A PROPOSAL FOR REUSING SIMULATION MODELS IN THE DESIGNOF PRODUCTION SYSTEMS IN CONSTRUCTION

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ABSTRACT

One of the main difficulties of using simulation in the management of construction projects is the fact that developing simulation models is time consuming. One of the possible strategies to cope with this problem is the reuse of an existing model or part of it in other simulation study. Although many authors have pointed out that the unique nature of construction projects leads to the necessity of starting each model from the scratch, the reuse of models for simulating projects of the same market sector seems to be reasonable. This paper aims to assess the main benefits and difficulties of developing reusable simulation models for designing production systems for housing projects. A case study in which a simulation model was developed for supporting that task in a construction company involved in repetitive housing projects is presented. The development of this model took into account the possibility of reusing it in other similar projects of the company in order to reduce the time for doing the simulation study. The main findings are related to the limitations and requirements of reusable models as well as to the implementation of those models in the design of production systems for real construction projects.

KEYWORDS

Simulation; Reusable models; Production system design.

1. INTRODUCTION

Simulation has been widely used for modeling the behavior of production systems, and understanding the combined effects of variability, interdependence and uncertainty. It is especially useful if the system does not exist yet, i.e. for analyzing 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 to support the decision-making process involved in the conception and design of complex production systems (Welgama and Mills, 1995). Moreover, since the operational behavior of the system under study can be reproduced, it is possible to compare alternative designs and to measure the effects of different policies on its 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[10] Conferences 11 papers about simulation in construction have been presented in the last ten years.

Shi and AbouRizk (1998) pointed out that, despite the potential of using simulation in the construction industry, 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.

The aim of this paper is to make an assessment of the benefits and difficulties of developing and implementing reusable simulation models for designing production systems for housing projects.
Firstly, it is presented a brief literature revision on the use of simulation and, more specifically, a visual simulation model as a tool to support decision-making process in the design of production systems. Also, some key concepts on reusable and generic models are presented. Then, it is described a case study in which a simulation model was built taking into account the possibility of reusing it in other similar projects from the same company in order to reduce the model development time[11].

Finally, the main benefits and difficulties in using that approach, as well as some requirements to use those models in the production system design are presented and discussed.

2. SIMULATION IN CONSTRUCTION

One of the first simulation tools for construction management was CYCLONE, which was developed by Halpin in 1973. 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 that language, including several ones related to the application of lean production principles and concepts to construction management.

However, typical construction simulation models provide information that is hard to communicate to decision-makers (Kamat 2003). Very often, they are not trained in simulation, and do not have means and time to validate or verify the models based only on numerical outputs (Ioannou and Martinez 1996). Thus, construction practitioners are often skeptical 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).

3. VISUAL INTERACTIVE SIMULATION (VIS)

In recent years, several studies have applied visual modeling and simulation techniques for analyzing 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) suggests 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 visualization 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 analyze their impacts (Au and

[10] IGLC is the International Group for Lean Construction makes up a network of professionals and researchers in architecture, engineering, and construction (AEC) whose goal is to improve the AEC process as well as product, by developing new principles and methods for product development and production management, based on lean production concepts.

[11] This paper has focused on the process of developing and applying a model which was intended for being reused in another project of the same company. However, at the time this paper was written this study was not already finished and it will be reported in another paper.

Paul 1996). A VIS model can be formed by block diagrams, icons, charts, and texts to show the system behavior 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 visualizing these changes the user can test the simulation model and validate its results (Shi and Zhang 1999), obtain insights on the real system behavior (Welgama and Mills 1995), compare various alternative scenarios and predict the future behavior 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, a Visual Interactive Modeling and Simulation (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).

4. GENERIC AND 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 purpose which can be used through a number of organizations; (b) a reusable model is one used in another context for which it was originally intended (Robinson 2003). Developing a reusable component of a simulation model is another similar concept. In that case, part of a model is reused in a new simulation model, in a new context or for other purposes (Robinson 2003).

Pidd (2002) presents a spectrum of different types of reuse (Figure 01). That spectrum shows four points on a scale and two different horizontal axes (frequency and complexity). According to that author, the first axe indicates that reuse is much more frequent at the right-hand end, code scavenging. The second axis runs in the opposite direction, where code scavenging is relatively easy, but successful reuse of entire simulation models can be very difficult (Pidd 2002).

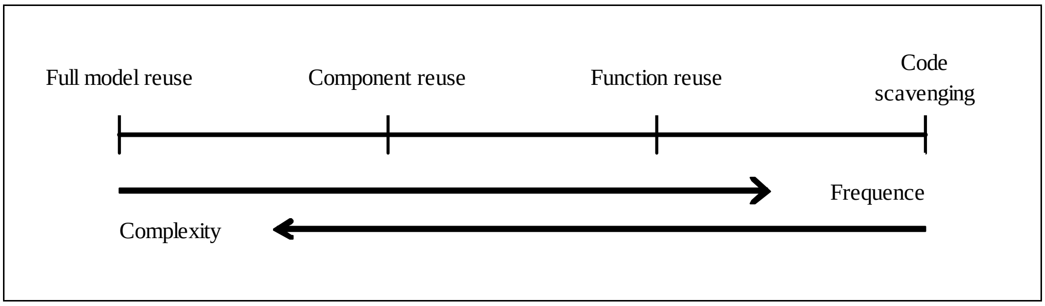

Figure 1: model reuse spectrum (based on: Pidd 2002)

According to Paul and Taylor (2002), there are many forms of reusing simulation models: (a) reusing modeling basic components; (b) reusing subsystems' models, i.e. the modeler has previously developed generic models of parts of the production system which can be adapted to a new model; and (c) reusing a previous model which has similar features to the system under study.

Reusable models are especially useful when someone is modeling systems of the same domain or sector. According to Mukkamala et al. (2003), in that case the modeling process is repetitive and the models are similar but slightly different. Thus, the modeling 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 modeling approach. Oloufa et al. (1998) developed a pre-programmed library of production resources aiming to reduce the development time of simulation models. When modeling 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.

5. RESEARCH METHOD

In order to guide the discussions a model for devising the production system design (PSD) of repetitive low income housing building projects (Schramm et al. 2004) was used. This model grouped the main PSD[12] 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. Figure 02 presents the proposed model.

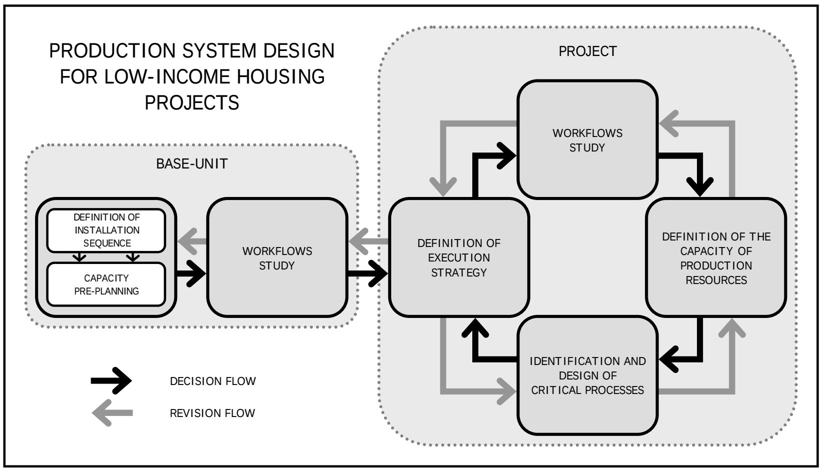

Figure 2: the production system design model (Schramm et al. 2004)

A major limitation of that model was that it employs deterministic methods to model the production systems what is one of the main reasons to the use of simulation models to model the effects of variability on the performance of production systems.

In the study it was used a general-purpose visual interactive simulation package, named Arena® (Rockwell Software Inc. 2005) to develop the simulation model.

6. CASE STUDY

The case study was carried out in a small construction company located in Canoas, a small town of the Porto Alegre metropolitan area, South of Brazil. That company has been involved in developing and building low-middle residential building projects.

The project investigated consisted of a low-rise terraced housing project which was made up of 112 ninety square-meter two-story houses, grouped into 21 blocks of 4, 8 or 10 dwellings. The main construction techniques used were: load-bearing concrete block walls, pre-cast concrete slabs and ceramic roof tiles.

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[12] Production System Design is a managerial activity that should take place before a project construction phase. In that stage the production system should be structured to accomplish the project goals. According to Skinner (1985), the production system design (PSD) aims to establish a set of manufacturing politics which can be grouped into two parts. The first is related to facilities and equipments, resource capacity, and technologies to be used. The second is related to infrastructure, i.e. decisions related to vertical integration level, production planning and control, workforce management, quality control and so forth.

Several weekly meetings were held among the research team and the company's production engineer. Eventually, company's architect and key subcontractors were invited to the meetings.
The first decision made was to establish a constructive sequence to build the project's base unit[13]. Based on previous case studies, the definition of a sound constructive sequence is a fundamental decision since it is the base for the model building[14]. Although the company had already built three previous projects with the same features (dwellings configuration, constructive techniques and materials, etc.), it was not possible identify a unique constructive sequence.
Thus, after a number of meetings an agreement on the most suitable construction sequence was reached. Besides the technological constraints that sequence took into account the production and transfer batch sizes[15], the times to process completion (in terms of a triangular distribution) and the resources which would be used to complete each process.

Based on that discussion, a precedence diagram was built and sent to the project site to be pinned on the site office wall and discussed with all involved. That discussion brought in production engineer, foreman, project planner and key subcontractor in order to explain the document and make a commitment to follow the standard constructive sequence. Figure 04 presents part of that precedence diagram.

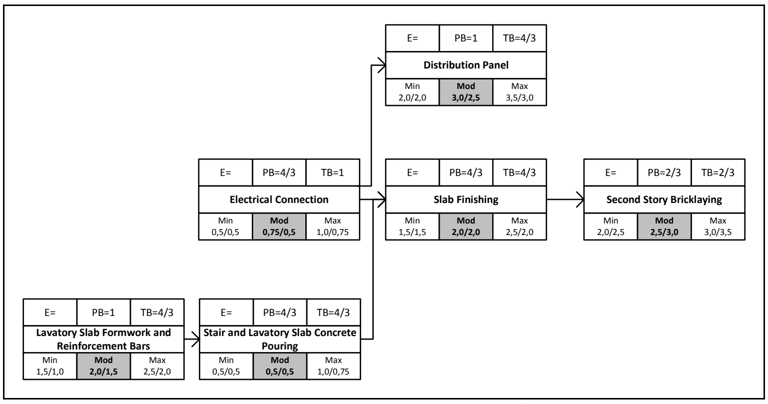

Figure 4: part of the precedence diagram built from the meetings

The second step was to build the simulation model in order to help the study of the base unit workflows, the execution strategy and the impacts of those decisions on the entire project workflows.

In order to put in practice the possibility of reusing that model in other company's projects, a generic simulation module was proposed for summarizing each production process features (production and transfer batch sizes, time to completion and the required resources). Besides simplifying and reducing the modeling time, the generic module allowed to record and write specific process data (process start and finish time, process lead time and so on) which would be used to build planning and control tools (as lines of balance, production control charts and S-curves, for instance). Figure 05 shows the conceptual model of the generic simulation module.

[13] A base unit is a repetitive production unit which is replicated many times during the project production phase.
[14] That decision plays a vital role when the model is being built aiming the reuse.
[15] The process batch is equivalent to the quantity of one product that is processed by a resource before starting the production of another product, and the transfer batch is the quantity of units that will be moved at the same time from one workstation to the next. According to Umble and Srikanth (1995), the transfer batch does not need and should not be the same as the process batch and the transfer batch should be ideally as small as possible.

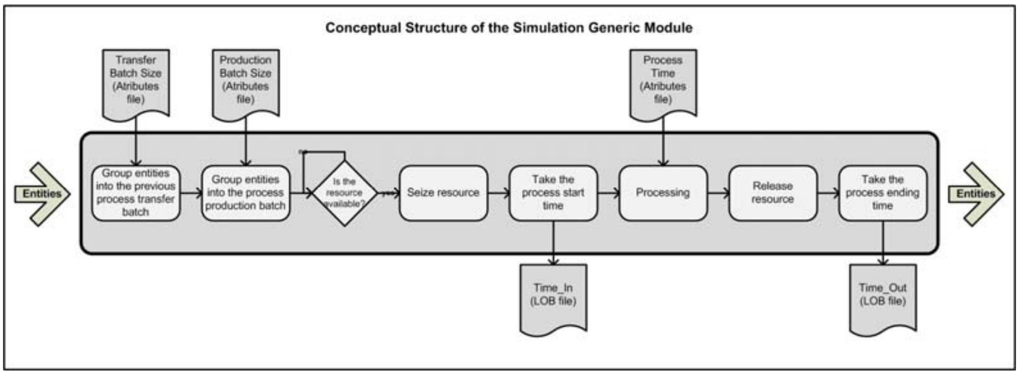

Figure 5: conceptual model of the generic simulation module

It is worthwhile mentioning that by using the generic simulation module only 10 mouse clicks were necessary to configure a production process. Instead, if the modeler used all required commands to configure each process features it would be necessary 85 mouse clicks to accomplish that objective.

A simulation model was built using the generic module considering the need for model flexibility, i.e. the possibility of simulating scenarios considering different execution strategies, use of resources, for instance, and the possibility of reusing the model in other company's projects whit similar features (mainly the same kind of base unit and production sequence). Other objective was allow to the production engineer to be able to test different scenarios through a user-friendly interface, in which he could change some parameters, run the model and check the more relevant results without having to know how to use the simulation software.

Using the generic module, not only input data of the model but also the simulation outcomes could be entered and accessed through a MS-Excel® spreadsheet. Thus, besides each process time to completion and the production and transfer batch sizes, the number of house blocks in which the project was grouped into, the number of dwellings in each block and the sequence in which they would be built could be easily configured by the modeler/user. Figure 06 presents part of the input spreadsheet.

Batch's Name	Batch Size	Batch	Foundations					First Story Bricklaying				
			Min (days)	Mode (days)	Max (days)	Production Batch (dwellings)	Transfer Batch (dwellings)	Min (days)	Mode (days)	Max (days)	Production Batch (dwellings)	Transfer Batch (dwellings)
A	4	A	5	7	10	4	4	5	5	6	4	4
B	4		5	7	10	4	4	5	5	6	4	4
C	4		5	7	10	4	4	5	5	6	4	4
D	4		5	7	10	4	4	5	5	6	4	4
E	10	B	5	7	10	4	4	5	5	6	4	4
F	4		5	7	10	4	4	5	5	6	4	4
G	4		5	7	10	4	4	5	5	6	4	4
H	4		5	7	10	4	4	5	5	6	4	4
I	4	C	5	7	10	4	4	5	5	6	4	4
J	10		5	7	10	4	4	5	5	6	4	4
L	4		5	7	10	4	4	5	5	6	4	4
M	4		5	7	10	4	4	5	5	6	4	4
N	4	D	5	7	10	4	4	5	5	6	4	4
O	4		5	7	10	4	4	5	5	6	4	4
Q	4		5	7	10	4	4	5	5	6	4	4
R	4		5	7	10	4	4	5	5	6	4	4
S	4	E	15	20	25	10	10	4	4	5	3	3
T	4		15	20	25	10	10	4	4	5	3	3
U	8		15	20	25	10	10	4	4	5	3	3
V	10		15	20	25	10	10	4	4	5	3	3
P	10		15	20	25	10	10	4	4	5	3	3
			15	20	25	10	10	4	4	5	3	3
			15	20	25	10	10	4	4	5	4	4
			15	20	25	10	10	4	4	5	4	4
			15	20	25	10	10	4	4	5	4	4
			15	20	25	10	10	4	4	5	4	4

Figure 6: input spreadsheet

At the other end, the simulation outcomes were designed to improve and facilitate the engineer understanding on the impacts of changes in the production system configuration. In order to facilitate the study of project's workflows study a Line of Balance could be automatically from the simulation outputs. That tool provided a direct and easy mean to visually assess any production system change. Moreover, that tool could be used to control the production system performance during the production phase as well. Figure 07 shows part of a Line of Balance devised from the simulation model.

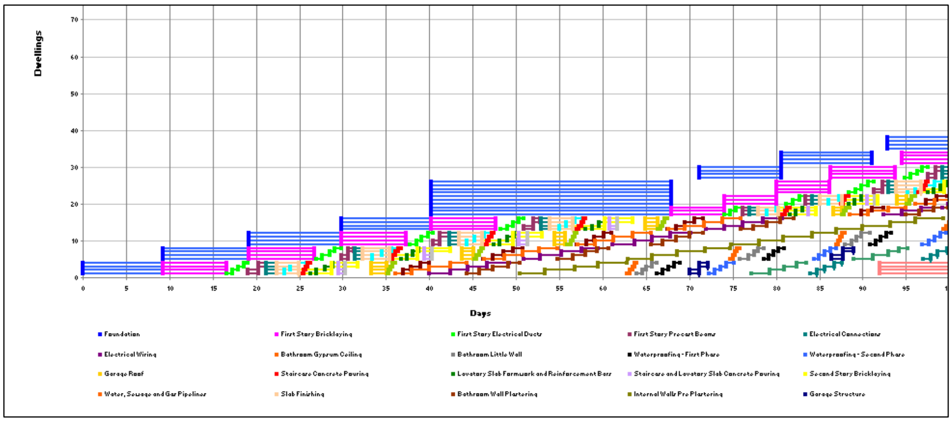

Figure 7: Line of Balance devised from the simulation model

Other tool devised from the model was a production control chart. That tool allowed the engineer to control each critical process's outcomes. Figure 08 shows that tool.

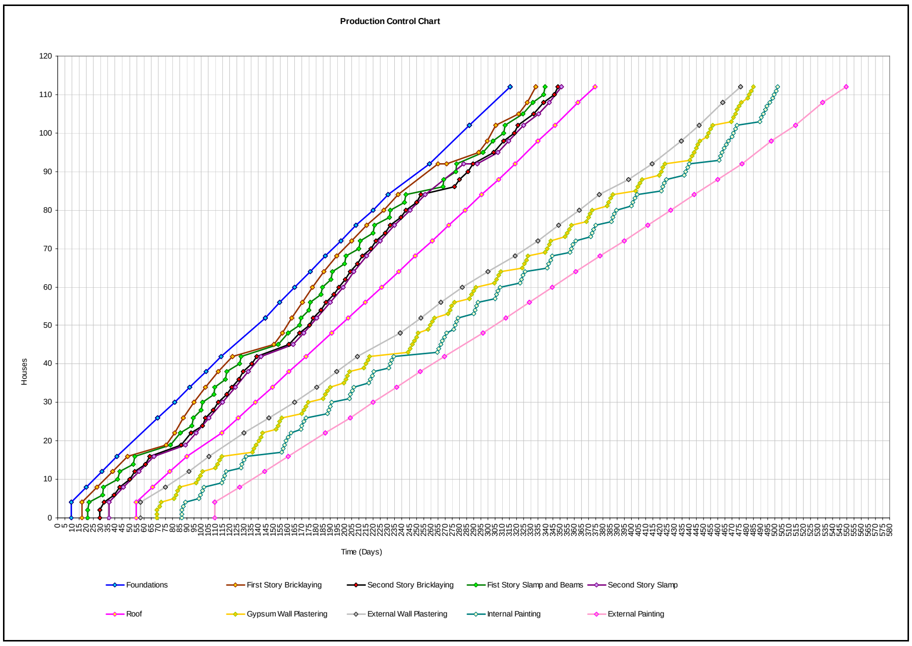

Figure 8: production control chart

Also, an S-curve can be devised from the model, allowing the production engineer assess the impacts of the production system design on the cumulative costs and expected receipt plotted against time.

7. DISCUSSION

Based on the case study, it is possible to point out some difficulties and requirements about the adoption of reusable simulation models in the design of production systems of construction projects.

Firstly, one of the main difficulties in using that kind of simulation models is related to the necessity of a minimum level of process standardization. In special, the case study showed the importance of establishing a sound constructive sequence in order to build a model that effectively represented the project production system. This problem is not related only to reusable models but to any model of construction processes or operations. Thus, a first requirement to use simulation as a decision taking tool is to reach a minimum level of process standardization.

Secondly, in order to build the generic simulation module, it was necessary to include a group of parameters that could represent any construction process. Thus, besides the basic features as time to completion, required resources and their capacity, for instance, it was included the concepts of production and transfer batch size. Thus, that module could be used in any simulation model, allowing its reuse as well. Besides contributing to reduce the model building time by simplifying the use interface, the module provided a simple form to collect the more relevant data from each process which was used in a number of useful tools (line of balance, production control chart, etc).

Thirdly, although in practice the reuse of the model has not already been tested (that will be done soon), some tests that have been made and the results pointed out that this is feasible. In those tests, the researchers change some project's features, like the production start time of each house block, the number of dwellings in the project, the number and the size of blocks, and some process's time to completion.

Finally, while the generic simulation module can be reapplied in other simulation models in different contexts, the proposed reusable model has some limitations. It can only be reused if the production sequence keeps the same for the next projects. Also the model is only adequate to projects of that company or, projects with the same features.

8. CONCLUSIONS

A generic simulation model and a reusable model were proposed in order to improve the process of designing production systems of construction projects. A case study in which those artifacts were tested was described and the main findings and difficulties for applying that strategy discussed. The main findings pointed out to the reduction of the model development time and the flexibility in the testing of different system scenarios.

The tools devised from the simulation outcomes was designed to help the production engineer to control some key points of the project, specially workflows and project's physical advance. In that specific case, other series of tools were also devised to improve a process of mass customization the company was adopted but that was not presented in this paper.

The main difficulties to apply as simulation as reusable models are related to the need of establishing a standardized production sequence. Although that relative "flexibility" could be positive to cope with uncertainty, the lack of a standard procedure inserts also its share of uncertainty to the system, making it harder to control.

Thus, based on the case study findings, one of the main requirements to the use of both simulation and reusable models in construction is to standardize the construction sequence of the project, by discussing it during the production system design phase.

Other important requirement is the necessity of creating construction processes data gathering protocol to be used during the model building process. After a number of case studies, the research team has faced with the complete lack of historical data on the production processes. Also, in order to reach more reliable models is fundamental to enter data that could effectively feature the process. In practice, in the absence of historical data, the research team has used process's time to completion based on subjective probability from the engineer or foreman experience.

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REFERENCES

Alves, T. C. L., Tommelein, I. D., and Ballard, G. (2006). "Simulation as a Tool for Production System Design in Construction." Proc., 14th Annual Conference of the International Group for Lean Construction, IGLC, Santiago do Chile.

Au, G., and Paul, R. J. (1996). "Visual Interactive Modelling: a pictorial simulation specification system." European Journal of Operational Research, 91, 14-26.

Draper, j. D., and Martinez, J. (2002). "The Evaluation of Alternative Production System Designs with Discrete Event Simulation." Proc., 10th Annual Conference Of The International Group For Lean Construction, IGLC, Gramado.

Hajjar, D., and Abourizk, S. M. (1998). "Modeling and Analysis of Aggregate Production Operations." Journal of Construction Engineering and Management, 124(5), 390-401.

Hajjar, D., and Abourizk, S. M. (1999). "Simphony: an environment for building special purpose construction simulation tools." Proc., Winter Simulation Conference, WSC, Phoenix, 998-1006.

Hong, Z., Shi. J. J., and Tam, C. M. (2002). "Visual Modeling and Simulation for Construction Operations." Automation in Construction, 11(1), 47-57.

Ioannou, P. G., and Martinez, J. C. (1996). "Animation of Complex Construction Simulation Models." Proc., 3rd Congress on Computing in Civil Engineering, ASCE, Reston, 620–626.

Kamat, V. R. (2003). "Extensible and Scalable 3D Visualization of Simulated Construction Operations." Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI, 443 pp.

Law, A. M. and Kelton, W. D. (2000). Simulation Modeling and Analysis, 3rd Ed. McGraw Hill, New York.

Law, A. M., and Mccomas, M. G. (1992). "How to Select Simulation Software for Manufacturing Applications." Industrial Engineering, 24(7), 29-35.

Mukkamala, P. S., Smith, j. S., and Valenzuela, J. F. (2003). "Designing Reusable Simulation Modules for Electronics Manufacturing Systems." Proc., Winter Simulation Conference, WSC, New Orleans, 1281-1289.

Nasereddin, M., Mullens, M. A., and Cope, D. (2007). "Automated Simulator Development: A Strategy for modeling modular housing production." Automation in Construction, 16, 212-223.

Oloufa, A. A., Ikeda, M., and Nguyen, T. (1998). "Resource-based Simulation Libraries for Construction." Automation in Construction, 7, 315-326.

Paul, R. J.; Taylor, S. J. E. (2002). "What Use is Model Reuse: is there a crook at the end of the rainbow?" Proc., Winter Simulation Conference, WSC, San Diego, 648-652.

Pidd, M. (2002). "Simulation Software and Model Reuse: a polemic." Proc., Winter Simulation Conference, WSC, San Diego, 772-775.

Robinson, S. (2003). Simulation: The Practice of Model Development and Use. John Wiley & Sons, Chichester.

Rockwell Software Inc. (2005). Arena User's Guide.

Schramm, F. K., Costa, D. B., and Formoso, C. T. (2004). "The Design of Production System for Low-Income Housing Projects." Proc., 12th Annual Conference on the International Group for Lean Construction, IGLC, Helsingor, 317-329.

Shi, J. J. (1999). "Computer Simulation in AEC and its Future Development." Proc., Berkeley-Stanford Construction Engineering and Management Workshop, Stanford University, Palo Alto.

Shi, J. J., and Abourizk, S. M. (1997). "Resource-based Modeling for Construction Simulation." Journal of Construction Engineering and Management, 123(1), 26-33.

Shi, J. J., and Abourizk, S. M. (1998). "An Automated Modeling System for Simulating Earthmoving Operations." Computer-Aided Civil and Infrastructure Engineering, 13, 121–130.

Shi, J. J., and Zhang, H. (1999). "Iconic Animation of Construction Simulation." Proc., Winter Simulation Conference, WSC, Phoenix, 992-997.

Welgama, P. S., and Mills, R. G. J. (1995). "Use of Simulation in the Design of a JIT System." International Journal of Operations & Production Management, 15(9), 245-260.