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Automated post-simulation visualization of modular building production assembly line

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ABSTRACT

Simulation is often used to model production processes with the aim of understanding and improving them. In many cases, however, information produced by simulation is not detailed enough and can be misinterpreted. The use of visualization in combination with simulation can provide project participants with a detailed-level model to prevent misinterpretation of information and to understand the production process. The purpose of this research is to automate the visualization process as a post-simulation tool through sharing interactive information between simulation and visualization. The proposed methodology has been applied to the production line of modular buildings with the output of lean, simulation, and visualization in the form of animation. Based on the new scheduling developed by applying lean principles, a simulation model was built and its output was extracted to an ASCII file to be used as input for visualization. 3D visualization was developed using Maxscript in 3D Studio Max for automation of the visualization process. The proposed methodology has been applied to a case study to illustrate the essential features of the work and its benefits for decision making.

1. Introduction

Modular buildings are pre-fabricated buildings that started to gain popularity in the early 20th century. The Modular Building Institute (MBI), founded in 1983, defines modular as a construction method or process where individual modules, stand-alone or assembled together, make up larger structures. Even though revenue growth in the modular building industry has recently dropped, it remains a market with increasing benefits.

The modular building industry is also becoming more widely recognized for its environmentally-friendly construction process, speed of construction, and waste reduction at cost competitive prices [1]. Further improvement of productivity and potential cost reduction can be gained by redesigning the production process, facility layout, and material handling. Previous research has shown that various disciplines including lean [2,3], simulation, or integrated systems are used to set stable and effective production flow. A combination of these principles has also been used for such purpose; see [5–7].

Computer simulation is defined by Pritsker [8] as the process of designing a mathematical–logical model of a real world system and experimenting with the model on a computer. It can be used to eliminate unforeseen bottlenecks, to effectively use resources, and to optimize system performance before an existing system is altered by the proposed design. There are many existing simulation tools that have been developed and used in construction. Simphony [9], used in this research, is an example of such tools. Simphony was developed under the Natural Science and Engineering Research Council (NSERC)/Alberta Construction Industry Research Chair Program in Construction Engineering and Management. It can be used either as a general purpose or a special purpose simulation (SPS) tool.

Parallel to the use of simulation several researchers and planners in recent years have focused their work on using 3D visualization in the fields of construction management, productivity and cost analysis, resource management, and assessment of site layout [7–9]. Based on their work, it has been found that 3D visualization provides more realistic and clear feedback of the simulation output and dynamic graphical depictions. These include features such as the state of each task at a specific time, the work space required for construction activities, and clear communication about the work with the project participants.

2. Problem description

Based on lean principles, and in particular the use of Value Stream Mapping (VSM), many researchers such as Haitao Yu [2], Roberto J. Arbulu and Iris D. Tommelein [3], and Ping Wang [4] have developed stable and effective production flow in fabrication shops for improvement of productivity and reduction of cost. These various efforts have not yet seen fullscale success. Although lean production using VSM is a powerful concept for designing a new schedule for

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continuous material and production flow, workforce management, and balance of subtasks on the production line, the proposed design needs to be continuously adjusted and changed until the developer's purposes are obtained. Implementing changes on a real production line without prior validation can be risky, costly, and time-consuming. Alternatively computer simulation can be used as an environment for validating the proposed design. It is an efficient and cost-effective tool to experiment with the potential performance of the proposed design before applying it to a real production line.

Despite its advantages however, simulation describes an abstraction of reality and for many users is difficult to understand on its own. Visualization of simulated construction processes can help in analyzing and communicating simulation results to assist in the decision making process. The use of dynamic graphical depictions in visualization can show the simulated operations as they would be in reality. The main differences between simulation and visualization can be summarized as follows:

(1) Construction participants who have no simulation knowledge cannot fully understand the simulation results and process flow because it's provided in numerical and logical computation. 3D visualization, on the other hand, creates smooth and natural scenes for quick and easy understanding.
(2) In a simulation model, the workspace requirement and limitation in production processes is not provided. However, in 3D visualization geometric information such as coordination of all components is provided to identify workspace.
(3) A simulation model focuses only on a target object's movement. On the other hand, every level of detail of the construction activities can be described in visualization. For example, the only movement in a simulation model could be related to modules on the manufactured production line, but in visualization, all components such as employees, conduit, door, FRP, exterior board, and crane in the production line can be shown and animated.
(4) In the simulation model, users cannot easily identify errors in the logic of the schedule. However, 3D visualization can provide scheduling animation while animation of all components is running. So, the errors in the schedule can be identified.

3. Proposed methodology

To achieve the objective of this research, two challenges needed to be addressed: 1) how to share information whereby output data from simulation is used as input parameters for visualization and 2) how to reset the animation key frames of the 3D objects and import the simulated input data to the 3D visualization as the output data of the simulation model changes.

The proposed research methodology shown in Fig. 1 is categorized by three distinct phases which are the lean VSM model, simulation, and visualization. The input parameters of VSM as a lean production tool contain information such as the current scheduling, transfer time, subtask process time, and cycle time for stations. Based on the current production process, a VSM is produced. Usually a production manager will study the VSM model produced to analyze the production process as a system and find out where the real problems and wastes are to suggest improvements. To improve the production processes, a proposed system is then suggested based on continuous production flow and takt time, which is related to waste reduction. The focus is on developing an improved future production process to meet customer demands for the products. The takt time is calculated by dividing the net available production time data for a specific period by the customer demand for the same time period. Based on this calculation, the new proposed schedule is drawn. The criteria for the new VSM are takt time and scheduling. The output of the VSM represents the proposed improved scheduling for the production line.

Following the process described above, two simulation models are generated based on the original schedule and the proposed schedule represented by the two VSM models. Both simulation models are built in Simphony with the required data consisting of transfer time, subtask process time, and scheduling. Before building the simulation models, the process times of subtasks are converted to probability distribution functions. The cycle time statistic of the production line, generated from the original and future state simulation models, can be compared in order to validate the proposed scheduling improvement of the production processes. The input information required for the simulation includes the original and proposed schedules and process times for activities at each station. The output from simulation consists of the modular cycle time statistic and the ASCII file. The ASCII file which includes start times and finish times for subtasks and travel times between stations, is a unique file that imports the simulation result into 3D Studio Max. The data in the ASCII file is automatically extracted and stored in a Microsoft Access 2007 database. The generation of the ASCII text file is key to automating the visualization process based on the simulation model.

A 3D visualization model is then built using modular component specification, scheduling fitted in the simulation model, transfer time, 3D components, 3D production modular, and the ASCII file. The proposed scheduling and the ASCII file are criteria input data for the 3D visualization. In particular, the ASCII file is used to simply set or reset animation frame keys of the 3D objects and 3D scheduling chart between their process time points for real movement of components without any reworks in the visualization model. To animate the 3D objects in 3D Studio Max, the Maxscript shown in Fig. 2 is used in this research. Maxscript is a built-in language tool to automate repetitive tasks, to combine existing functionality in new ways, and to develop user interfaces. Therefore, the setup of animation key frames using Maxscript is implemented only once eliminating the need to redesign the Maxscript code when the data in ASCII file is changed due to changes in the simulation outputs. The output of the 3D visualization involves a virtual reality model with a 3D scheduling chart. The 3D scheduling charts are animate subtask bars between specific times, while components related to the tasks are animated simultaneously. The virtual reality model in combination with the 3D scheduling chart is able to effectively validate various assumptions such as the proposed scheduling and requirement and limitation of work space.

4. System architecture

This work builds on a previous work by Haitao Yu [10], who proposed an improved manufacturing production line based on lean using VSM. In this work, simulation is used to validate and verify the results of the proposed model. In addition a 3D visualization model is built to generate the dynamic graphical depiction to assist decision makers in understanding detailed information of the manufactured production line. This information includes the limitation and requirement of workspace and the current state of the production process. It is believed that a combination of lean, simulation, and visualization provides decision makers with a better understanding of the proposed operation and helps to predict the performance resulting from alternative decisions.

To achieve the objectives described above, a system database has been developed to store all the information needed for building Value Stream Mapping (VSM), simulation, and visualization. Fig. 3 shows the architecture of the proposed system. The central database comprises five elements: 3D object libraries designated for modular components, scheduling, component specification, time data, and ASCII file. The time data contains the following information: (1) list of activities, (2) transfer time between each station, (3) start time and finish time of activities, and (4) cycle time. The schedules are managed based on number of employees required for operations at every subtask and prioritized subtasks that must be performed within a set period of time in