USING LEAN PRINCIPLES AS A FRAMEWORK TO STUDY INFORMATION TECHNOLOGY IN CONSTRUCTION

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ABSTRACT

Information Technology (IT) in Construction is currently a hot topic in research and practice. However, there is need for a theoretical framework to support the analysis of how IT impact construction processes.

Research developed by the authors, that considered participation of the first author in IT implementation in real projects, explored the relationship between design and production theory principles, and the prevalent (transformation) and new production models (flow and value). A Transformation-Flow-Value (TFV) model of the design process provided important basis to understand the forces of change that IT offers to the construction industry, describing the impact of Computer Advanced Visualization Tools (CAVT) and attaining a synergistic effect between IT and Lean Principles. The research combined empirical evidence with lean theoretical background and developed a quantitative framework based in Freire and Alarcón (2000) and a qualitative framework adapted from Koskela (2000) to analyze the impact of IT CAVT. This paper presents both frameworks and discusses how the impact of IT CAVT to the design and construction processes can be studied using Lean Principles as a theoretical framework.

KEY WORDS

Lean Principles, Information Technology

INTRODUCTION

This paper presents results of a PhD's research carried out at Catholic University of Chile. Between 1999 and 2002 the impact of Information Technology (IT) Computer Advanced Visualization Tools (CAVT) to the design and construction processes was studied using Lean Principles as a theoretical framework. The Computer Advanced Visualization Tools (CAVT) concept developed as part of the research was met to be insufficient for its original purpose intended to understand and describe the design and construction processes. Production theory and lean principles where then found to provide a suitable framework to evaluate the impact of CAVT in the construction industry. Case study research was used as main research strategy and used as an intellectual exercise that led to idea transfer and sense making coming from a single, but exemplary case study enlarging in this way the range of empirical studies of how construction IT is used and including its application context in the construction industry (Rischmoller et al. 2002). The results coming from the single case study were then validated and analytic generalization is claimed so that the research conclusions could be extended industry wide.

Part of the research results presented in 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

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systems: computing is worthwhile only as far as it can contribute –better than alternative means– to the realization of principles of production (Koskela 2000). 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 using Lean Principles as a theoretical framework.

INFORMATION TECHNOLOGY AND CAVT IN THE CONSTRUCTION INDUSTRY

IT DEFINITION

In this paper Information Technology IT is defined as the body of knowledge that deals with production, distribution, storage, recovering, but mainly, utilization of information. The broad scope of the previous definition can be narrowed when considering its application to productive activities that involve what in this paper are defined as the three main elements of IT: people, processes and tools (Figure 1).

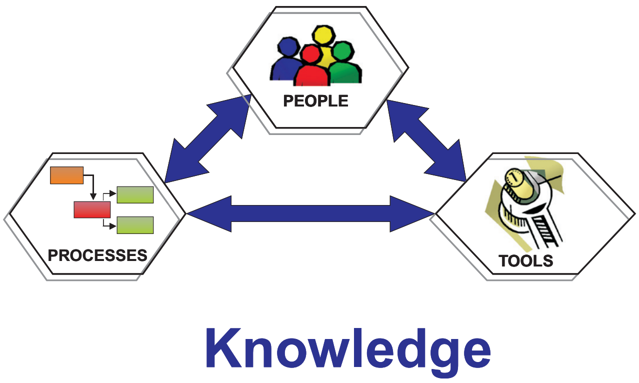


Figure 1: Main elements of IT

These three elements are interlinked and it is argued that in the construction industry, it is precisely in the links between them where reside the main causes that have led to the either low level of adoption or underutilization of available Information Technology related tools, processes and people.

IT IN CONSTRUCTION

Since IT tools (i.e. hardware, software, internet, etc.) and IT qualified people are common to any IT application environment, it is in the processes side, where the general IT definition can be confined to an specific activity or domain. Construction Information Processes tightly linked to Construction Industry Materials Processes interact with each other permanently at many different levels during any project life cycle. Firstly the information process produces information which indirectly or directly controls the material activities taking place (e.g. design drawings production). Secondly the information processing activities constantly need feedback information about what's actually happening in the material process, in order to check compliance with the designs or monitor the progress of the work against the schedules (e.g. installation reporting, cost control budgets, etc.). This relationship was first depicted by Bjork (1999) (Figure 2). However, in the Construction Industry, despite praiseworthy efforts, information processes effectiveness and efficiency can, in the best of the cases, be considered partially successful and mostly limited and even disregarded. Enginnering-Procurement-Construction (EPC) Projects Design and Construction Firms can be located in the "partially successful category". The rest of the construction industry, traditionally craftsman-oriented, with many small participants, which for example, in USA alone, accounts for 656,000 construction-related firms can be located in the "mostly limited or even disregarded" category. Of the latter, over 62 percent of the construction-related firms have fewer than 4 employees, while less than 1 percent have more than 100 (ICAF 2000). Each firm carries out only a few steps of an increasingly complex process, and no one organization has as much as five percent of construction dollars (Eastman et al, 2002). Several authors coincide in the fact that IT has not been adequately adopted by EPC/AEC industries (Turk 2000; Betts 2000; Rischmoller et al. 2001).

Dealing with documents like Request for Information (RFI) from constructors to designers, Notices of Change (NOC), Field Change Notices (FCN), Backcharges, and others common in EPC projects; and materials, costs and schedule contingencies introduced in the original estimates in Architectural-Engineering-Construction (AEC) projects, are symptoms that show how Information Processes issues have not yet been solved in the construction industry. Most of EPC/AEC projects stakeholders are used to cohabit with these issues while a small group of researchers (academic and industry practitioners) and software vendors are trying to push the Construction Industry to a new IT era, with relatively small success.

CAVT CONCEPT

Information Technology Tools being used by the EPC/AEC industry are numerous. From fax machines to internet communications, from office automation software to advanced CAD applications, from laser sensors to automated data acquisition; all these technologies deal with

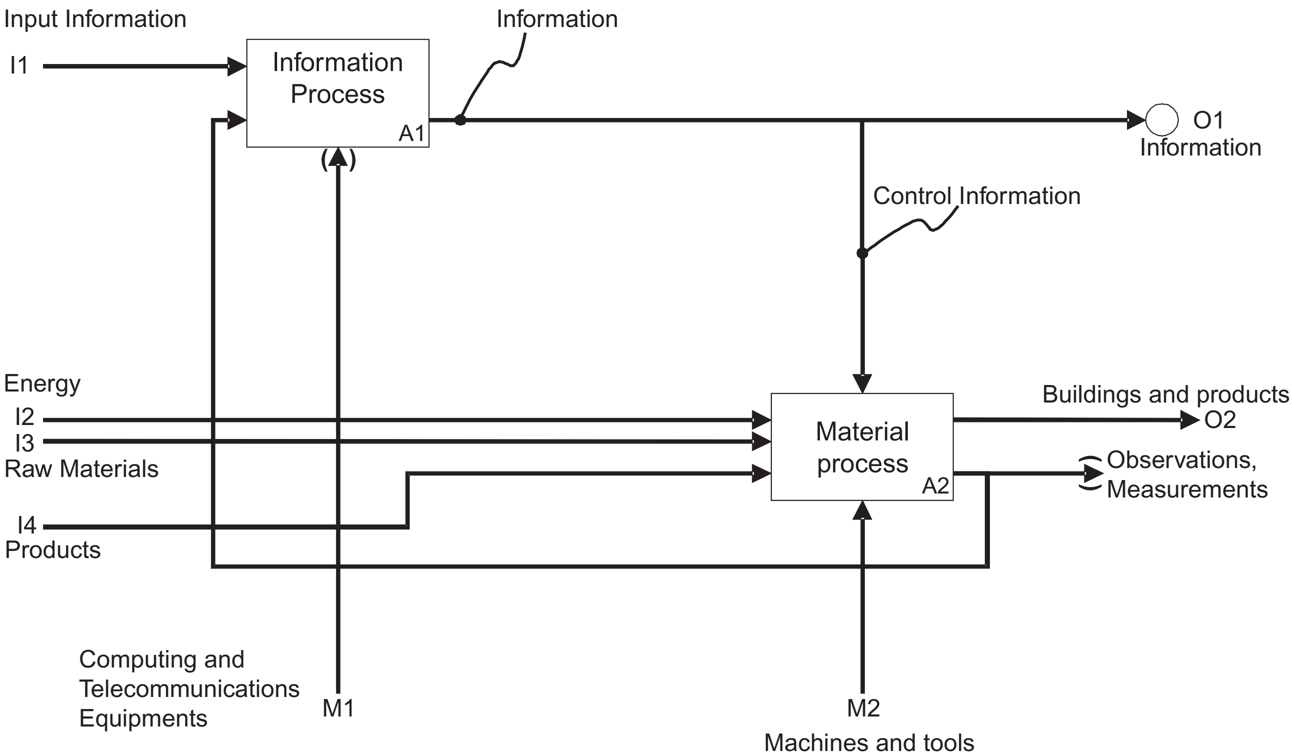


Figure 2: The Construction Process seen as two Interacting sub-processes (Bjork, 1999)

information within the EPC/AEC industry (Rischmoller et al, 2000). All these technologies reduce or replace human efforts, either physical or mental and have a profound effect on the construction industry. This paper will focus in specific IT tools that led to the Computer Advanced Visualization Tools (CAVT) concept development.

The CAVT concept is defined 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 provides a definition, which could evolve over time, since it is not tied to any particular tool (i.e. software tool). Another important feature of the CAVT definition is that despite it is mainly related with the visual aspect of project representation, it is no limited to such approach which only constitute its ultimate output. CAVT might lead to a 3D rendering, or a 2D plot, or a bill of materials, or a work order report, or a virtual reality environment, each coming from a unique product and process model representation, which can be visualized through a computer based display device.

IMPACT OF CAVT IN THE DESIGN PROCESS OF INDUSTRIAL PROJECTS

THEORETICAL FOUNDATION

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). These concepts give direction for research and practical experimentation, and add to conceptual clarity. Koskela's production theory is based in concepts of production each one with a particular view of production. These concepts 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) The Value generation concept. The first letter of each of these three concepts gives name to Koskela's proposed theory: TFV Theory of Production. Each of these concepts captures an intrinsic production phenomenon. The TFV production theory proposes that production management needs the three views that should be used simultaneously and in an integrated and balanced way.

LEAN DESIGN MODEL

The research called Lean Design to the application of Lean production principles to the modeling, analyzing and understanding of the design

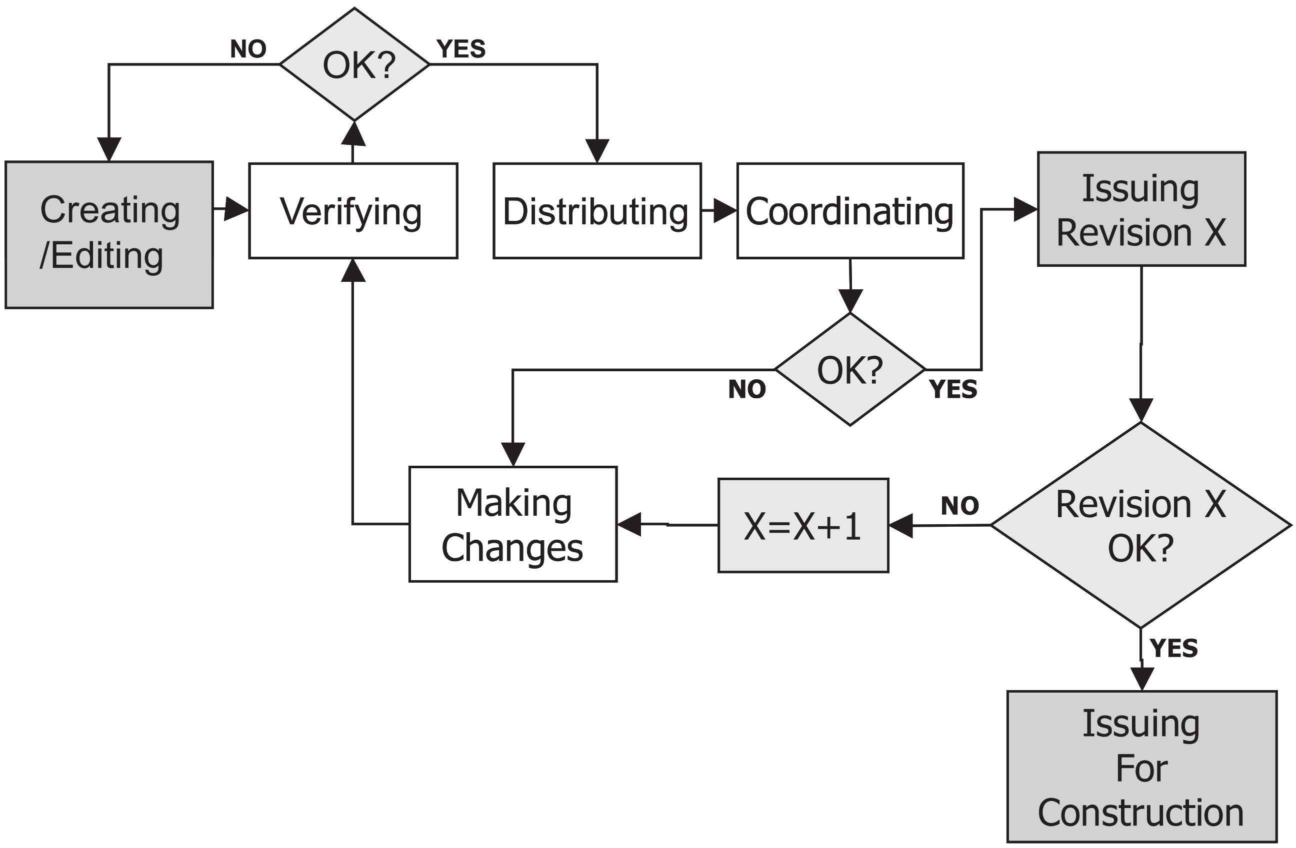


Figure 3: A proposed simplified generic model of the design process of EPC/AEC projects

process in the EPC/AEC industry. Lean design deal with the management of uncertainty and complexity in the design process, aiming at reducing waste and improving value-adding activities. Lean design provided useful concepts for developing an efficient and effective approach for managing the design process in the EPC/AEC industry and to study the impact of CAVT.

A simplified generic model of the design process of EPC/AEC projects was developed as part of the research (Figure 3). The concept of this model allows the application of lean principles to design. Since the design process is basically an information process, the model presents six types of activities (represented by the gray and white boxes) that act directly over the information that flows and is transformed during the design process, refining information iteratively in every "issue-loop".

(1) Verifying, (2) Distributing and (3) Coordinating (in the white boxes) are activities that, from the client's point of view, do not add value and consequently introduce waste to the design process. This waste can be expressed as (1) inspection, (2) moving and (3) waiting activities as shown in Figure 4. While (4) Creating and (5) Issuing are activities that do add value to the design process and can be paralleled with transformation processes (Figure 4). The similarities between the flow model described by Koskela (1992) and the research proposed Lean Design model become notorious. (6) Making changes is equivalent to rework.

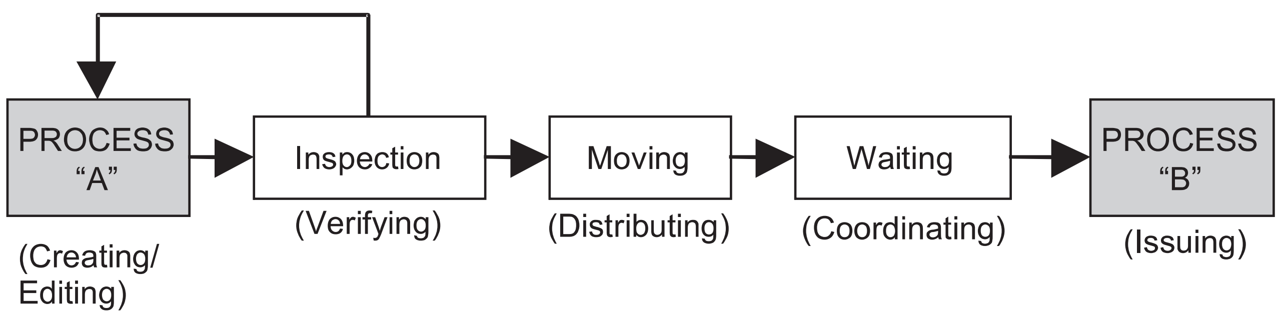


Figure 4: Similarities between the flow (Koskela, 1992) and Lean Design Models

QUANTITATIVE FRAMEWORK TO EVALUATE LEAN DESIGN

Freire and Alarcón (2002) diagnosed and evaluated the design process for three projects of a design contractor in Chile. These projects did not use CAVT but "traditional" tools. Freire and Alarcón (2002) used lean principles and tools to carry out measures that led to conclude that the main categories of waste in the design process are:

- Ignorance of client requirements
- Bureaucracy and paper work
- Interdisciplinary coordination
- Information not available
- Rework

Freire and Alarcón (2002) also studied the time distribution in the design process. The measures shown in Table 1 and Table 2 were obtained by measuring times in the design process of a design firm mainly dedicated to the engineering of civil, mining and industrial projects, for a period of approximately one year. The measures were obtained collecting data in formats designed for this purpose with collaboration of company personnel and participation of researchers. Table 1 shows the time distribution in the design process measured for each category. These categories are paralleled with the activities proposed in the Lean Design model of Figure 3.

Freire and Alarcón (2002) categories	Lean Design Model	Duration (%)
Designing	Creating/Editing	50.2
Verifying information	Verifying	8.2
Collecting information	Distributing/Coordinating	28.1
Correcting information	Make Changes	12.2
Issuing	Issuing	1.4

Table 1: Distribution of Time in the Design Process

Freire and Alarcón (2002) also measured the time from the beginning until the end of work in drawings for the different specialties involved in the design, the cycle time, and calculated the waiting time for each category obtaining the results presented in the following table. Waiting time is defined as the additions of period of times when the activity is stopped. The values shown in Table 2 were obtained calculating waiting times as a percentage of the total time spent in each category. For instance, 21% of the time used in collecting information is spent in waiting.

Table 2: Waiting Times in the Design Process

Freire and Alarcón (2002) categories	Lean Design Model	Waiting Time (%)
Designing	Creating	8.3
Verifying information	Verifying	4.0
Collecting information	Distributing/Coordinating	21.0
Correcting information	Make Changes	7.1
Issuing	Issuing	0.0

QUALITATIVE FRAMEWORK TO EVALUATE LEAN DESIGN

Five principles covering the value generation cycle in the design process were used as a qualitative framework to analyze the impact of CAVT. These principles are adapted from the value generation principles proposed by Koskela, 2000:

- **Customer requirements captured by the design**: aiming to ensure that all customer requirements, both explicit and latent, have been captured by the design.
- **Customer requirements available during the design**: aiming 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.
- **Suitable capability of the production system**: aiming to ensure the capability of the production system to produce as required.
- **Construction requirements satisfaction**: aiming to ensure that requirements and constraints of the construction process have been taken into account during design.
- **Impact of design errors during construction**: aiming to minimize the impact of design errors detected during construction.

If design information is inadequate, materials are missing, or prerequisite work is incomplete, the assigned work will cost more, take more time or be done incorrectly, if at all (Ballard and Howell, 1998). The five principles of value generation that helped us to evaluate the impact of CAVT deal with uncertainty reduction, which if improved, shall help to achieve a construction world that is more stable and predictable. Once production units are shielded from workflow uncertainty, time and energy are released for improving downstream performance, specifically for detailed design of work methods with high involvement of direct workers and line supervisors (Ballard and Howell, 1998).

IMPACT OF CAVT

The five principles covering the value generation cycle in the design process presented in this paper (qualitative framework) were associated to the main categories of waste in the design process (quantitative framework) identified by Freire and Alarcón (2002) (see 3.3) and arranged into five CAVT impact categories as presented in Table 3. Some associations appear pretty obvious (i.e. category A) and other associations appear forced (i.e. category C). These associations, however, provided order to describe and discuss the impact of CAVT tackling the value and flow aspects of construction. The transformation perspective was included in the discussion of the impact of CAVT combining each category with the Lean Design model (Figure 3).

Table 3: CAVT Impact Categories

Impact Category	Production Principles VALUE (Qualitative framework)	Waste categories FLOW (Quantitative framework)
A	Customer requirements captured by design	Ignorance of client requirements
B	Customers requirements available during design	Bureaucracy and paper work
C	Suitable capability of the production system	Information not available
D	Construction requirements satisfaction	Interdisciplinary coordination
E	Impact of design errors during construction	Rework during Construction

Based on evidence coming from case study research developed over a four year period, the impact of CAVT is presented in (Rischmoller et al, 2002) as tables that compare traditional approaches to design with design carried out using CAVT. The impact of CAVT from the flow perspective considered how the type of waste and waiting times associated to each CAVT impact category in Table 3 could become reduced. And the impact of CAVT from the transformation perspective explored how the value adding activities in the lean design model could be improved.

BENEFITS OF APPLYING CAVT TO THE DESIGN PROCESS

The evaluation of the impact of CAVT was not explicitly looking for improvement opportunities, but only to describe how the design process is affected by CAVT. Considering the value aspect included in the principles of value generation framework, as well as the flow approach presented in this paper, introduces, however, a new perspective for the description of the benefits of applying CAVT to the design process.

The research results propose that Automation, Visualization and Computer Advanced Visualization Tools (CAVT) can be arranged in an IT tools pyramid where CAVT are located at the top supported by automation and visualization tools (Figure 5).

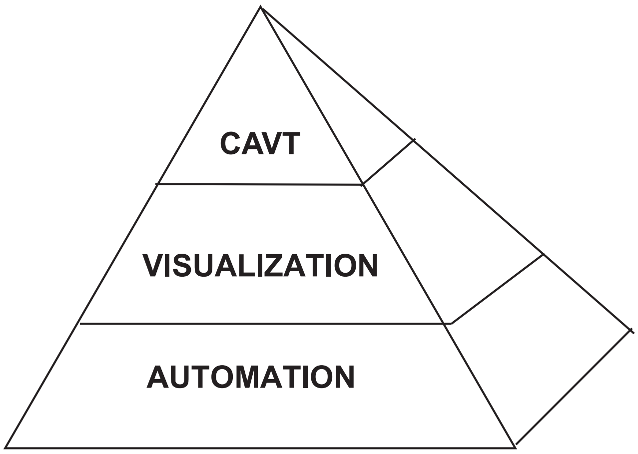
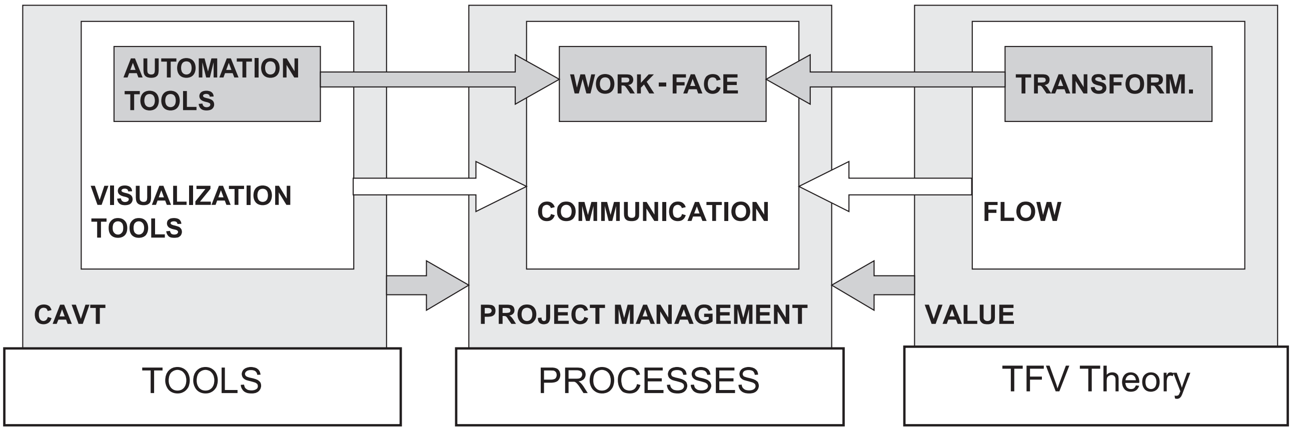


Figure 5: IT Tools pyramid

Each level of the pyramid is associated with a level of information related activities inherent to the design process. Automation tools bring benefits to the design process mainly at the work-face level (where basic design activities and processes are executed, e.g. drafting) and information is transformed in "tangible" entities in the form of documents, electronic files or any digital representation. Visualization tools bring benefits to the design process mainly at the communication level facilitating the communication processes among project stakeholders and consequently improving the flow of information during the design process. CAVT bring benefits to the design process mainly at the Project Management level, where decisions affecting the work-face and transformation processes are made and where communication and flow of information is influenced, adding value to the design process itself.

Figure 6 shows the relationship between IT tools, design related processes and TFV theory, and how CAVT benefits are directly related with value adding activities. Nevertheless, since Automation tools are part of Visualization tools, which

Figure 6: Different levels and fields of influence to depict benefits of CAVT



indeed are part of CAVT, the flow and transformation approaches are not disregarded.

A SINERGISTIC EFFECT BEWTEEN LEAN PRINCIPLES AND IT

CAVT impact description proved how the needs and wishes of a customer condensed into a digital visualization of the product and processes required to materialize a construction project can be fulfilled in unprecedented ways. CAVT lead to reduction of uncertainty aggressively in the early phases of the project engineering and consequently during production (construction). CAVT also contributes to predict the fulfillment of the central targets set to production with higher precision, designing, producing and delivering products as required by customers. The perfection of internal customer-supplier-relationships contributes to a reduction in variability and uncertainty, major causes of rework and waste in construction.

It is clear the overlap of how CAVT deals with waste and the requirements/value relationship, with the objectives pursued by lean principles. We argue that this should be more than overlap, but a synergistic approach in which both IT research and lean principles do not deal separately with variability, uncertainty and complexity, but converge in a new approach that shall provide important benefits to the construction industry.

FURTHER RESEARCH

The focus in the research presented in this paper was on IT. Lean principles were used as a theoretical support to explain IT impact in the construction industry. On going research at Catholic University of Chile related to management of buffers in construction (Gonzalez et al, 2004) is using the opposite approach, in which lean and production theory principles are the focus and IT is being used to support the research (Gonzalez et al, 2004). Percentage of Planned Activities Completed (PPC) at the research case study reached over 90% using CAVT. Research carried out by the Production Management Center (GEPUC) in Chile and also by Ballard (2000) show that in average, and despite some exceptions, the application of Last Planner technique increase plan reliability below the 70% PPC level. In this paper it is stated that further research considering the synergies between IT CAVT and Lean Principles could lead us beyond Last Planner application current results. It is also stated in this paper that the quality of assignments that can be achieved when using IT CAVT and lean principles together, is so high that the need of an strategy of shielding production from work flow uncertainty proposed by Ballard and Howell (1998) could eventually evolve to an “un-shielding” production approach through the early utilization of Technical Information Buffers (Gonzalez et al, 2004).

CONCLUSIONS

This paper presents results about the study of Information Technology and the ability of construction industry organizations, to adapt to take advantage of their emerging functionality, which requires both understanding of how they might function and readiness to change. Production theory and lean principles were found to provide a suitable framework to describe the design and construction processes and evaluate the impact of CAVT in the construction industry.

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