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IMPROVING THE VALUE GENERATION CYCLE IN THE DESIGN PROCESS OF INDUSTRIAL CONSTRUCTION PROJECTS

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ABSTRACT
Construction can be claimed to be on the threshold of a new paradigm that will bring about major changes in performance in the 21st century. Information Technology (IT) plays a key role within this context of change. The practical application of IT has already led engineering and construction corporations to reach high levels of performance in contrast with the rest of the industry. Design of industrial process plants using **Computer** Advanced Visualization Tools (CAVT) is the most glaring example of such developments. Nevertheless, researchers in construction IT appear reluctant to embrace the issues associated with implementation and industry practice. The rhetoric and visions associated with construction IT have turned out to be alarmingly distant from reality of construction usage of IT. This paper presents results from a research about the impact of **CAVT** in the design process of industrial process plants. The research methodology considers the industry as point of departure, through a case study using the observation-participation method, and then confronts insights coming from practical issues with theoretical analysis and traditional approaches. The **TFV (Transformation-Flow-Value)** production theory is used as the conceptual framework in the analysis of engineering and construction processes. Five main principles covering the value generation cycle in the design process of industrial construction projects are identified and presented, and utilizing these principles as the conceptual framework, important changes and improvements due to the impact of **CAVT** are pinpointed.

KEYWORDS
4D Simulation, Industrial Construction, Production Theory, Case Research, Evaluation

1. INTRODUCTION

This paper shows how production theory provides a suitable framework to evaluate the impact of specific IT tools (CAVT) in the construction industry. Improving the understanding of the ever more relevant changes that CAVT will produce should lead to improved understanding of the mechanisms to improve performance of construction. This paper subscribes to the view that major development efforts like use of IT in construction have to be redirected in concordance with a new production theory foundation (Koskela, 2000). The introduction of computers to construction does not qualitatively provide anything new. From the point of view of theoretical analysis of production systems: computing is worthwhile only as far as it can contribute – better than alternative means- to the realization of principles of production (Koskela, 2000). The Observation-Participation method applied to a relevant and special case study complement the utilization of production theory as a response to the lack of an adequate theory of engineering design which is currently a major bottleneck, both for practice and research, including the information technology oriented endeavors (Fenves, 1996).

2. COMPUTER ADVANCED VISUALIZATION TOOLS

Computer Aided Design (CAD) is a concept that has become insufficient for the wider area in which “CAD” tools, techniques, etc. are applied nowadays. CAD when used in real projects is theoretically limited to the design stage, however, an IT strategy can no longer afford to start and finish with design (Bentley, 1998). The concept of Computer Advanced Visualization Tools (CAVT) have been defined by (Rischmoller et al, 2000) as "the collection of all the necessary tools, which allow for the visual representation of the ends and the means needed to accomplish an AEC/EPC design and construction project". CAVT defined in such a broad sense will provide a definition, which could evolve over time, since it is not tied to any particular tool (i.e. software tool). A 4D model involves linking of the CPM Schedule to the 3D model to visualize exactly what the plan entails by simulating the construction schedule and actually showing which pieces of the project will be constructed in what sequence. 4D-PS allows simulating and interacting with construction sequences (schedules) through graphic display devices. If the sequence is not just right, schedulers adjust the schedule and rerun the 4D simulation to verify it.

3. PRODUCTION THEORY, A THEORETICAL FRAMEWORK SUITABLE TO IT RESEARCH

The theoretical foundation of the research required concepts to describe the design process of construction industrial projects. The concepts that were used are explicit elements of the exploration towards a production theory and its application to construction, proposed by Lauri Koskela (2000). Koskela’s production theory is based in concepts of production that can be tracked in the past, at least until the beginning of the 20th century: (1) The **Transformation** concept, (2) Production as a **Flow** concept, and (3) **Value** generation concept. The first letter of each of these three concepts gives the name to Koskela’s proposed theory: TFV Theory of Production. The TFV production theory proposes that production management needs the three views described below, and that they should be used simultaneously and in an integrated and balanced way.

3.1 Transformation

The focus is on transformations that add value. Production is seen as a transformation of inputs in finished products (outputs). Production management is centered in the breakdown of the total transformation in primary transformations and tasks, carried out as efficiently as possible. The transformation view of production has been the dominant during the 20th century. Porter’s value chain theory of the firm (1985) is an example of an approach that gives a perceptible form to the transformation view of production.

3.2 Flow

This view focuses on activities, which do not add value. In addition to the transformation activities in the production view, flow activities including waiting, inspection and movement are added. Variability is the crucial factor in the behavior of flows. Production management is focused in minimizing production stages in which transformations are not carried out, especially reducing the variability. The flow view of production was proposed first by Gilbreths (1922), and has provided the basis for the Just in Time (JIT) approach and the production philosophy known as Lean Production. Hopp and Spearman (1996) have demonstrated, using queuing theory that much of the results used as heuristics in the JIT framework, can be mathematically proven.

3.3 Value

The focus is in the production control from the point of view of the client. Production is seen as a means to the fulfillment of client needs. Production management focus on translating client needs precisely in a design solution and then developing products accordingly with design. The value generation view was started by Shewhart (1931) and later on refined in the total quality movement framework. A synthesis of production theory based on this vision has been presented recently by Cook (1997).

4. RESEARCH METHODOLOGY: MOTIVATION AND STRATEGY

4.1 Problems related to IT Research in the AEC/EPC Industry

The problems with which IT research deal are well known since the sixties, and today after more than 30 years have not yet been solved (Turk, 2000). The rhetoric and visions associated with construction IT have turned out to be alarmingly distant from the reality of construction IT usage (Koskela, 2000). Frequently it has been highlighted that the assimilation of IT in the construction industry has been slow, slower than in other industries. Researchers seem to live under the impression that they have all the fantastic solutions and that all what is missing is a way to make that construction industry use them (Turk, 2000). Within our work in construction IT research, we appear to be continuously frustrated by the failure of industry to adopt the self-evident advances that our research demonstrates. There is a need for us to adopt a different approach if we want to move forward the uptake of our technological advancements (Betts, 2000). We need to address the needs of the competencies and capabilities of our engineers, project managers, architects and constructors to operate the technologies we are seeking to develop.

4.2 Case Study Research as a Research Strategy

Construction IT research has been mainly related with prototypes. However, according to Turk (2000), the value of prototypes related with construction IT research is doubtful. The results are little proven until some CAD systems vendor implements them, or they are utilized by industry. And if this doesn't happen immediately after the research, it is very probable that general advances in computer science will solve the problem. Prototype experimentation coming from real life projects in the construction industry, has been relatively rare, in contrast with the construction management area, where an important part of the literature about research reports about case studies or more extensive empirical research (Bjork, 1999). The empirical study of how IT is used currently has not been and adequately developed field of research (Bjork, 1999).

Case study research is posed as main research strategy. Case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. In this sense the case study, unlike the experiment, doesn't represent a "sample", and the researcher's goal is to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistic generalization). The research goal in case study is a generalization analysis and not a particularism one (Yin, 1994).

5. THE OBSERVATION-PARTICIPATION METHOD APPLIED TO THE CASE STUDY

5.1 Case Selection

The "selected" case holds the following characteristics, which confer it special potential and relevance to the research results: (1) It is a pioneering study in Latin America, (2) The scope of the visualization tool's implementation on the project goes beyond what had been applied before, (3) It was developed by an international leader engineering and construction corporation (ENR Magazine, 2000), and (4) Most of the personnel working in the project was recruited locally and didn't have previous experience using CAVT.

The case project is a large single-phase expansion of an existing industrial process plant. Plant Design System (PDS), Primavera Project Planner (P3) and SmartPlant Review (SPR) are the main commercial software tools used to develop 4D-PS at the case project. All these powerful tools are well known within the case project contractor community, however they had not been integrated before to the extent achieved at the case project. PDS allows for the development of a 1:1 scale digital product model of the project, and also creates and maintains a database of valuable information for specification compliance, streamlining and planning of operations, maintenance, and downstream retrofit projects. Through computer simulation to support 4D-PS, a detailed construction plan/schedule was developed for all the concrete (approx. 100,000 m3) foundations of the case project. 4D-PS offered the planning team the opportunity to evaluate a number of alternatives, which in the past due to the lack of time, technology and resources was impossible. In some cases the team evaluated up to 20 alternatives for parts of the project, as well as for the sequencing of the complete project. The team was also able to visualize brainstorming results.

5.3 The Observation-Participation Method (OPM)

The OPM is a special mode of observation in which, unlike traditional case study research, one is not merely a passive observer. Instead, one may assume a variety of roles within the case study situation and may actually participate and influence the events being studied. The project had plenty of leading edge CAVT available, however, they were not being fully applied when the first author first joined the project. Not only the impact of CAVT in use was investigated, but the potential of new non-used available CAVT were promoted and investigated at the case project (i.e. 4D tools). The OPM applied to the case project allowed the study of a real-life situation that IT Research had only rarely been able to study in the past (Haymaker and Fischer, 2001; Staub et al, 1999; and Collier and Fischer, 1996. OPM applied to the case study offered the opportunity to see what others have not yet seen (Stake, 1998) and allowed access to events and groups otherwise inaccessible to scientific research. The research carried out using the OPM provided the opportunity to work as part of the project team, doing the research from within the project, working daily with the construction and engineering project team. In the case of 4D, OPM did not simply lead to the evaluation of schedules using 4D models, but instead led to the development of actual plans and schedules through a new developed work process: 4D Planning and Scheduling (4D-PS).

6. IMPACT OF CAVT

6.1 Transformation-Flow-Value Theory as a conceptual framework to analyze CAVT impact

The value aspect in design is much more significant, and by nature different in comparison to construction (production), since the customer requirements are translated into a design solution during this stage (Koskela, 2000). Thus, we have initially selected to analyze the CAVT impact from a value perspective. However, by focusing design on minimizing value loss, flow and transformation aspects are also to a considerable extent considered. Value is generated through fulfillment of customer needs and requirements in a cycle, where customer requirements are captured and converted, through one or several stages, to a product or service delivered to the customer (Koskela, 2000). Five principles of value generation derived from the TFV framework will be used to analyze the impact of CAVT in the design process of industrial construction projects: (1) Customer requirements captured by design, (2) Customers requirements available during design, (3) Suitable capability of the production system, (4) Construction requirements satisfaction, and (5) Impact of design errors during construction. The first two principles are more tightly linked to client expectations during the design stage. The last two principles strongly involve the next process following design, construction. And the third principle (suitable capability of the production system) concerns to the external client and the construction contractor alike (either internal or external client).

Table 1 summarizes the hypothetical main impact of CAVT regarding the geometry, specifications and coordination mechanisms in the design process, based in evidence coming from prior research. Following a summarized description of the hypothetical impact of CAVT in the five principles covering the value generation cycle in the design process is presented.

Table 1: Main impact of CAVT

	Traditional	CAVT
Geometry:	**2D Drawings**	**3D intelligent model (digital reality)**
Intends to convey the necessary information to get a graphical representation of an un-existing reality, to be materialized.	They are the main "product" of the design. Bi-dimensional paper hand or computer drawn drawings.	A digital 3D model is transformed from a very basic sketch to a complete 3D digital representation of the designed product during the design.
Specifications:	**Books, notes, etc.**	**Computer Database**
Convey all the non-graphical information related to the designed elements.	Text documents containing descriptions, compliance requirements, etc.	Specifications are stored in a computer database. They are used as an input that allows for a 100% specification driven and compliant design. Specifications are visualized in a computer interface linked to the 3D model elements.
Coordination of design	Meetings are carried out periodically, mainly to discuss around drawings and specifications contents and development.	Coordination is focused on the 3D model instead of 2D drawings. The design is carried out in a common multidisciplinary virtual space, where "everybody" is watching in real-time what others designers are doing. Meetings are carried out around the 3D intelligent model (digital reality) periodically to tune (refine) the design

Customer requirements captured by design

This principle aims to ensure that all customer requirements, both explicit and latent, have been captured by the design. Table 2 summarize the impact of CAVT to this principle compared to traditional design approaches.

Customers requirements available during design

This principle aims to ensure that relevant customer requirements are available in all phases of production, and that they are not lost when progressively transformed into design solutions, production plans and products. Table 3 summarizes the impact of CAVT to this principle compared to traditional design approaches.

Table 2: Customer requirements captured by design

Traditional	CAVT
Drawings in paper or electronic format: Customer has to wait for printed copies of 2D drawings to review them and provide input to the designer (i.e. changes, corrections, etc.). This approach introduces rework purposely in an iterative 2D drawing process and the design at all. **Interferences during construction:** An expedite design doesn't warrant avoiding interferences during construction. In fact, due to the intricate abstractions needed to "visualize" design from 2D drawings, rework during construction due to design interferences is an accepted pain and contingencies to compensate such a rework are accepted as a common part of the construction budget development. **Manual material take-off:** Despite modern automation tools are used to carry out material take-off tasks during the design, these tools are just a help to expedite a manual process. Inaccurate quantities are accepted as normal and contingencies percentages are a common part of the material take-off process as a protection against uncertainty.	**Drawings extracted from the 3D-Model:** Customer early agreement and understanding of the design are carried out by reviewing 3D models interactively before issuing any paper or electronic 2D drawing. Drawings are 100% compliant with the design. **Zero interferences design:** Interferences are detected early during the design using 3D as well as 4D tools. Automated and visual clash checking is part of the CAD culture. It is possible to achieve and document a zero interference design. **Automated material take-off:** CAVT allows for exact material quantity take-offs. Only contingencies for normal waste of material at the jobsite need to be introduced.

Table 3: Customer requirements available during design

Traditional	CAVT
Drawings: Printed 2D drawings are the main media to transmit design progress information to the customer. This approach demands a sequential iterative process in which the customer has to wait for printed 2D drawings to be reviewed and the designer has to wait for customer reviews to continue with the design. **Specifications:** Printed specifications drafts are submitted to the customer for review. Specifications are not automatically linked to the graphical part of the design, and manual work needs to be done to achieve this link before reviewing or creating them.	**3D Model review meetings:** 3D model visualization is used to review design requirements with the client. Graphical and non-graphical information showing the design status is visualized in real time during agreed or non-agreed meetings. Specifications are created prior to the 3D modeling design and they are stored into electronic databases. Specifications are then linked to every graphical element

Suitable capability of the production system

This principle aims to ensure the capability of the production system to produce products as required. Table 4 summarizes the impact of CAVT to this principle compared to traditional design approaches. The suitable capability of the production system is mainly focused on the construction process considering deadlines, resources utilization, construction sequences, time-space conflicts, etc. as the main variables. This principle is closely related to construction planning and scheduling.

Table 4: Suitable capability of the production system

Traditional	CAVT
Focus on the design posing demanding requirements during construction: The focus during design is in man-hours planning, budgeting and controlling. Despite constructability programs are incorporated during design, their relevance is limited. The design production system traditionally is dimensioned in terms of man-hours needed to complete a drawing. This approach does not consider minimizing waste and resources during the construction stage as a key goal for the project success as a whole. Design has nearly become an end instead of the mean that it should be.	**Truly construction driving production system capability :** The ability to visualize the products (designs) as well as processes (construction sequence simulations-4D Models) early during the design stage consider explicitly minimizing waste and resources during the construction stage as a key goal to achieve. Construction schedules can be tested early using the 4D simulation capabilities ensuring an optimum production system during the construction stage as well as during the design stage of the project.

Construction requirements satisfaction

This principle aims to ensure that requirements and constraints of the construction process have been taken into account during design. Table 5 summarizes the impact of CAVT to this principle compared to traditional design approaches. Construction requirements satisfaction are mainly related to the physical features of the designed artifacts from a single point of view and considering them within the whole project context. This principle is closely related to constructability activities early during the design stage of the project.

Table 5: Construction requirements satisfaction

Traditional	CAVT
Early Constructability: Early design coordination meetings involve construction-experienced people. Notes and sketches record the construction experience input. **"Later" Graphical-Constructability:** The traditional approach is reactive, consisting in reviewing already issued 2D-Drawings to identify needed changes, which demands re-work. **Specifications review:** This task rarely involves construction input and is mainly carried out by designers.	**3D Conceptual Design** allows early constructability to provide dramatically improved input compared to traditional approaches based in sketches, notes or even 2D drawings. **4D-Planning and Scheduling:** The 4D-PS process requires to work with 3D designed elements prior to 4D modeling. This makes constructability arise in a natural way (even if not formally planned in the project). 3D modeling reviews alerts of needed changes to designers, which are done early before issuing drawings.

Impact of design errors during construction

This principle aims to minimize the impact of design errors detected during construction. Table 6 summarizes the impact of CAVT to this principle compared to traditional design approaches.

Table 6: Impact of design errors during construction

Traditional	CAVT
Request for information (RFI), Notice of Change (NOC) and similar documents are plentiful during the construction stage of the project. This reflects deficiencies in the design as well in the effectiveness of the design communication effort using 2D drawings. "Acceptable" rework and delays levels become commonly and accepted during construction. The capacity to solve design problems of usually small designers teams working during construction become usually surpassed or it is enormously enlarged. Either solution impact negatively leading to construction rising costs and/or making schedules falls through.	Construction is anticipated and early involvement of construction personnel allows early detection of errors. Quantity of RFIs, NOC and similar documents decrease dramatically, construction efficiency increase, schedules are commonly fulfilled or improved as well as costs reduced or not exceeded.

6.2 Case Study Sample/Evidence

Customer requirements captured by design
The approach used to ensure that the customers' requirements were captured by design was to approve the design in the 3D model prior to 2D drawing extraction. Clash checks and 2D drawings extraction from the 3D model complemented this activity. The effort to track and report the progress of the design based in the 3D model progress was not completely successfully. However, when compared to traditional 2D drawing review approaches the level of certainty regarding the compliance with what was expected by the customer increases enormously. This subject still presents ample opportunities for the development of techniques and tools by which progress of 3D models can be tracked and reported more accurately and objectively.

Customer requirements available during design
The 3D model facilitated design coordination. Periodically design coordination meetings with the client were arranged from the beginning of the project. These meetings had the on going 3D model of the project as central feature. Action items for design modifications were agreed in these meetings. Thus the 3D model helped to ensure that customer requirements were available during design.

Suitable capability of the production system
Four-dimensional Planning and Scheduling (4D-PS) was applied to carry out the planning and scheduling tasks for the concrete foundations of the project, early during the design stage. The application of this technique allowed not only ensuring that the capability of the construction/production system for the concrete works was ensured. But it improved the production rates by 25% compared to previous contractor experience related to concrete works, and led to savings of 10% of the original budget and the completion of the work two months ahead of schedule. The successful 4D-PS application to the project, proving to be productive and effective, gave rise to convert this technique in a new work process aimed to be standardized by the case study Contractor Corporation.

Construction requirements satisfaction
4D-PS allowed a truly construction driving production system for the concrete works in the case project. 4D-PS was also applied in a lesser extent to structural steel erection and some major equipment's installation. The schedules developed under the 4D-PS support proved to be extremely realistic compared to those developed traditionally. While those construction schedules developed traditionally acted as master reference plan, schedules developed using the 4D-PS were used jointly with animations reflecting these schedules, as powerful communication mechanisms which led to satisfy construction requirements much better than in previous projects, regarding scheduling issues.

Impact of design errors during construction
Visualization of the 3D project model early during the design, automatic clash detection as part of the 3D model development process and accurate materials quantity take-off, have led to reduce the contractor's rework at the jobsite from historical 5% to 1% of the total cost of the case project. This important achievement is now being improved further with the application of 4D-PS with a tendency to a near zero-defects construction jobsite in the near future.

Case study CAVT limitations
Despite the benefits of CAVT application to the case project, the novelty and rapid change of the tools produced some troubles mainly when faced with required changes in steady standardized work processes and organizational structures. Even the case project contractor efforts to embrace CAVT are significant, not always CAVT produced the expected success. The final balance was however positive in the case project, with big potential benefits yet to be obtained and explored.

7. CONCLUSIONS

After more than two years working with PDS on the case study project, the local contractor branch has become a nearly full-fledged, PDS-capable organization among the top levels of the contractor’s global community and the industry at large. Fostering further development in the effective use of this technology is now part of the contractor’s work process development scheme, recognizing that the classical, 2D-bound methods of project execution will soon be a vestige of the past, much as drafting boards are today.

The production theory has provided a suitable framework to evaluate the impact of CAVT in the design process of industrial construction projects. The conceptual framework provided by TFV concepts has helped to improve understanding of the mechanisms to improve performance of IT tools like CAVT. The impact of CAVT was possible to be studied under five main principles covering the value generation cycle in the design process of industrial construction projects. Such a conceptual framework provided a sound conceptual framework to analyze the important transformations and improvements achievable through the implementation of CAVT. Undertaking CAVT IT research as described in this paper has led to the rise of a new work process that has proved to be productive and cost effective (4D-PS). As a consequence, a leading, international, engineering and construction company is carrying out efforts to engage a new tool set and work process.

8. REFERENCES

Bentley G. (1998). "Greg Bentley's Remarks from A/E/C Systems '98",

Betts, M. (2000) "The Strategic Management of Information Technology in Construction", Construction Information Technology, *Proceedings of CIT 2000 The CIB-W78, IABSE, EG-SEA-AI International Conference on Construction Information Technology*, Reykjavik, Iceland, 28-30 June, 2000, G. Gudnason (Ed.), Icelandic Building Research Institute. Vol. 1, pp. 21-28.

Björk, B-C. (1999). "Information Technology in Construction: domain and research issues", *International Journal of Computer-Integrated Design and Construction*, 1(1), pp. 3-16.

Collier, Eric, and Fischer, Martin. (1996). "Visual-Based Scheduling: 4D Modeling on the San Mateo County Health Center." *Proceedings of the Third Congress on Computing in Civil Engineering*, Jorge Vanegas and Paul Chinowsky (Eds.), ASCE, Anaheim, CA, June 17-19, 800-805,

Cook, H. E. (1997). *Product Management - Value, quality, cost, price, profit and organization*, Cahpman & Hall, London, 441 p.

Dertouzos, M. (1998). *What will be. How the world of Information will change our lives*, HarperEdge, USA,

ENR Magazine. (2000). "2000 ENR Top 225 International Contractors", http://www.enr.com/dbase/2000tic.asp

Fenves, S.J. (1996). "The penetration of information technologies into civil and structural engineering design: state-of-the art and directions toward the future", *Information Representation and Delivery and Structural Engineering Design*. Ed. By B. Kumar and A. Retik. Civil Comp Press, Edinburgh, pp. 1-5,

Gilbreth, Frank B. and Gilbreth, L. M. (1922). "Process Charts and Their Place in Management", *Mechanical Engineering*, January, pp. 38-41, 70,

Haymaker, John and Fischer, Martin. (2001). "Challenges and Benefits of 4D Modeling on the Walt Disney Concert Hall Project." Working Paper Nr. 64, Center for Integrated Facility Engineering, Stanford University, CA (available in pdf format at http://www.stanford.edu/group/CIFE/Publications/index.html).

Hopp, W. and Spearman, M. (1996). *Factory Physics: Foundation of Manufacturing Management*, Irwin/McGraw-Hill, Boston, 668 p.

Jagbeck, A. (1999). "IT support for construction planning", Doctoral Thesis, KTH, Stockholm.

Koskela, L. (2000). "An exploration towards a production theory and its application to construction", Technical Research Centre of Finland, Publication 408.

Laitinen, J. (1998). "Model Based Construction Process Management", Doctoral Thesis, KTH, Stockholm.

McGovern, G. (1999). *The caring economy: Business Principles for the New Digital Age*, BlackHall Publishing, Dublin, Ireland,

Mahoney, D. (1999). "All Eyes in CAD", Computer Graphics World, Volume 22, No 5, May.

McKenney, J. (1999). "Waves of Change: Business Evolution through Information Technology", Harvard Business School Press, Boston, Massachusetts.

Negroponte, N. (1998). *Being Digital*, Alfred A. Knopf, Inc., New York, USA.

Rischmoller, L., Williams, M., Fox, R., Alarcon, L. (2000). "Automation and Visualization tools to improve support for Process Integration in the Construction Industry", *Proceedings of INCITE 2000, International Conference on Construction Information Technology 2000*, Hong Kong, China, 17-18 January, 2000, H. Li-Q. Shen-D. Scott-P. Love (Ed.), The Hong Kong Polythecnic University, pp. 533-551.

Rischmoller, L., Fischer, M.,Fox, R. and Alarcon, L. (2000). "Impact of computer advanced visualization tools in AEC industry", Construction Information Technology 2000, *Proceedings of CIT 2000 The CIB-W78, IABSE, EG-SEA-AI International Conference on Construction Information Technology*, Reykjavik, Iceland, 28-30 June, G. Gudnason (Ed.), Icelandic Building Research Institute. Vol. 2, pp. 753-764.

Rischmoller, L., Fischer, M.,Fox, R. and Alarcon, L. (2001). "4D Planning and Scheduling (4D-PS): Grounding Construction IT Research in Industry Practice", Construction Information Technology 2000, *Proceedings of the CIB-W78 International Conference IT in Construction in Africa*, Mpumalanga, South Africa, 29 May - 01 2001, pp. 34-1 - 34-11.

Robbins, D. (2001). "New Strategies for Managing Complex Projects", *PM Network magazine*, April 2001, pp 46-48

Shewhart, W. A. (1931). *Economic Control of Quality of Manufactured Product*, Van Nostrand, New York, 501 p.

Staub, S., Fisher, M., Melody, S. (1998). "Industrial Case Study of Electronic Design and Schedule Integration", Working Paper, No 48, CIFE, Stanford University.

Stake, R. (1998). *Investigación con Estudio de Casos*, Ediciones Morata, S. L.,

Tapscott D. (1998). *Creciendo en un Entorno Digital - La generacion Net*, McGraw Hill,

Turk, Z. (2000). "Paradigmatic Framework for Construction Technology", Construction Information Technology 2000, *Proceedings of CIT 2000 The CIB-W78, IABSE, EG-SEA-AI International Conference on Construction Information Technology*, Reykjavik, Iceland, 28-30 June, G. Gudnason (Ed.), Icelandic Building Research Institute. Vol. 2, pp. 948-958.

Williams, M. (1996). "Graphical Simulation for Project Planning: 4D Planner" Proceedings of the ASCE Third Congress on Computing in Civil Engineering, pp. 17-19.

Yin, R. (1994). "Case Study Research, Design and Methods", Sage Publications, London.