneously. However, according to state of the art of integrated system in construction, those integrated system have not included construction process, time, and cost together. The main objectives of the current systems are: 1) to integrate information between design stage and construction state, 2) to enhance effective communication among construction team, 3) to enhance the effectiveness of project monitoring. These systems have usually integrated virtual reality or 3D technology with other technologies, e.g., scheduling software, information system, and the Internet.

Consequently, the objective of this research is to propose a new innovation of decision-making system for integrating construction planning. This new system will integrate of construction processes in 3D, time, and construction process cost by using virtual reality technology.

2.6 Conclusion

This chapter presents various literature reviews of the relevant research in three main topics, namely 1) the state of the art of integrated systems in construction, 2) the applications of virtual reality technology in construction, and 3) simulation modeling in construction.

Simulation modeling can help in designing complex construction operations and making decisions where traditional methods prove ineffective. However, there has been limited use of simulation in construction planning due to the fact that they cannot provide users with more realistic feedback from simulation analysis. Thus, virtual reality technology has been applied to facilitate the usability of construction process simulation as an operations management tool in the construction industry. The 3D visualization of the planned construction operations will provide easier accessibility for the planners by graphically illustrating the configuration of the system in a very realistic format. However, the VR and 3D technology have been used only as tools to visualize construction processes according to construction schedules.

Because of the fragmentation of traditional planning and the limitation of human thinking, the construction planners need a tool or the integrated system, which is able to visualize construction process, calculate time and cost simultaneously. However, integrated systems from various literature reviews did not integrate construction process, time, and construction process cost. Thus, the aim of this research is to propose the integrated system of 3D construction processes, time and construction process cost in order to enhance an effective decision-making of construction planners.