USING VISUAL INTERACTIVE SIMULATION TO IMPROVE DECISION-MAKING IN PRODUCTION SYSTEM DESIGN

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ABSTRACT

The performance of production systems in construction is strongly affected by variability, interdependence and uncertainty. Simulation models are useful for modelling the behaviour of production systems, and understanding the combined effects of those factors. Although simulation is widely used in several industrial sectors and their benefits are well-known, most of the applications in construction have been developed by academics. Very little has been reported in the literature on the use of simulation for the design of real production systems in the construction industry. One of the main causes for its poor dissemination is the lack of confidence and perception of validity in simulation models by decision-makers. Visual Interactive Simulation (VIS) is a technique which integrates mathematical and symbolic models with runtime interaction and real-time graphic display of the model output. Such features can potentially make it easier to introduce simulation in the task of designing production systems in construction, by getting decision-makers involved in both processes of building and using the model.

This paper presents an exploratory study on the application of VIS for improving the decision-making process in the production system design of a building project. A process of external wall plastering was used to test the use of VIS and to assess the difficulties and benefits of this technique. The main findings are related to the improvement of communication and understanding between the user and model builder, as well as the need for creating opportunities for reflection.

KEYWORDS

Visual interactive simulation, production system design, decision-making.

INTRODUCTION

Designing production systems is an activity that has been often overlooked in construction sector. Several IGLC Conference papers have pointed out the need for explicitly separating the design of production systems from the tasks involved in managing them (Ballard et al. 2001, 2001a). Some previous papers from the authors have discussed the role and the scope of decisions involved in production system design in construction projects (Schramm et al. 2004, Schramm et al. 2006). The design of production systems in construction must take into account the complex nature of construction, in which variability, interdependence and uncertainty strongly affect the outcomes of a project. In this context, it is necessary to

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use stochastic methods that can effectively help managers to make decisions in the early stages of a project.

Simulation has been widely used for modelling the behaviour of production systems, and understanding the combined effects of those factors. It is especially useful if the system does not exist yet, i.e. for analysing the performance of production systems in the design phase (Law and Kelton 2000). One of the main benefits of using simulation is that it allows managers or engineers to have an idea of the overall effects of local decisions in the production system (Law and Kelton, 2000). Through simulation models it is possible to understand the implications of the complexity of a production system (Robinson 2003), and support the decision-making process involved in the conception and design of complex production system (Welgama and Mills, 1995). Moreover, since the operational behaviour of the system under study can be reproduced in a simulation model, it is possible to compare alternative designs and to measure the effects of different policies on system performance (Robinson 2003).

Despite the well known benefits of using simulation to support decision-making, its use has been very modest in the construction industry. In fact, in the proceedings of the Winter Simulation Conference between 1997 and 2006, the papers on simulation applied to construction management represent only 3.5% of the papers presented. Moreover, in IGLC Conferences 11 papers about simulation in construction have been presented in the last ten years.

Shi and AbouRizk (1998) pointed out the potential of using simulation in the construction industry. However, according to those authors, there is still a need for making simulation widely used in the sector, especially by making it an effective user-friendly tool and by reducing model development time. In general, simulation studies in construction have focused on individual construction operations or processes. Little has been written about the use of simulation for designing production systems in construction. Most of them have used simulation for testing propositions using hypothetical or existing production systems (e.g. Draper and Martinez 2002, Alves et al. 2006, respectively). None of them have explicitly used simulation models to support decision-making in the design and implementation of new production systems in construction.

This paper presents a discussion on the impacts of using Visual Interactive Simulation (VIS) as a tool to support decision-making in the design of production systems. An exploratory case study was carried out aiming to test the use of VIS to model and simulate an external wall plastering process. Although just a single construction process has been studied, the findings of that case study were used to make propositions to be tested in the further studies. In addition, an approach to reduce the model development time by using generic models which will be tested in further studies is also presented.

SIMULATION IN CONSTRUCTION

Simulation has been used as a tool for construction management since 1973 when Halpin developed CYCLONE. Based on that system, many other simulation programs were proposed aiming to develop simulation models for support decision making in construction management. More recently, STROBOSCOPE has been one of the most used simulation languages in the construction field. Many studies have been developed using this language, including several ones related to the application of lean production principles and concepts to construction management.

However, typical construction simulation models provide both information that is hard to communicate to decision-makers (Kamat 2003). Very often, they are not trained in simulation, and do not have means, time and training to validate or verify the models based only on numerical outputs (Ioannou and Martinez 1996). Thus, construction practitioners are often sceptical about simulation models and find difficult to rely on their results (Kamat 2003). Besides, there are other causes that contribute to limit the application of simulation in construction (a) the complexity of the construction processes and the difficulty to devise models of those processes (Oloufa et al. 1998); (b) the increase in the model's development time due to that complexity (Shi and AbouRizk 1997); and (c) frequently, a simulation model is perceived as a "black box" by the users, making it difficult to understand it and rely on it (Shi and Zhang 1999).

VISUAL INTERACTIVE SIMULATION (VIS)

In recent years, several studies have been developed applying visual modelling and simulation techniques to construction activities, aiming to make this tool friendlier to its users (Oloufa et al. 1998, Hajjar and AbouRizk 1998, Hajjar and AbouRizk 1999, Shi 1999, Hong et al. 2002, Nasereddin et al. 2007). Kamat (2003) suggest that this has become a trend in construction simulation. For example, Ioannou and Martinez (1996) used the visual postprocessor PROOF to animate STROBOSCOPE models in 2-D, while Kamat (2003) has studied techniques of 3-D visualisation of STROBOCOPE simulation models.

Visual Interactive Simulation (VIS) is a technique that involves the use of a dynamic display in which the user can change the model's parameters during the routine execution to analyse their impacts (Au and Paul 1996). A VIS model can be a compound of a mixture of block diagram, icons, charts, and texts to show the system behaviour while running a simulation (Au and Paul 1996). The dynamic features and the discrete changes of a process can be seen on the computer screen (Law and McComas 1992, Law and Kelton 2000). By visualising these changes the user can test the simulation model and validate its results (Shi and Zhang 1999), obtain insights on the real system behaviour (Welgama and Mills 1995), compare various alternative scenarios and predict the future behaviour of the system (Ceric 1997).

The advantages of using VIS are pointed out by many authors; however, two are especially relevant for this research. Firstly, through visual display it is possible for the user to follow the events while they occur and to identify potential mistakes, i.e. it is easier to verify and validate the model (Law and McComas 1992, Law and Kelton 2000, Robinson 2003). Secondly, VIM/VIS environment is adequate to increase the understanding of the model by the user as well as to promote its participation in the development and run processes (Pidd 2002, Robinson 2003). VIM/VIS improves the communication of the model and its results for all project participants, specialists or not (Law and McComas 1992, Law and Kelton 2000, Robinson 2003), making it possible to devise solutions that are jointly discussed by different members of the simulation study (Robinson 2003).

GENERIC/REUSABLE MODELS

Some studies that have tested the use of alternative model development strategies to reduce the development time of simulation models. Oloufa et al. (1998) explain that in manufacturing production systems are fairly stable and the time and money invested for building models tend to result in a good cost-benefit relationship. By contrast, as production systems in construction are temporary, it is necessary to reduce the time available for developing models in order to answer questions more quickly (Oloufa et al. 1998).

Two alternative solutions can be used for reducing the model development time: (a) a generic model is one built for a particular context which can be used in other organizations; (b) a reusable model is one used in a different context from that which was originally proposed (Robinson 2003). Developing a reusable component of a simulation model is another similar concept. In that case, part of a model is re-used in a new simulation model, in a new context or for other purposes (Robinson 2003).

Reusable models are especially useful when someone is modelling systems of the same domain or sector. According to Mukkamala et al. (2003), in this case the modelling process is repetitive and the models are similar but slightly different. Thus, the modelling effort can be reduced by using domain specific modules or templates which encapsulate the specific logic of that domain and hide many of the model details (Mukkamala et al. 2003).

In the construction sector there are some examples of the generic/reusable modelling approach. Oloufa et al. (1998) developed a pre-programmed library of production resources aiming to reduce the development time of simulation models. When modelling a specific project, the user chooses the resources needed and specify the project logic, by linking them. Nasereddin et al. (2007) have proposed a reusable simulation model to be used in a modular housing factory. In that study, a generic model was employed, and the model could be configured to address specific situations, through a spreadsheet for data input.

RESEARCH METHOD

Previous IGLC Conference papers by the authors have discussed the role and the scope of decisions of Production System Design (PSD) in construction projects. Schramm et al. (2004) have proposed a model for devising the PSD of repetitive low income housing building projects. This model grouped the main PSD decisions in six sequential steps. It also suggested that the PSD in those projects should be carried out before the construction phase began, since most project requirements and design details are usually defined in advance. Schramm et al. (2006) proposed an adaptation of the PSD model for the so called complex and fast projects (e.g. hospitals, industrial and commercial buildings), in which there is a much higher level of uncertainty. In this adaptation, the PSD is produced in stages, as the level of uncertainty is gradually decreased.

A major limitation of those studies was that both of them employed deterministic methods to model the production systems. Considering that, the decision was made to develop further studies in which the effects of variability on the performance of production systems are considered by using visual interactive simulation.

This paper presents an exploratory study that was initially carried out as part of that research project. The main objective of this study was to investigate the potential benefits and difficulties in applying visual interactive simulation for supporting decision-making in the PSP of building projects. The study also aimed to assess the feasibility of using a general-purpose simulation package, named Arena® (Rockwell Software Inc. 2005), and also to develop simulation capabilities in the research team. This study was carried out in a construction company based in Porto Alegre, South of Brazil, which has been recognised as a leading organization on the application of lean production concepts and techniques in the construction industry. They have successfully used the Last Planner System for several years, have a highly standardised but flexible production process, and are very effective in terms of quality management. This company is currently involved in the development and construction of residential building projects the three different states: Rio Grande do Sul, Santa Catarina and Paraná.

In this exploratory study, the process of external wall plastering was chosen. This process often represent a bottleneck in terms of keeping the projects on time: it is fairly traditional, since it depends on labour skills and tends to be affected by the weather conditions; there is great potential for reducing waste and improving safety conditions. The exploratory study involved several meeting between one of the researchers and a production manager from the construction company. The simulation model was built by the researcher and shown to the manager in some of those meetings. The aim of that model was to support the company on the decision of choosing a strategy for carrying out that process.

CASE STUDY

The project that was investigated in the exploratory study consisted of a twenty-three storey residential building for higher-middle class in Porto Alegre. Figure 01 shows the façades of the building.

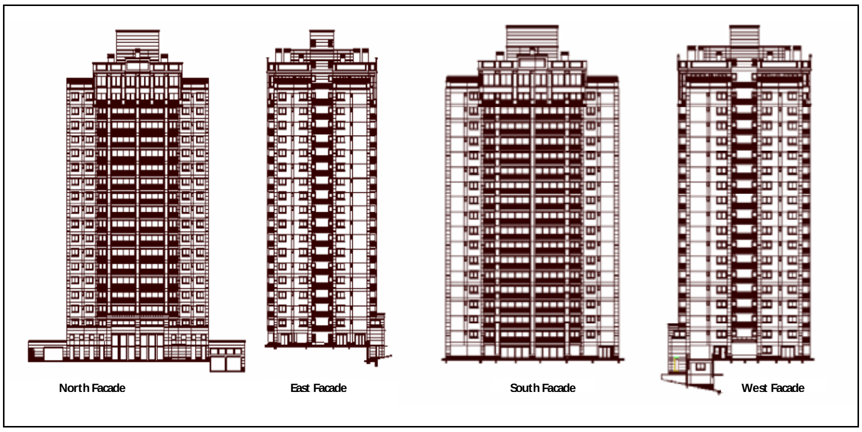

Figure 1: Façades of the building

The plastering process can be divided into four steps: cradle assembling, rendering coat, finishing coat, and cradle disassembling. Each façade was further divided 4 to 5 sections, each one assigned to a specific crew. Originally, according to the long-term plan, the entire process would be undertaken as a single step, i.e. the plastering process would start only after all external walls had been built. Thus, the simulation model was used to assess the reduction of the external wall plastering lead time if a different production strategy was chosen – for instance, starting the plastering process while the bricklayers were still building external walls. Thus, VIS was used to answer the following question: "when should external wall plastering start in order to reduce its lead time and, at the same time, to keep the crews in continuous flow?".

It is important to point out that the aim of this research project is to use VIS for supporting PSD, which should be carried out shortly before the beginning of the production phase. Thus, the production processes and their interactions should be represented in a low level of detail. However, more detailed models should be used later on, as more information is made available.

The model was built and run using default capabilities of the Arena software. As previously stated, there are several forms to animate a simulation model. In this study, a flowchart (a process map) was used to represent production processes. The flow of the entities – work orders – through the process steps was animated, in order to check the model logic. Some graphs were also used to help the users to understand the model behaviour. The type of animation adopted was chosen considering the need to make the model easy to understand as well as to develop it quickly. The more detailed and complex the model the longer tends to be the development time.

The development of the model followed a sequence. Firstly, information on the process was gathered for devising an initial conceptual model. That conceptual model then validated by using a technique called structured walkthrough, in which both modeller and the user inspect each part of the model to check if it reproduces the real system. At this point, the animation was used to help the manager to compare the model behaviour with his perception of the real system. After that, some adjustments were made in the model before it was finally submitted and approved by the company (figure 02).

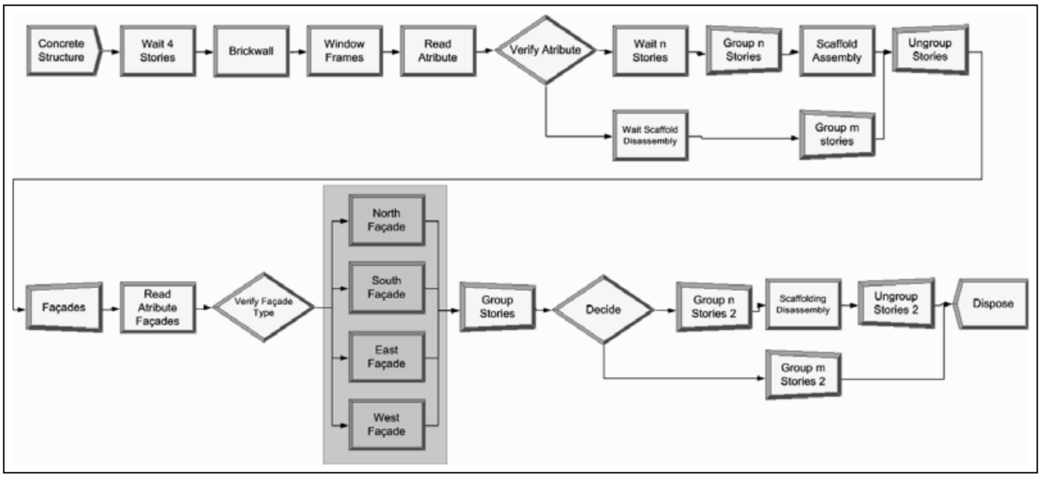

Figure 2: process model

However, at that stage, some information about the number of scaffolds to be used was not yet available. As that information was very important for running a simulation, the researcher decided to adopt an evolutionary modelling strategy, in order to avoid stopping the modelling process. That strategy consists of the building the model using more aggregate constructs to represent that part of the model until the required information is available. In that case, the rendering coat and the finishing coat steps were represented by four process boxes, one for each façade (light gray area in the figure 02).

Based on new information (number of scaffolds) the process boxes were depicted based on the number of work crews employed. The next step was to define the most adequate cumulative distribution function (CDF) that stood for each activity's duration variability and to run the simulation model.

Seven scenarios were simulated. Scenario 1 considered the strategy originally planned in the long term project plan, as previously explained. Other six alternative strategies were also tested in which the eighteen standard stories were divided into two production batches to allow to start the plastering process earlier before all external brickwalls had been built as originally planned (scenario 1). The floor in which the building was divided was called "cut-off point". Table 01 presents the simulated scenarios.

Table 1: simulated scenarios

Scenario	Cut-off Point (floor number)	Batch 1 Size (floors)	Batch 2 Size (floors)
1	20	18	0
2	16	14	4
3	15	13	5
4	14	12	6
5	13	11	7
6	12	10	8
7	11	9	9

Figure 03 presents the average lead times of the plastering process, in particular, as well of the processes of structure erection, bricklaying and plastering together, after running 40 replications for each scenario.

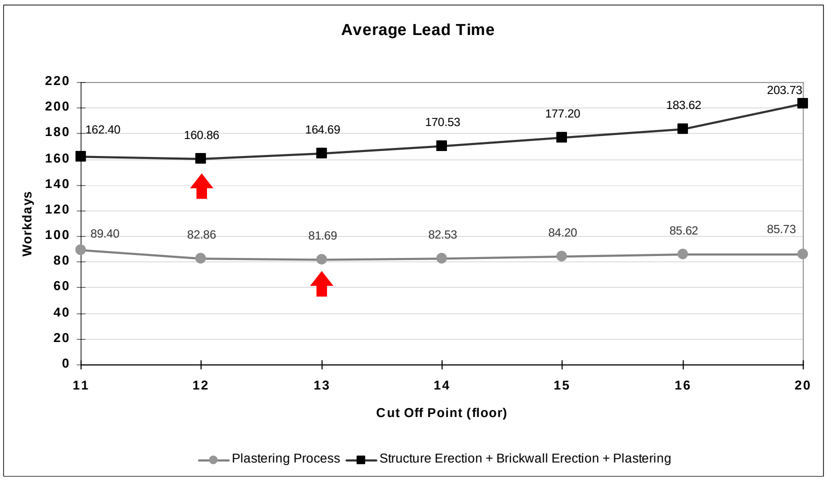

Figure 3: simulation results

Figure 3 indicates that the reduction of the production batch size decreased both lead times. In scenario 6 the shortest lead time of the three processes together was obtained. Under these conditions, the average lead time was reduced 42 days. On the other hand, scenario 7 was the shortest lead time of the plastering process. Moreover, there was a trend to increase the processes lead time when the first production batch size was smaller than 10 floors (scenario 7) due to the increase in the waiting time, since the plastering process workflow was blocked by the bricklaying process, which took a longer cycle time.

DISCUSSION

The modelling using blocks to form a process flowchart made the model development easier, especially because no programming was required and all data was input by writing directly on each flowchart box. Thus, the researcher opted to develop the conceptual model directly on the computer screen and, after validating it, to build the final model.

The model validation was also improved by the animation. Although only the entities were animated, its use allowed the manager to understand the model logic. The manager understanding of the plastering process increased during the study. Some process activities had been previously overlooked and the modelling process helped him to better understand their importance and interdependencies.

The VIM/VIS techniques allow building the model using an evolutionary strategy, i.e. it was possible to build the model according to the available information level about the system.

Thus, the first version of the model considered the system in a more aggregate manner. Since more information was available and the uncertainty level decreased, the model could be further detailed.

Six fourteen-five minute meetings were held between the production engineer and the researcher, over a period of three months, in which the model was improved based on the meeting outcomes. During those meetings the production engineer and researcher discussed the model building process until a suitable model was reached, i.e. a test/evaluation/test cycle was repeated until the modeller and the engineer had reached an agreement.

Visual modelling increased the modelling process transparency, since the entire model logic was graphically represented, and the flow of the entities could be checked through the animation. Literally, the manager was able to see problem on the computer screen, increasing his confidence that the model reproduced the system under study.

Two difficulties were found during the model development process and both of them were related to particular features of construction sector. Firstly, there was some difficulty to obtain historical data to model the activity durations. In order to deal with this problem, the durations were defined based on the subjective probabilities elicited from the manager. Secondly, although the execution sequence defined was based on the long-term plan, that sequence was not rigid. If there was a problem in the production process the sequence of activities could be modified as a contingency. Rather than an exception this was a rule. Thus, such changes in strategy could not be easily reproduced by the model.

CONCLUSIONS

Many studies have been devised to asses the benefits of lean concepts and principles to construction. Most of these studies have used traditional simulation methods to reach their objectives. This paper proposes the use of VIM/VIS techniques to improve the production of PSD. The case study indicated that VIM/VIS techniques can improve the modelling and simulation processes by adding process. The animation made it easier for the manager to understand the impacts of local changes in a systemic way, even though the full potential of visualisation provided by the software has not been used yet.

Those techniques promoted the involvement of the decision-maker into the process in an iterative manner. Therefore, both modeller and user were committed to understand the eventual problems under consideration. Thus, those techniques could be effectively used to make the modelling and simulation processes easier and simulation a more effective and a better user friendly tool.

Based on the simulation results, it was possible to assess the impacts of the reduction of the transfer batch sizes on the process lead time, allowing the production manager to choose the strategy to carry out the process. Moreover, the results could be used to help the decision making in further similar projects of the same construction company.

Although just a single process has been modelled, some propositions have been made for future studies, in which the PSD for entire projects will be investigated:

- Using VIM/VIS to develop the PSP using an evolutionary modelling, in order to deal with the high uncertainty that exists in early stages of the project;
- Evaluate the potential of reusing models or components in projects from different construction sectors, in order to reduce the model development time;
- Increasing the flexibility of such models, making easier to modify them to adapt to occasional production changes;

- Testing other ways of visualising the model results, and evaluating the trade-off detailing level *vs*. development time.

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