1. INTRODUCTION

Information Technologies being used by the 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 information within the AEC industry. All these technologies reduce or replace human efforts, either physical or mental and have a profound effect on the AEC industry. The study of IT applications in construction is however, still a young field of research, still struggling to define its place within the large family of academic disciplines (Bjork, 99). This paper presents results of research about IT in construction. The focus of the paper are CAVT applied to the design and construction planning processes at the project operational level. Within the AEC industry we need to represent not only the visual animation information, but also the underlying information about facility components and activities (Kunz et al, 99). In that sense CAVT definition involves more than graphical representation features. A wider definition of CAVT is presented, involving their ability to visualize information regarding the ends (Product Models) and means (Process Models) for AEC project process development.

Computer Graphics issues, central to CAVT in the AEC industry are overviewed and briefly discussed in this paper. Demand for higher quality displays and limitations of existing interfaces, powerful and affordability of new processors and software capabilities, and interoperability needs are discussed.

Information Technology for the AEC industry involves the integration of all product development processes and the management of the information flow between them, irrespective of the data models chosen in the different implementations of one and the same process (Scherer, 94). Product and Process Modeling are the main topics related with the former approach, that have gained more attention in the last years within IT research in the AEC industry. Central to Product Models is the visual representation of the project product, commonly associated to some 3D CAD modeling effort. Different approaches have extended the “physical” representation of the project product, to include not only geometric information within it, but also the relying data which support the different activities during the several phases involved in an AEC project. This paper extends this approach to what will be defined as the Digital Reality. Process Modeling has been trying to represent the detailed tasks and transformation of specific entities among simultaneous activities oriented to complete a design into a constructed facility within AEC industry. Construction process modeling in form of 4D models is presented in this paper as the technology that will trigger the major changes expected from CAVT impact.

The research is mainly based in the application of CAVT to a real project by an Engineering and Construction company which design stage is currently near 70% advanced. Three main processes were studied in the case project during the design phase: (1) 3D Modeling Design, (2) Constructability and (3) Construction Planning and Scheduling. The description of the impact of CAVT to these processes is described in this paper, and it is the main source from which insights presented in this paper come from.

2. CAVT CORE IT TOOLS

Advanced animation/multimedia IT visualization tools are being used successfully in military and commercial flight simulations, the entertainment industry, medical research, marketing and other fields (Rischmoller et al, 00). Computer Aided Design (CAD), Virtual Reality (VR) and 4D Modeling were presented and discussed by (Rischmoller et al, 00) as representative of the more advanced IT graphic computing visualization tools suitable for AEC industry purposes.

CAD and VR when used in real projects, are limited to the design stage, however, an IT strategy can no longer afford to start and finish with design (Bentley, 98). 4D modeling goes a step further and involves construction. Traditional 4D-CAD models are purely graphical representations of a facility and its time-based construction process. To link facility, process and organization analysis, however, we need to represent not only the visual animation information, but also underlying information about facility components and activities (Kunz et al, 99). Available 3D design tools are already providing benefits, especially within the plant design industry, where 3D design has reached an important level of development.
3D modeling enjoys a “well” developed approach, in most of AEC leading companies. 4D and Virtual Reality, are technologies that are starting to cross over the boundary between research and practice. New tools and technologies and interfaces are being developed at construction IT laboratories (i.e. Workbench and Information Mural at Stanford). Common to all these tools is their ability not only to represent visually, the final products aimed by AEC industry, but also the processes needed to be carried out to achieve the final products.
CAVT is defined as the collection of all the necessary tools, which allow for the visual representation of the ends and the means of AEC needed to accomplish an AEC 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. Even CAVT is mainly related with the visual aspect of project representation, it is no limited to such approach, which will constitute its ultimate output. However, 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.

3. COMPUTER GRAPHICS AND CAVT

3.1 Computer graphics

Personal computers have moved computer science away from the purely technical imperative. Computers are no longer the exclusive realm of military, government, and big business. They are being channeled directly into the hands of very creative individuals at all levels of society, becoming the means for creative expression in both its use and development (Negroponte, 95). AEC industry is not unaware of this situation. Central to CAVT is computer graphics. Early computer graphics required a machine fully dedicated to provide the image. It was no different in principle than today’s personal computer, but it filled a large room and was very expensive. Computer graphics was born as a line-drawing medium that demanded a great deal of computing power to control the beam of cathode ray tube. Only ten years later did computer graphics start to move away from graphics of line drawing to a graphics of shapes and images (Negroponte, 95). AEC industry is starting to take advantage of the former. In the past ten years hardware and software for AEC industry, has been closer to research and development instances within a few AEC companies, and universities, than to practical applications in real projects. Today, that approach is bluring, and some research prototypes are finding its way to practice. While research doesn’t stop, some available commercial hardware and software tools has reached an adequate level of powerful, affordability and ease of use, which should allow for a massive application of CAVT tools in the AEC industry in the near future.
Central to CAVT is Computer Graphics. Following a brief discussion about computer graphics relevant aspects to AEC industry is presented:
Computer graphics in the AEC industry is closely related to Computer Aided Design (CAD). Those with experience in the information world know that the CAD sector is one of the most

innovative in adopting advanced solutions (Montero, 99). Early CAD was very technology-intensive, beyond the capabilities of most computer processes, early displays and systems capabilities of the day (Eastman, 99).
Computer graphics as CAD, is dependent on three different types of computer technologies:

- Display Technologies
- Processor Capabilities
- Software Capabilities

3.2 Display technologies

Evolution in display technologies has allowed us to move from low resolution monochrome static displays, incapable of displaying much detail or to quickly update a display, to large-scale monitors and high performance graphics boards supporting increasingly fast dynamic color displays (Eastman, 99). There are two main technologies currently in use, regarding computer information display onto a monitor screen, Liquid Crystal Display (LCD) and Cathodic Ray Tube (CRT). A LCD is a light switch digital technology, pixel on; pixel off that takes a bitmap and lays it out on the screen, so there is no flicker, no distortion, no problems with geometry. With a CRT, a gun ignites a phosphor, which glows and lights the image on the screen. When the gun moves on to the next phosphor, the first phosphor is still glowing for a bit-producing flicker. The phosphor does not turn off as fast as a LCD (Maclean, 00). Perhaps the only bad news is that the large, flat, LCD monitors that many of us covet aren't going to drop in price for some time. In fact, IBM's Petersburg reports that the number of flat panel monitors shipped and installed globally is quadrupling. But the four million flat panels projected global shipments in 1999 are still dwarfed by projected 100 million CRT monitors being shipped world wide in 1999 (Maclean, 00).
Demand for higher quality displays increases with the rising use of computers in general. In AEC industry, not only the rising use of computers influences the demand for better display technology, but limitations related to reach a suitable environment for enhancing collaboration amongst multiple participants, have been identified in existing interfaces (Koo and Fisher, 98). In response to these limitations, the CIFE community at Stanford University has studied new interfaces, specifically the Responsive Workbench and the Information Mural, in the efforts of developing a virtual production planning environment (Koo and Fischer, 98)

3.3 Processor Capabilities

In the past ten years, the chronology of high-powered graphics computers have been associated to mainframes with multiple graphics terminals, engineering workstations and lately personal computers. According to the purpose of graphic computing utilization, minimum and maximum (*high*) requirements were established. What is the past was *high*-end requirements, has been transforming constantly to *minimum* requirements in the future. The price range of engineering workstations ten years ago, was typically US$10,000 to US$100,000, though a US$30,000 workstation was certainly adequate for most applications (Alciatore, 91). The same power, or even more power, as compared to former workstation can be found with no difficulty today in a PC at a much lesser cost. Computing power has risen 100 million-fold since the late 1950's-with a 100,000-fold rise in power coupled with a thousand drop in cost (McGovern, 99). Every computer has one or more processors. They are the laborers that process information-chips that carry out the instructions given by software programs (Dertouzos, 98). *Moore's Law*, named after Gordon Moore, a founder of Intel who first observed the relationship (Dertouzos, 99), is a defining factor in all modern industry. Following *Moore's Law*, new computer processors are developed roughly every eighteen months that are twice as powerful and roughly half the price. No one ever lost betting on

Moore's Law, or won betting against it. And it is a template by which one can judge the behavior of even the most cutting-edge companies (McGovern, 99).

3.4 Software Capabilities

Within the AEC industry, currently the most advanced available software is used at the design stage. A 1997 study focused on the full range of IT use revealed that design firms tended to equate information technology with CAD (Fallon, 00). Design firm principals have clearly become more interested in the topic of integrating CAD technology effectively into their work processes and in the specific features required to make CAD effective for everyone in the firm-not just drafters (Fallon, 00). Process and Power industry is an important part of the construction industry from which other sectors of the construction industry could get great benefits, if an organized benchmarking process is carried out. Plant design leads the use of currently available CAVT. Intergraph Process & Building Solutions is a global organization that supplies software and services to the process, power and marine industries. They lead the 3D process plant design and visualization software market with a revenue share of 59%, according to latest Daratech analysis for 1999. Services provided by Intergraph to their customers may sound odd to those not in the Process and Power industry. For example: Implementation and Start-up, Project Execution Assistance, Customized Training, Upgrade and Transition Services, General System Support Services, Custom programming, Coordinated development efforts, and Fast-Response technical support. However, plant design software domain is not a paradise.

Transferring data from one software system to another is one of the most formidable problems in the plant life-cycle workflow. Problems occur in point-top-point software solutions when a new software version is released or a new system is added. Also systems are not designed to handle change management, often causing data to be re-entered or creating problems downstream in the plant life cycle. For data use to be seamless, data must be part of plant asset, independent of the computer system that generated it, provided in the form most useful to the people who need it, keyed once, revised with change controls, and readily available for future projects (Foster, 99).

Building industry trough International Alliance for Interoperability (IAI) is making big efforts against the lack of interoperable software solutions, that limits the designers' ability to achieve any form of efficiency in productivity (IAI, 97). The IAI started by twelve companies involved with the AEC industry, which were interested in being able to work with each others information without being concerned with what software they were using or which anyone else was using (IAI, 97).

The introduction of new technologies supporting interoperability, creation and maintenance of a common facility model, changes the paradigm of the software development process for the AEC industry and will provide benefits in the future. CAVT must be ware of this, and must become a central part of this process.

4. PRODUCT AND PROCESS MODELING REVISITED

4.1 Adequacy of Product and Process Models

Information Technology for the AEC industry involves the integration of all product development processes and the management of the information flow between them, irrespective of the data models chosen in the different implementations of one and the same process (Scherer, 94). Product and Process Modeling are the main topics related with the former approach, that have gained more attention in the last years within IT research in the AEC industry.

Central to Product Models is the visual representation of the project product, commonly associated to some 3D CAD modeling effort. Different approaches have extended the "physical" representation of the project product, to include not only geometric information within it, but the relying data which support the different activities during the several phases involved in an AEC project. Process Modeling has been trying to represent the detailed tasks and transformation of specific entities among simultaneous activities oriented to complete a design into a constructed facility.

Product and Process modeling efforts are mainly related with the research community. Product and Process models coming from the academic world, are however very different from 3D models being developed within the AEC industry, specially those dedicated to design. The study of the practical application of 3D and 4D modeling tasks to a real project, part of the research of this paper, proved that the concern of real projects are the *results* and the *tools* to achieve the results. The tools are mainly the available hardware, software and skills needed to use them. The knowledge about Product and Process modeling coming form the academic community, is usually overlooked or developed in a tacit fashion, more guided by the common sense, than for an ordered approach based in techniques, methodologies or prototypes coming from the academic community.

CAVT require ever diminishing "computer" skills from engineers, in this way results are achieved faster and with less effort than only a few years ago. CAVT application to the AEC industry should allow the necessary break between the results and the tools, creating a niche where the accumulated knowledge about product and process modeling could fit, providing great benefits to the AEC industry, and starting a new phase of research from a practical perspective, instead of the prototype testing approach used commonly to date.

CAVT will lead to the transformation of product models into Digital Realities. Regarding process modeling, construction process modeling supported currently by 4D technology, should be the trigger that will enlarge CAVT to the construction phase of AEC projects, allowing for the attainment of levels of integration never seen before.

4.2 3D Product Model - The Digital Reality

According to traditional rationalistic philosophy, the difference between "reality" and our understanding of that reality, is not an Issue, because it claims that there exists a rather simple mapping between the two. Our ability to intelligently act in the world around us is due to the mental images or representations of the real world around us, that we have in our minds.

The Aerospace industry has succeeded in transforming real world that exists in form of paper, in engineers' minds and in computer files into a visually available digital reality represented in a computer,. The Boeing 777, is refereed by the Boeing company, as the first paperless aircraft in the sense that it had a 100% digital definition before the start of construction (Onarheim, 99).

Virtual Reality (VR) and CAD environments, are the most common tools used to produce sophisticated visual information displays of 3D Product models in a digital form within the construction industry. If prizes were awarded for best oxymoron, virtual reality would certainly be a winner (Negroponte, 95). Virtual as opposite to Reality states a big contradiction of both words together. "Walkthroughs" into a 3D CAD model produces a sense of "being there", even without using electronic glasses and gloves, typical common devices of virtual reality technology. 3D Visualization as the most obvious advanced capability of CAD products has been identified by CAD vendors as the competitive edge that will provide more share of existing CAD market (Mahoney, ??).

The level of detail and realistic views that 3D product models can achieve by using CAVT, and that will be achieved in the near future, lead us to state that the 3D Product models are no

longer just a representation of what will be constructed in the future, but they are instead a digital form that we will call the Digital Reality.
Naming of the Digital Reality has more than semantics implications. The process of design, varies from trying to replicate the future by representing it with the use of computers, to a transformation of a digital reality in a new process of refining it. This new approach is developed concurrently in a common, collaborating and multidisciplinary digital dimension, pursuing an optimum and constructable design. The digital reality is in this way dynamic, unlike a 3D product model, which is static. Furthermore, CAVT is evolving toward easier and faster simulation, as well as construction of the Digital Reality, within the computer, and even outside it with devices like the workbench response table at Stanford University (Koo and Fischer 98). Widespread use of CAVT make us envision the result of the design stage as not only geometric information in 3D models, but also in complete construction planning and scheduling visualization models, i.e. represented in complete 4D+? Models, which may include scope and cost beside time (Staub and Fischer, 99). We also envision construction tasks being completely transformed by narrowing of the degree of uncertainty existing in the past at the job site. CAVT at the jobsite will transform the jobsite so as to have no resemblance to anything we know today. So digital reality spoken in two words, represents to the construction industry the foundation over which completely new paradigms for the design and construction processes will emerge, transforming the way AEC projects are developed even today with the "widespread" use of information technologies.

4.3 Construction Process Modeling

Designers develop digital realities, and contractors need to construct these digital realities, this can be done also digitally before going to the job site.
The construction industry relies on processes, of varying complexity to accomplish every task it is related with. These processes are the means that allow the transformation of abstract information into a physical reality, which is the goal of a construction project. Simulations have been used widely to represent construction industry processes. In general, simulation refers to the approximation of a system with an abstract model in order to perform studies which will help predict the behavior of the actual system (Alciatore, 91). A previous modeling effort is essential to develop any simulation task. Model development efforts must invariably consider the general modeling technologies upon which new models will be based (Froese, 1995).
Within the computer graphics and visualization context, in the last years 3D modeling has reached a high level of development in the AEC industry, specially in the Plant Design industry where 3D and shaded models have become an inherent part of any design. Currently available CAVT provide the most advanced technologies to visually model the construction process, by allowing the development of 4D models. However, despite its availability, this advanced CAVT feature has not been widely implemented yet in AEC projects.

4.4 4D Technology – The trigger of CAVT impact

4D models reflect the realities of project execution more closely than the approaches used in practice today (Fischer et al, 99). 4D modeling was applied to a real project as part of this research. Construction planning and scheduling were supported by available 4D modeling tools on the project. Field personnel knowledge was introduced into 4D models, and used to generate project schedules with computer software. The former, together with a comprehensive study of theoretical and practical approaches of 4D modeling around the world, has lead us to conclude that this is the technology that will trigger the major changes expected from CAVT impact described in this paper.

Thanks to computer advances, it is expected that CAVT will continuously reduce the construction process modeling effort. CAVT and 4D modeling technology are commercially available today, yet we are not taking advantage of them. In the future it is expected that CAVT will allow the visualization of the mapping scheme developed to support the relationships between the different hierarchical representations of design, cost, control and schedule information represented at different levels of detail (Staub and Fischer, 99). In this way, AEC projects which are highly complex systems with a high degree of connectivity between objects and attributes, will become everytime more explicit with CAVT application not limited to the design stage, but also to the construction phase of AEC projects. The next benefit will extend CAVT to the whole life cycle of AEC projects. This will reduce complexity and uncertainty, allowing for increasingly more realistic models of products and processes within the AEC industry.

5. CASE PROJECT

The study of CAVT applied by an Engineering and Construction company, to a real project was developed during the research. This case project is being designed directly in 3D using CAVT. The 2D drawings approach will not be discarded, as they are going to be a byproduct of the 3D modeling design effort, only at the end of the design phase. A full-scale, electronic model (digital reality) of the facility was planned for the project, and CAVT with powerful 3D rendering capabilities are also being used, providing a complete visualization environment to interactively review the large, complex design of the case project.

4D modeling and Simulations related to the movement of the elements of the 3D model were not contemplated originally. The available hardware and software tools allow the accomplishment of these activities. Trying to take full advantage of available CAVT on the case project, 4D modeling and Visual Simulations to study assembly and erection tasks, were introduced as part of the construction department tasks, when the project design was 30% complete.

6. RESULTS OF CAVT APPLICATION TO THE CASE PROJECT

CAVT application to the case project included extensive analysis, study and contact with experts in ITC being carried out as part of the research presented in this paper. Three main processes of the design phase of an AEC project will be presented in this part, as a sample intended to show the results of the study on the impact of CAVT in the AEC industry. An adaptation of the IDEF0 method showed in Figure 1. will be used to model processes supported by an AEC project organization, with the following considerations: (1) the output of a process can become the input of another process, (2) processes representation is not time dependent.

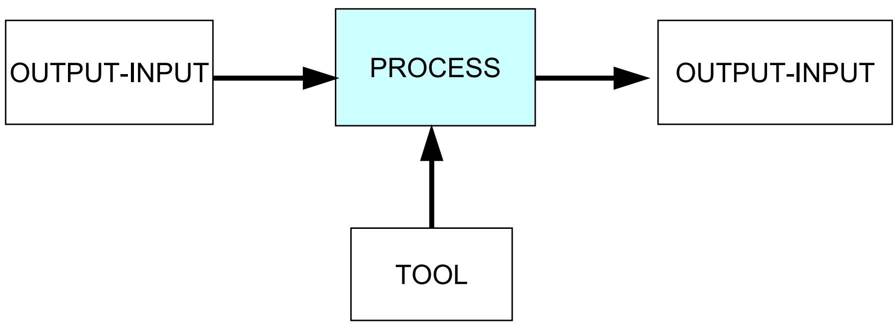

Figure 1. Adapted IDEF0 for processes representation

6.1 The digital reality in practice

Figure 2, shows a simplified sample model representing the following three main processes studied in the case project during the design phase:

- 3D Modeling Design **(A)**
- Constructability **(B)**
- Construction Planning and Scheduling **(C)**

The model correspond to the status of the project before enlarging the application of CAVT to 4D modeling and Visual Simulations of erection and assembling tasks. As can be seen, processes **(B)** and **(C)**, were not using and even taking full advantage of the 3D modeling design process. There are numerous players involved at various intervals throughout the life-cycle of the project, all adding and retrieving information. However, even today, in the midst of one of the greatest information revolutions in history, much of this work is still done manually (IAI, 97) using paper based documentation (i.e. 2D drawings). This is not the situation in the case project. CAVT are used in case project, in the form of 3D CAD modeling and visualization tools for the design phase of the project. Despite the project is not taking full advantage of CAVT, the product modeling effort resembles the digital reality approach presented in this paper, and is providing the following benefits to the project:

- Improved design development process
- Enhanced Interdisciplinary coordination during design
- Superior material quantities control
- Zero interferences intended to save construction costs
- Improved communication and compliant with client requirements
- Verify maintainability and operability

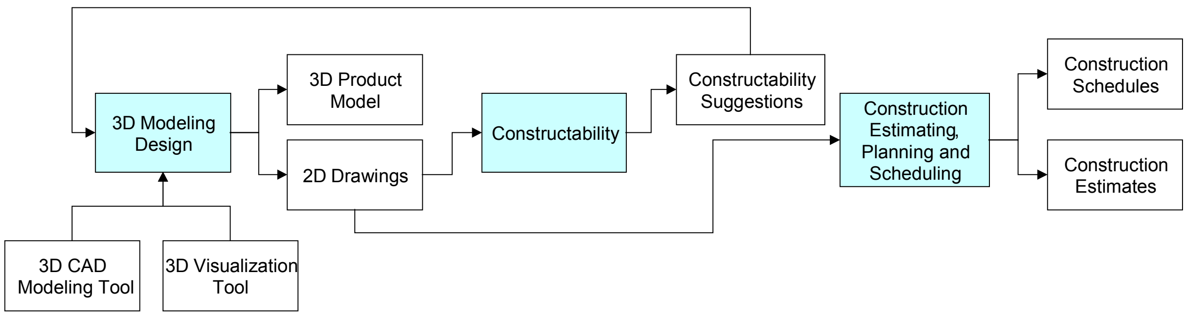

Figure 2. Processes organization– Existent approach

6.2 4D Modeling and Simulations – Enlarging CAVT

Figure 3 shows a new model of the processes from the case project presented in this paper, after the application of 4D modeling and Visualization Tools to simulate structure erections and equipment assembly, enlarging the CAVT application on the project. This new model shows how processes (**B**) and (**C**) become supported completely by CAVT.

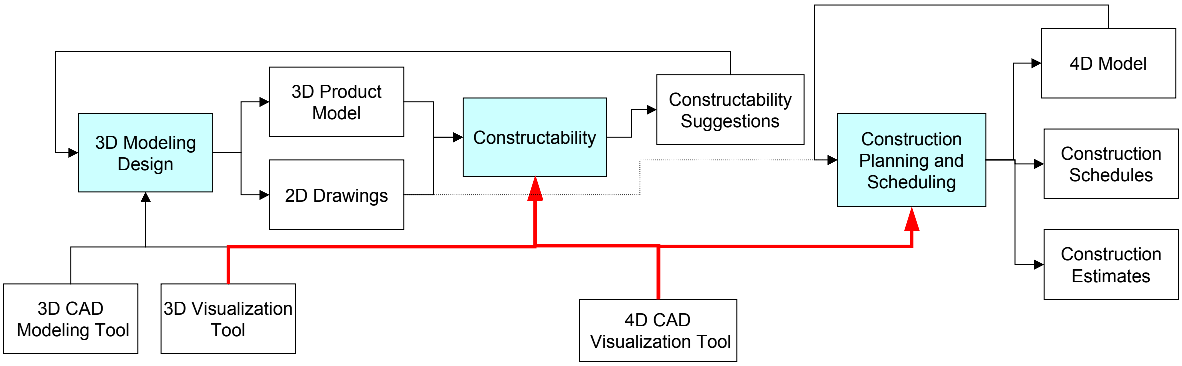

Figure 3. Organization Processes – Improved approach

Introduction of 4D modeling and Simulations to the project, was carried out by the construction department as a *new activity*. Huge benefits are expected for the construction stage of the project, and the design phase of the project also obtained direct benefits by the enlargement of CAVT application on the project. The main benefits of CAVT application enlargement to the project are presented as follows:

- Construction Planning and Scheduling tasks supported by 4D modeling and simulations led to realistic and more detailed schedules. Construction people discussed planning and scheduling issues around the 4D models visual environments. Even though new schedules were larger than before, bar charts from the scheduling software were rarely reviewed or even printed. Every activity and element in the 4D models was easily named in construction terms, and using filtering features from scheduling software, it was easy to find activities to be modified in an interactive and iterative process of planning and scheduling using 4D models and simulations in daily sessions.
- Constructability reviews became a logical consequence from the planning and scheduling efforts supported by CAVT. While planning the construction sequence visually, constructability suggestions aroused in a natural way. This lead to an improvement in the quality of constructability suggestions and even to the detection of issues that probably would have not been detected if only supported by 2D drawings.
- Communication of constructability issues to design people improved dramatically through the use of 4D models. This lead to an incremental gain in Design-Construction Process Integration.
- Complete correlation of the Construction plan with the Design and Engineering model was attained.

6.3 Organizational structures

The facility delivery schedule for a project, depends on the details of the Product, the methods used in the design and construction Process, and the design and performance of the development organization (Kunz et al, 99). The enlargement of CAVT from 3D to 4D and use of Simulations was not originally contemplated for the case project. Even though the methods in the design and construction process were improved, the original organization proved to not be prepared to take advantage of the tools and improve performance.

Coordination mechanisms were difficult to implement between the *new activity* in the construction department and the rest of the activities on the project. The *new activity* was not only new in the sense that it had never been used on the project before, but it was novel to almost all the people involved in the project. Something similar occurred with the Dependencies mechanisms for the *new activity,* which was difficult to relate with the rest of the activities using existing dependency relationships on the project.

Extending the organization definition from being an aggregate of individuals each responsible for defined tasks (Kunz et all, 99), to its processes and their dependencies and coordination mechanisms (Malone et al, 99), it can be noticed that current organization for the case project constituted an obstacle, rather than a facilitator for the efficient application of CAVT.

7. CONCLUSIONS

CAVT has been defined in an evolutionary context in this paper, which should not restrict their application to a particular tool, but instead should leave open doors to embrace new CAVT as they appear. CAVT allows one to visualize the geometric part of an AEC project, as well as Visualization of the information of a project. CAVT are a reality now and the AEC industry is not yet taking full advantage of them. CAVT advance is vertiginous. If we are not taking advantage of them now, how will we take advantage of new CAVT arising constantly? And how will we participate actively in its development?. This research has provided important insights coming from a closer approach of academic community and AEC practice. This approach encouraged in the future should bring benefits about not only the impact of CAVT, but IT research and application in the AEC industry.

The impact of CAVT in the AEC industry is related to integration and collaboration improvements, which will lead to better, cheaper and faster ways of developing AEC projects. The main impact of CAVT goes beyond current well known improvements, to a new unsuspected pace for improvements in the AEC industry. How soon will we embrace CAVT, not half-heartedly, but in the way that has been presented in this paper is an uncertainty.

Power and Process industry is an engineering and construction sector which we should be more aware of, it has a lot of similarities with the rest of the AEC industry, and we should take advantage of its advances using a benchmarking process approach. Some Engineering and Construction companies have accomplished significant advances in comparison to the rest of the industry using CAVT. They have not, however undertaken the subject in a fashion that would allow them to take full advantage of CAVT. In the future, some of these companies may retain their leadership position, while others will lose it to new and perhaps smaller companies who could transform radically to fully assimilate CAVT application in the AEC industry.

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