Concha, Marcelo; Alarcón, Luis F; Mourgues, Claudio; Salvatierra, José, 2015. Using Organizational Modeling to Assess the Impact of Lean Construction Principles on Project Performance. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 711-721, available at www.iglc.net

USING ORGANIZATIONAL MODELING TO ASSESS THE IMPACT OF LEAN CONSTRUCTION PRINCIPLES ON PROJECT PERFORMANCE

Marcelo Concha[1], Luis Fernando Alarcón[2], Claudio Mourgues[3] and José Luis Salvatierra[4]

ABSTRACT

This article delves the use of organization modeling to assess the impact of Lean construction concepts on project performance. The research calibrated four virtual models of construction project organizations developed using the Virtual Design Team (VDT) method and SimVision® VDT computational tool. The models were validated comparing their predictions with actual results obtained in the projects, and the assessment and approval of technical experts of the companies in the study.

Then, the four models were used to evaluate the impact on project performance using alternative organizational designs, each of them inspired in Lean production concepts and principles.

The results proved that VDT models can be used to evaluate the impact of the Lean concepts in projects performance, representing these notions in the organizational design and showing the benefits of implementing them. In general, the models predicted positive impact in terms of cost, time, variability and waste reduction in organizations inspired by Lean principles and concepts. These outcomes contribute to expand the uses of VDT methodology, proposing a method to include Lean principles in the organization design, and allowing companies to model Lean Project Management concepts at the planning and design phase, achieving improvements in terms of cost, schedule and variability.

KEYWORDS

IGLC23, organizational design, VDT, lean Construction.

[1] M.Sc. on Civil Engineering in the Pontificia Universidad Católica de Chile, I+D+i Consultant, Centre of Excellence in Production Management, GEPUC, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Edificio Mide UC 3er Piso, Macul, Santiago, Chile, Phone +56 2 2354 7050, mconcha@gepuc.cl

[2] Professor, Department of Construction Engineering and Management, Pontificia Universidad Catolica de Chile, Santiago, Chile. E-mail: lalarcon@ing.puc.cl

[3] Assistant Professor, Construction Engineering and Management Department, Pontificia Universidad Catolica de Chile, Chile. E-mail: cmourgue@ing.puc.cl

[4] Assistant Professor, Department of Civil Engineering, Universidad de Santiago de Chile, Av. Ecuador 3659, Estación Central, Santiago, Chile, Phone +56 2 27182818, jose.salvatierra@usach.cl

INTRODUCTION

The Stanford Center for Integrated Facility Engineering (CIFE) has developed a methodology to help companies design project organizations, being part of progress in terms of industrial design. This methodology is based on the assumption that the primary development work is the knowledge about it and coordination: both are seen as information processing activities (Galbraith, 1974) and communication. These efforts resulted in a modeling system called Virtual Design Team (VDT), in which rational agents process information associated with direct labor, rework, coordination and waiting times for decisions (Levitt and Kunz, 2002). In parallel, a theory of production in which production is established by a set of processing activities and workflow processes that add value (Koskela, 2000) emerged. Although both efforts discussed similar topics - from different perspectives –there is no understanding of how these jobs are linked. For example, understanding the variables of organizational modeling that can represent concepts and principles of the Lean Construction philosophy, displaying their impact in projects and organizations. In this line, the objectives of this study are: firstly to found barriers to the implementation of VDT models in real projects, secondly to propose a way of modeling concepts of Lean Production with VDT, and thirdly to evaluate the impact of Lean Production principles in the project performance through the VDT simulation methodology.

BACKGROUND

Traditional planning analyzes each activity as a transformation process, dividing it into sub-processes, which are done with certain rates of performance. One problem with this approach is the high variability in meeting the expected rates for those sub-processes. Gonzalez and Alarcón (2003) analyzed the programming of buffers in response to this variability in construction. Buffers try to cover spaces that usually occupy rework, project coordination activities and various kinds of contingencies. It showed that buffers help to reduce the impact of variability in projects and a programming buffers methodology in repetitive projects was proposed.

Koskela (2000) proposed a theory of production - Lean Construction - which seeks to reduce the variability of transformation processes incorporating the concept of production as transformation, flow and value generation. The key to this new theory of the production process is in the balance between these three elements.

Several authors have used various methods to assess the impact of Lean in projects or production. For example, Agbulos and Abourizk (2003) simulated drainage maintenance processes under the application of Lean concepts. Their approach was to model the process based on activities that add and not add value. Furthermore, Schroer (2004) used a probabilistic approach in discrete simulation to understand Lean manufacturing principles, using the Modular Manufacturing Simulator. Another study (Ales, Tommelein and Ballard, 2006) introduced the concepts of buffers, batch size, variability and their interactions in a simulation environment (STROBOSCOPE) to model different scenarios, showing how change the cycle times under different configurations. The study showed that in all scenarios, as variability increased, the necessary buffers also increased, as the project duration.

While these and other studies have contributed much to the understanding of Lean Construction and it impacts, their approach from the perspective of processes has shelved organizational aspects of Lean Construction.

Although project organization modeling exists since several years, its adoption has been slow in the construction industry. The Virtual Design Team methodology (VDT) (Levitt and Kunz, 2002; Levitt, 2009) is one of the most important efforts regarding the modeling of project organizations. VDT was created to allow managers and contractors "Designing project organizations as engineers design bridges" (Levitt, and Kunz, 2002), ie, to evaluate multiple organizational alternatives prior to the implementation and to select the best option for the project. This type of analysis has been explored in many studies (Kunz, Levitt and Thomsen, 1997; Levitt and Kunz, 2002; Nissen and Buettner, 2004; Khosraviani and Levitt, 2005; Carroll et al., 2006).

Regarding the operation of VDT, this methodology identifies four fundamental probabilities that determine the different levels of information processing within the organization, in terms of direct labor (direct work and rework of project activities), exceptions and decision-making processes (coordination between workers of activities that are connected in terms of information, and decision waiting times), involving meetings and external noises affecting the daily work. These probabilities are (ePM, 2005): Information Exchange Probability, Noise Probability, Functional Error Probability and Project Error Probability.

Based on the Contingency Theory (Galbraith, 1974), which states that organizations must adapt projects to project environment, and based on the extensive literature on organizational design, VDT defines four key aspects to incorporate the features of organizations: Team Experience, Centralization, Formalization and Matrix Strength. In addition, VDT considers a number of variables that allow modeling, for example, the experience of workers or the uncertainty of the information necessary to perform an activity. The representation of VDT processes allows including transformation and flow processes, with considerations of the value generated by them. Table 1 shows the elements under the VDT modeling methodology and its relationship with Lean processes.

Table 1: Types of Labor Division in VDT and its association with transformation, flow and value added processes.

VDT elements	**Lean Construction elements**			
	Transformation	Flow	Value	No Value
Direct work	x		x	
Rework		x		x
Coordination		x		x
Decision wait		x		x

RESEARCH METHODOLOGY

The research methodology consisted in three main phases: VDT methodology calibration for study cases of Chilean projects, the definition of Lean principles representation in the VDT environment and assessing the impact of these principles in projects (Figure 1). SimVision® VDT tool was used to run simulations. SimVision® allows to model organizations and projects: the hierarchy map, activities that have to be done by workers, links between activities representing rework and coordination, type of workers and their skills, meetings, milestones, financial data of projects and caracteristics of an organization, such Centralization and Formalization.

The first phase (calibration) was necessary because the VDT methodology has not been previously applied to projects in Chile. This is relevant because some modeling variables are susceptible to cultural issues and results can differ between countries based on local conditions, such economy, laws, among others. The study cases are four projects of a traditional building construction company (Company A). Initially, the relevant variables were selected for calibration and then the necessary data was assembled. The variables were selected through simulating different organizations on SimVision and analyzing different combinations of parameters and variables. After a deep analysis, it was detected that the variables that most affect in representation of an organization through VDT are the 4 probabilities and all the parameters related to them. Collection of these data was performed through interviews, field visits, obtaining tender files with project information and a survey to collect information related to the input parameters of SimVision® and flow processes. Finally, they were created and simulated models for calibration and modeling. Note that before, during and after the process of data collection, difficulties in the sector, - technical and related to the dedication to research participation - were detected. The second phase of the methodology was to define a way to represent the Lean concepts and principles on VDT modeling environment. Finally, the third phase was to simulate the models created and evaluate the impact of Lean principles in carrying out study cases.

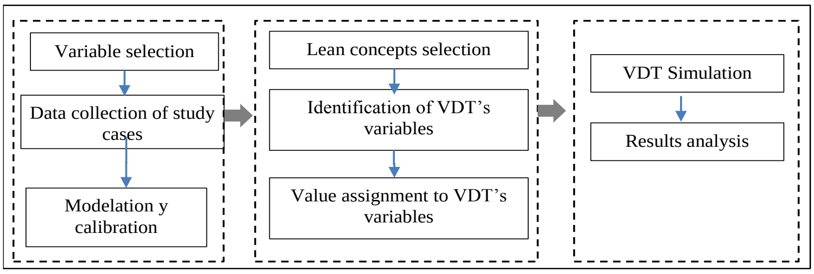

Figure 1: Stages and activities of research methodology.

VDT CALIBRATION AND IMPLEMENTATION BARRIERS

The entry probabilities initially used were obtained from a study of VDT (Ibrahim and Nissen, 2004), which obtained probabilities for Information Exchange 0.7, 0.2 for Noise, 0.05 for Functional Error and 0.05 for Project Error. In general, calibration consisted of modeling projects with fixed initial amounts of work, based on the probabilities of that study, then go modifying until the Cost and Time of each model is adjusted to actual performance in each case with a maximum error margin set at 5%. This limit was set in order to have an adequate margin of error does not exceed the possible profits of projects, commonly defined between an 8 and 15% depending on project type. The results of the calibration are shown in Table 2 (Concha and Alarcon, 2014). Those results were subjected to approval of professional technical management and planning of each company, through a structured interview to assess the quality of the predictions of 14 aspects of time, cost, quality and representativeness of links interactions from the simulation environment (for further information about the specific aspects, see Concha and Alarcón (2014)). The answers were based on how well the models predict real projects results, according to the obtained differences between modeled and real performance, and also under the judgment of each professional regarding the prediction of each model makes sense to the observed on the field.

Table 2: Probabilities calibration results.

Probability of calibrated VDT	Company A
Probability of Information Exchange	0.733
Probability of Noise	0.300
Probability of Functional Error	0.080
Probability of Project Error	0.080

The results of surveys grouped responses of the four projects, in total, 56 predictions. Respondents were four professionals of Company A (Finance Manager, Technical Manager, Head of Quality Management, Head of Planning). The survey scale was the follow: **N / A (Not Applicable)** is marked when the queried feature is unrelated to the investigation or study it was not possible. **Very Poor:** Marked when the model prediction is totally different from reality. In quantitative terms, when far more than 70% of actual results. In terms of plotted parameters when the prediction is 3 categories above or below the actual result (usually there are 4 categories, green level - optimal, yellow level - normal orange level - warning level red - dangerous level). **Poor:** Marked when the model prediction is considerably different from the reality. In quantitative terms, when it has more than 70% of difference in relation to actual results. In terms of plotted parameters, when the prediction is 2 categories above or below the actual result. **Regular:** dialed when the model prediction is not as close to reality, but not so far. In quantitative terms, when far between 5 and 30% of reality. In terms of plotted parameters, is when the prediction is 1 category different compared to the actual result. **Good:** marked when the model prediction is close to reality, but not as accurate. In quantitative terms, when modeled results are 3 to 5% far from reality. In terms of plotted parameters, it is when the prediction is in the same category as compared to the real result but closer to the lower level or higher than the actual outcome. **Very Good:** Marked when the model prediction is very close to reality. In quantitative terms, when modeled results are 3% far or less of reality. In terms of plotted parameters, it is when the prediction is in the same category as compared to the actual result and when is very close to the actual result.

This survey showed high approval of the calibration results (see Figure 2). The 72% of the answers obtained a positive rating, which means that about 72% of the issues were within 5% difference with real performance, in case of quantitative variables, and within the respective category, in case of qualitative aspects. It is also important to note that the response "Regular" obtained a 14%, achieving an aggregate percentage (adding the other two categories) of 86%, indicating that about 86% of predictions were in limits Regular at least. On the other hand, general aspects which obtained a category "Regular" tended to be those most difficult to measure and to corroborate in practice, such as Quality Product and Quality Process. This tended to encourage professionals to respond to the prediction of these factors was "Regular" when the possible reason behind that might not be as verifiable, except for a rough general opinion of experts in the field.

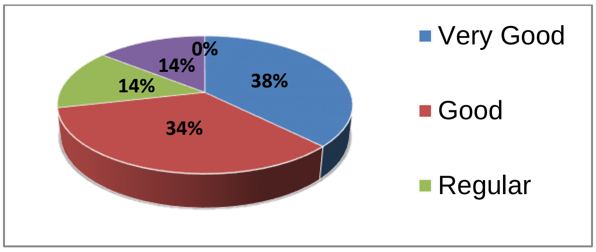

Figure 2: Review of the survey answers from models predictions applied to professionals related with planning.

The aspects most accomplished and evaluated correspond to the capture of the activities that most coordination and rework generated, followed by the cost and time, which generally had positive rating, agreeing with the good results achieved in models relating to these topics. The worst aspects achieved by the models were the "timing" of activities occurrence and the "timing" of the workers backlogs occurrence, because the models failed to predict them at a good way. However, it was not likely they could achieved that, given that the Projects Managers did not follow the Gantt chart in a strict order, so they performed activities to the extent that it could be done, without releasing restrictions to stay on schedule. This realizes the problems with which the sector faces in the local case for deploying virtual models like those in this study (see Table 3), which hinder proper integration of tools. At the date of the paper writing, Company A have implemented Last Planner System to plan projects, so this problem it is partially solved, so better model predictions could be obtained in the future.

LEAN CONCEPTS REPRESENTATION USING VDT METHODOLOGY

The second phase of the research was to define a way of representing Lean principles and concepts using the VDT methodology. This would help to see the impact of applying principles prior to implementation real projects. To this, a list of concepts of Lean Management philosophy was defined, then VDT variables that allow modeling these concepts were identified, and finally values were given to represent these variables VDT with Lean concepts. The list of Lean concepts and principles was defined based on an estimate – made by the researcher – about the possibility of representation through the VDT variables. The values of VDT variables representing the Lean concepts were obtained from interviews with experts in Lean Construction. The interviews consisted on open-ended questions to senior consultants of the Center of Excellence in Production Management UC to see how they interpreted each parameter according to the possibilities of the computer program, based on its experience in counseling. Table 4 summarizes the Lean concepts and their values with VDT variables (Concha and Alarcón, 2014) (Not Applicable = N / A, Low, Medium, High, PM = Project Manager, SL = SubTeam Leader, ST = SubTeam).

After defining the values of the VDT variables for each concept, different scenarios were modeled (VDT values configurations associated with each Lean concept) for the four projects from Company 2. For example, P1 is modeled in each project of Company A, assigning the values shown in the Column 2 in the Table 4. The results of the simulations for each of these projects were compared with the base case of the Company A, obtained during model calibration stage. For purposes of modeling each scenario, the “N/A” assignment in Table 4 means the variable in the base case remains constant.

Table 3: Main barriers detected for the VDT virtual model application in the future in local construction projects.

Problem	Type	Comment
Bad Planning execution	Technical and Management	They don’t execute activities as planned. Impossibility to predict results.
Lack of Knowledge Management	Technical/Strategical/Management	Historical information of projects is not used for new projects. Prevents adequately predict cost, schedule, machinery and HH.
Deficient Project Study	Technical	Inadequate use of HH and costs rates, sometimes from other locations out from Chile.
Project Rates used in the Project definition stage are incompatible with VDT models	Technical	Project Resources Rates need to be adjusted to reflect only direct work without rework (adjustments are needed to can use this rates in VDT).
Lack of time and direction to be part of researches.	Strategical	No management that promotes participation in research with HH's supervised and controlled. So far this contribution is voluntary and that downplayed it in terms of priority. Generates excessive times in the process of gathering information.

ASSESSMENT OF LEAN CONCEPTS IMPACTS ON PROJECT PERFORMANCE

In addition to the scenarios associated with Lean concepts set forth in Table 4, three additional concepts were included. They contain contrary aspects to Lean concepts or correspond to a typical misapplication (that do not meet requirements for proper operation). They are multitasking misapplied, flat organization misapplied, and hierarchical organization. Table 5 summarizes the results for each project and concepts in terms of their deviation from Cost and Time with respect to the base case.

It can be see that the impacts vary for each project, which makes sense if you consider the differences between the them, whose peculiarities and special conditions are reflected in differences in the other parameters of the VDT modeling, and consequently, in a different incidence in the Lean concepts implementation. However, a general trend is observed that most of the principles -except the negative scenarios (misapplied multitasking, flatter organizations misapplied and hierarchical organizations)- of the four projects contributed to lower cost and time outputs. Figure 3 shows the average variability within simulations of the projects from the base case. Concerning the principle of creating flatter organizations, illustrating its profit over the base case, which had a structure with some level of hierarchy marked but not as extreme as the hierarchical version (scenario N°11 in the Figure 3). Virtue of a flat organization versus a hierarchical is also appreciated, meaning that when comparing both cases, price and costs tend to be lower in the flat one. On the other hand, it is observed that a flat organization that does not have the trained personnel to make quality decisions (Scenario 10: misapplied flat organization), suffers the consequences in terms of cost and time. In all cases analyzed the cost and time worsened relative to a flat organization that does meet that condition. In addition, there are cases where even worse results are obtained compared to a hierarchical organization, and is understandable, since a hierarchical organization but with good professionals and experienced staff can make better decisions than other flat organization, but with professionals without experience or adequate skills. The quality of decisions is very important and will affect the projects. Another issue of relevance analyzed is multitasking, which reduced all projects cost and time. However, when the functional skills of people are disparate or low in some items (Scenario 9: misapplied multitasking), can cause increases in cost and time compared to a project with people with multitasking, who have high experience and good skills in all items. According to the theory, flexibility and multitasking should involve common denominators in terms of organizational configurations, since having multitasking teams provides flexibility in activities development.

Table 4: Possible VDT inputs involved in the Lean Production concept modelling.

VDT Input /Lean Production Principle	P1 Re-duce waste	P2 Re-duce va-riabi-lity	P3 Redu-ce cycle time	P4 Reduce work batches	P5 Increase flexibility	P6 Stan-dar-dize	P7 Flat Orga-niza-tion	P8 Multi-funcio-nality
Organizational Culture								
Team Experience	High	High	High	High	High	High	High	High
Formalization	N/A	High	High	N/A	Low	N/A	Low	Low
Centralization	N/A	Low	N/A	High	Low	Med. - High	Low	Low
Strength of headquarters	High	N/A	High	High	High	High	High	High
Activities								
Information Uncertainty	Low	Low	Low	Low	Low	Low	Low	N/A
Complexity of requirements	N/A	Low	Low	Low	Low	Low	N/A	Low
Solution complexity	N/A	Low	Low	Low	Low	Low	N/A	Low
Responsible Individuals								
Role of the Professionals	PM	PM	PM	N/A	PM	N/A	PM	N/A
Application experience	High	High	High	N/A	High	N/A	High	High
Ability in an area	High	High	High	N/A	High	N/A	High	Med. or high
Ability in other areas	N/A	Med.	Med.	N/A	Medium or high	N/A	Med. or High	Med. or High

Finally, Figure 4 shows the impact of the scenario "reducing waste" in the amounts of the various processes considered in SimVision®. The value shown is the base case compared with the average of the four projects from Company A, but in all projects were a significant decrease in terms of Rework, Coordination and Wait Decisions Times, activities that do not add value.

Table 5: Percent difference in Duration and Cost for Lean scenarios (8 Lean concepts plus 3 cases of poor Lean applications) as compared to the base case calibrated for each Project.

	Reduce waste	Reduce variability	Reduce cycle time	Reduce work batches	Increase flexibility	Standardization	Flat organizations	Multiskilling	Multiskilling poorly applied	Flat organizations poorly applied	Hierarchical organizations
Project					Difference in Duration (%)						
1	10.2	12.2	11.2	9.4	12.2	9.4	11.6	12.0	-3.5	-28.0	-8.3
2	11.4	17.3	14.4	-6.0	15.9	-5.8	7.5	15.2	-5.6	-77.2	-19.0
3	19.0	22.5	22.0	4.1	23.3	5.6	22.9	23.5	-12.2	-37.8	-38.4
4	8.2	17.1	8.4	10.7	25.4	11.4	21.7	25.6	-6.0	-39.4	-16.4
Average	12.2	17.3	14.0	4.6	19.2	5.1	15.9	19.0	-6.8	-45.6	-20.5
Project					Cost Difference (%)						
1	5.6	8.9	8.0	2.0	9.3	2.0	8.4	6.4	-6.8	-10.5	-9.6
2	2.1	2.0	1.0	-0.3	1.4	-0.2	0.4	1.1	-1.0	-11.8	-8.8
3	16.9	15.2	14.8	3.6	15.0	4.3	17.3	14.5	-4.9	-22.2	-28.7
4	7.0	7.2	7.0	2.1	6.9	2.1	6.7	6.3	-1.4	-9.3	-1.5
Average	7.9	8.3	7.7	1.8	8.1	2.1	8.2	7.1	-3.5	-13.4	-12.1

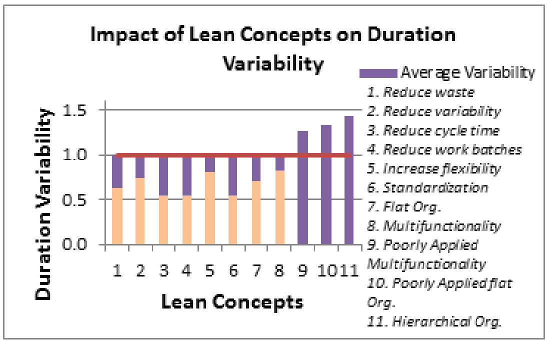

Figure 3: Variability Difference in Duration for each Lean concept scenario as compared to the base case calibrated for each Project.

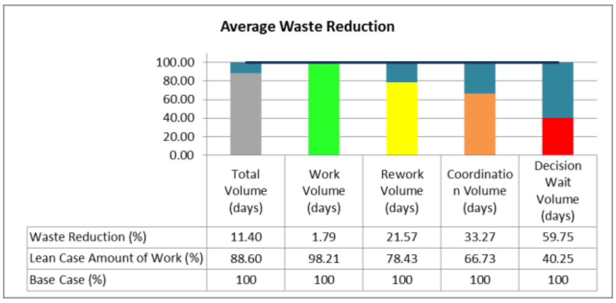

Figure 4: Reduction of process volume when applying the concept of waste reduction.

CONCLUSIONS

This research was able to model Lean Construction concepts through the VDT methodology. This not only achieve to show from another perspective the positive impacts of Lean on the projects results, but also offers a new methodology to include Lean principles in the design of organizations and projects processes. The calibration of VDT probabilities parameters adjusted to the reality of Chilean projects was effective. The values were within expectations and were validated by professional respondents. The only point to consider is that the Functional Error and the Project Error probabilities are a little low compared to the observed in the experience of the VDT expert modelers. This can occur because the returns that are handled in planning departments already include coordination work, so in the initial models, the net direct labor is increased, causing lower rework probabilities. This corresponds to one of the identified challenges to successful implementation of these models locally, which generally have to do with technical details such as improving planning and knowledge management, and insert into the strategy of organizations research promotion and development to improve the company and industry. With regard to the assessment of the impacts of Lean principles using the VDT methodology, a positive impact in all cases with the expected variations between projects was evident. On average, the principles caused greater impact on reducing the projects outputs were "Reduce Variability" and "Improving Flexibility", which shows the importance of generating a continuous flow and reduce uncertainty. The Lean principles that most reduced the time variability in the study projects were the principles "Reduce cycle times", "Standardize" and "Reduce work batches." This is consistent with the definition of these principles in theory. The concepts that had less impact are the principles "Increase flexibility" and "Flat organizations".

This research raises several lines of future work, such VDT calibrations depending on size/type of business, work areas, deadlines and other conditions, also, Lean organizational designs through VDT and its validation with real project results, and exploration of the VDT modeling with other Lean concepts.

REFERENCES

Agbulos, A. and Abourizk, S.M., 2003. An application of Lean concepts and simulation for drainage operations maintenance crews. Department of Civil and Environmental Engineering, University of Alberta, Canada.

Ales, C.L., Tommelein, I.D. and Ballard, G., 2006. *Simulation as a tool for production system design in construction*. In: *Proc. 14th Ann. Conf. of the Int'l Group for Lean Construction,* Santiago, Chile, July 25-27.

Carroll, T.N., Gormley, T.J., Bilardo, V.J., Burton, R.M. and Woodman, K.L., 2006. Designing a New Organization at NASA: An Organization Design Process Using Simulation, *Organization Science*, 17(2), March-April 2006, pp. 202-214.

Concha, M. and Alarcón, L., 2014. *Uso de modelación organizacional para evaluar el impacto de principios de Lean construction en el desempeño de proyectos*, Master. Department of Engineering and Management and the Committee on Graduate Studies of Pontifical Catholic University of Chile.

ePM, 2005. *SimVision Tutorial: UserGuide.* [online] Available at:< http://www.epm.cc/downloads/UserGuide_v11.pdf> [Accessed 24 June 2015]

Galbraith, J., 1974. Organization design, An information processing view. *Organizational Effectiveness Center and School*, 21, pp. 28-36.

González, V. and Alarcón, L.F., 2003. Buffers de Programación: una estrategia complementaria para reducir la variabilidad en los procesos de construcción.

Revista Ingeniería de Construcción, 18(2), pp.109-119.

Ibrahim, R. and Nissen, M., 2004. Simulating environmental contingencies using SimVision®,In: *Proc. North American Association for Computational Social and Organization Sciences (NAACSOS)*, Pittsburgh, Pensylvannia, June 27-29.

Khosraviani, B. and Levitt, R.E., 2005. *An Evolutionary Approach for Project Organization Design: Producing Human-Competitive Results Using Genetic Programming.* Ph. D. Department of Civil and Environmental Engineering, Stanford University.

Koskela, L., 2000. *An exploration towards a production theory and its application to construction*. Ph.D. Helsinki University of Technology.

Kunz, J.C., Levitt, R.E. and Thomsen, J., 1997. Intervention studies Using the Virtual Design Team, In: *Proc. International Conference on Computational Cybernetics and Simulation, IEEE*, Orlando, FL, October 12-15.

Levitt, R. and Kunz, J., 2002. *Design your Project Organization as Engineers Design Bridges*, *CIFE Working Paper #73*, Stanford, CA: CIFE, Stanford University.

Levitt, R., 2009. *Overview of The Virtual Design Team (VDT) Research Program: 1988-2010, CIFE Working Paper #52*, Stanford, CA: CIFE, Stanford University.

Nissen, M.E. and Buettner, R.R., 2004. Computational Experimentation with the Virtual Design Team: Bridging the Chasm between Laboratory and Field Research in C2, In: *Proc. Command and Control Research and Technology Symposium*, San Diego, CA, June 15-17.

Schroer, B.J., 2004. Simulation as a Tool in Understanding the Concepts of Lean Manufacturing, *SIMULATION*, 80(3), pp. 171-175.