ENVISIONING THE FUTURE: BUILT, NATURAL AND DIGITAL ENVIRONMENTS

Leonardo Rischmoller
School of Construction Engineering, Faculty of Engineering, Universidad de Talca, Chile

ABSTRACT: The paper will discuss how the forces and opportunities of change strongly related to the evolution of computer model-based design and construction are not only driving progress in Civil and Environmental Engineering (CEE) through a transition process but promise to advance the state of the profession through the emergence of completely new paradigms. Computer model-based design and construction will not only deal with the utilization of new tools to improve existing work processes, but with the emergence of completely new ways of doing things which will have to be designed, invented or discovered.

The paper introduces the Digital Reality, The Digital Built Environment and The Digital World concepts and summarizes how we make and use the built, natural and digital environments and how they interrelate. The paper also envisions actions that shall promote the extension of current research contributions by strengthening the overlap of research and teaching with computer, social and management sciences in order to address the scientific, engineering, economic, social and political aspects about how we design, build and operate the built, natural and digital environments and how to make their intelligent and sustainable use possible in an integrated comprehensive way.

1 INTRODUCTION

Construction Industry could be described as an activity that presents high levels of effectiveness, but low levels of efficiency. The built environment around us is the best evidence of the effectiveness of the construction industry. From the houses we live in and the offices and factories we work in, to the roads, railroads and bridges we drive on, and from the waterworks that keep us dry, to the gas, water, electricity and communication systems that comfort our lives, these finished construction projects testify every day about how through the times the different stakeholders participating in their conception, design and construction have achieved the goal of bringing the diverse constructed assets that form the built environment, satisfying the demands that communities of users place on them.

The efficiency involved in the construction of the built environment, is however something that has been importantly questioned by several academics as well as practitioners, especially in the last decades when every time more formal efforts to measure it have been developed. Taking the UK as an example, several reviews of the construction industry (Latham 1995 and Egan 1998, 2002) over the past ten years have challenged the industry to improve its efficiency as well as the quality of its output. Similar discussions and initiatives can be found in other countries than the UK. In USA, for example, while productivity continues to grow in most other sectors of the economy (manufacturing, finance, retail trade, and services) between 1968 and 1978, it was falling in construction (Allen, 1985).

This effectiveness-efficiency dilemma becomes more relevant as we progress into the 21st Century, and the construction industry faces an increase of the complexity of construction projects in terms of quality, functions, development processes and technical achievements and consequently its changing perception of interests and values.

In order to cope with this increased complexity, the construction industry is adopting (or developing) new techniques and technologies in the field of management, organization, collaboration, systems engineering, manufacturing and Information Technology. These new techniques and methodologies mean that we have to carefully consider not only how to implement appropriate management knowledge to address these techniques and methodologies, but also how the industry is structured and operates, and how it will respond to the risks and unpredictability in the new environments posed by forces of change.

When referring to Information Technology in Construction, these forces of change are strongly related to the evolution of computer model-based design and construction. Research about these approaches deal not only with the utilization of new tools to improve existing work processes, but with the emergence of completely new ways of doing things that will have to be designed, invented or discovered.

This paper presents ideas mainly labeled in three concepts (The Digital Reality, The Digital Built Environment and The Digital World) presented as what could be medium to long term research evolution about computer model-based design and construction. If we think that change is impossible we will not take charge of the future. This paper tries to envision the future and the changes that will come so that we can be aware and take charge of the future in the specific area of Information Technology in the construction industry.

2 CHANGES IN THE DESIGN AND CONSTRUCTION PROCESSES

Engineering firms devoted to the design of medium and large industrial projects lead a different way of doing things in design with more than two decades using digital product-modeling design tools and work processes. Systems like Integraph's PDS® (Plant Design System[1]) or AVEVA's PDMS (Plant Design Management System[2]) have led large engineering and construction contractors not only to change processes by putting some new technology to work, but the culture and leadership of organizations have been transformed and reinvented to fit with the irruption of these systems. In recent years new computer model-based capabilities has extended to demand from more sectors of the construction industry (e.g. Building Industry) the rising and formalization of new design methods and concepts, reconfiguration of supply chains, and the reaction of construction professionals and organizations to these new approaches. Building Information Modeling (Autodesk, 2002) Virtual Design and Construction (Fischer, 2006) and nD Modeling (Aouad et al, 2007) are examples of approaches that are leading performed-based design supported by product models to become the state-of-the art practice in building and design of all types of construction projects. Construction professionals are also increasingly taking advantage and contributing to the model-based design of facilities and their development processes and organizations (Fischer, 2006). In the ongoing quest to improve project planning and anticipate field problems before they occur, a growing number of construction professionals are using computer technology to build projects digitally before actual construction begins (Roe, 2002).

These changes occurring in the construction industry are decreasing the prevalence of the traditional document-based practice in many aspects of the design and construction work processes of construction projects. This is occurring not only in the automation of how things are carried out, but in the emergence of new ways of doing things that involve changing the relationship between many fundamental aspects of how and when construction projects stakeholders participate in the different stages of the projects, their relationship with the space in which their work is carried out, and the nature of the knowledge they use.

1 http://www.intergraph.com/pds/

2 http://www.aveva.com/products_services_aveva_plant_pdms.php

3 THE DIGITAL REALITY

The rapid advances in computing will allow, in the near future, not only the creation of virtual representations of construction projects, but indeed construction projects will 'exist' in computers like a Digital Reality (Rischmoller et al, 2000). 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 act intelligently 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 (Rischmoller, 2000).

The Aerospace industry has succeeded in transforming the real world that exists in the form of paper, in engineers' minds, and in computer files into a visually available digital reality representation in a computer. The Boeing 777, is for example, referred to by the Boeing Company as the first paperless aircraft in the sense that it was purely defined in a digital form before the start of construction (Onarheim, 1999).

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. However, if prizes were awarded for best oxymoron, virtual reality would certainly be a winner (Negroponte, 1995). 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. The level of detail and realistic views that 3D product models that can be achieved by using Computer Advanced Visualization Tools (CAVT), and that will be achieved in the near future, lead us to state that 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 (Rischmoller et al, 2000).

The 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, collaborative 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. Widespread use of CAVT allow us to 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+X (X = time, cost, etc.) Models, which may include scope and cost beside time (Staub and Fischer, 1999). 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 could emerge, transforming the way

AEC/EPC projects are developed even today with the "widespread" use of information technologies.

4 CONSTRUCTING DIGITAL REALITIES

Designers will develop digital realities and contractors will need to construct these digital realities, both of which can be done digitally before going to the job site. 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 1998).

The construction industry relies on processes, of varying complexity to accomplish every task with which it is related. 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 et al, 1991). 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 et al, 1996).

Within the computer graphics and visualization context, in the last few years 3D modeling has reached a high level of development in the AEC/EPC 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. Constructing digital realities digitally before, during and after construction projects are designed and materialized shall narrow the degree of uncertainty existing in the past at the job site. Construction management tasks shall be transformed so as to have no resemblance to anything we know today.

The Digital Reality will not only alter what happens at the jobsite, but shall alter dramatically how we currently deal with construction projects. Creating a Digital Reality instead of designing a project, and constructing projects digitally into the computer before going to the jobsite will redefine the current large-scale integration of design, construction, and other facility lifecycle concerns which will not happen only largely in the minds of professionals and may therefore be slow, incomplete, inconsistent, and error prone, but will occur in new digital environments.

Some of the changes envisioned due to the availability of construction projects as Digital Realities will be related to: (1) Stakeholder requirements and multi-disciplinary decision-making available at the forefront and visible; (2) facilitation of the recognition of life-cycle costs over short-term economics savings; (3) new design and construction methods that will naturally go beyond functional needs, cost effectiveness, and life-safety protection to include the natural and social environment as stakeholders of equal importance; and (4) new design and construction work processes that will meet project objectives and extend methods and tools to include social and environmental concerns and embrace and integrate multidisciplinary, multi-stakeholder interests to make the construction phase more sustainable.

5 THE DIGITAL BUILT ENVIRONMENT

Each construction project combines concerns and information from professional and other project stakeholders, lifecycle project phases, and economic, environmental, and social contexts in unique ways that need to be integrated for its successful realization (Fischer, 2006). As we progress into the 21st century the increasing complexity of construction projects (in terms of quality, functions, development processes and technical achievements) is being coped adopting (or developing) new techniques and technologies in the field of management, organization, collaboration, systems engineering, and Information Technology. All these efforts are mainly oriented for tackling every construction project individually and are far from trying to undertake the relationships and interactions between the different projects that form the built environment.

While the real built environment is made of several distinct kinds of construction projects, adding or grouping individual Digital Realities belonging to common geographical locations can lead to the "construction" of Digital Built Environments. However problems related to hardware and software compatibility and standardization, interoperability, work processes, cultural and economic aspects will have to be resolved before achieving the massive emergence of Digital Built Environments.

Working with construction projects as individual Digital Realities shall contribute to have a new generation of economically efficient, performance-based and environmentally sensitive individual facilities. However, working with groups of construction projects existing truly in real life but also 'existing' digitally (e.g. as built) within a computer shall contribute to the development of unexpected improvement of ways to simulate the creation, management, maintaining, and renewal of society's infrastructure within a Digital Built Environment, placing assessment and design of the built environment more squarely in its social and environmental context through scientific, transparent analyses.

The built environment forms a long-lasting, slowly evolving artifact with long term impacts, usually much longer than the initial brief, and linked to social, cultural and economic change, involving social, psychological and physical interaction between individuals, groups and constructed assets. In this sense the Digital Built Environment shall also unreel itself beyond short term design and construction goals to include the overlap of research and teaching with computer, social and management sciences in order to address the scientific, engineering, economic, social and political aspects about how we design, build and operate the built, natural and digital environments and how to make their intelligent and sustainable use possible in an integrated comprehensive way.

The National Engineers Week Future City Competition[3] is a sample of "primitive" Digital Built Environments existing today. This competition asks middle-school students, working in teams with a teacher and a volunteer engineer mentor, to create cities of tomorrow, first on computer and then in large tabletop models. These cities are created assembling a Digital Built Environment using SimCity[4], a simulation and city-building personal computer game, first released in 1989 and designed by Will Wright. In the game you can take on the roles of Mayor and City Planner as you design and build an entire city. A map can be chosen and then zone residential, commercial, and industrial areas. Roads and railways, police and fire stations, parks, stadiums, and more can be installed. And it also includes crime, pollution, fires, tornadoes, and other features to deal with, while you manage your town, restricted to keep a balanced budget.

Activities different from construction are already using in real life situations what started as computer games. At the Faculty of Medicine, University of Calgary, for example 3D and 4D Bioinformatics is being used to elucidate the causes of genetic disease using visual data exploration. These technologies are enabling them to analyze spatio-temporal patterns in genomic data and model this data (as well as the effects of change in data) in a virtual reality atlas of the human body or virtual reality atlases of other organisms. This exciting initiative uses the world's first Java 3DTM-enabled CAVE® (CAVE Automated Virtual Environment - developed at the COE) as a visualization tool for Bioinformatics research and development. In construction the media lab at Alborg University, Stanford University CIFE facilities, the Think Lab at the University of Salford and the Computer Analysis Visualization Environment (CAVE) already being used by the design-build contractor Parsons Brinckerhoff (Sawyer, 2006) are clues that convert the Digital Built Environment concept from not only merely speculative but a medium to long term reality in the construction industry.

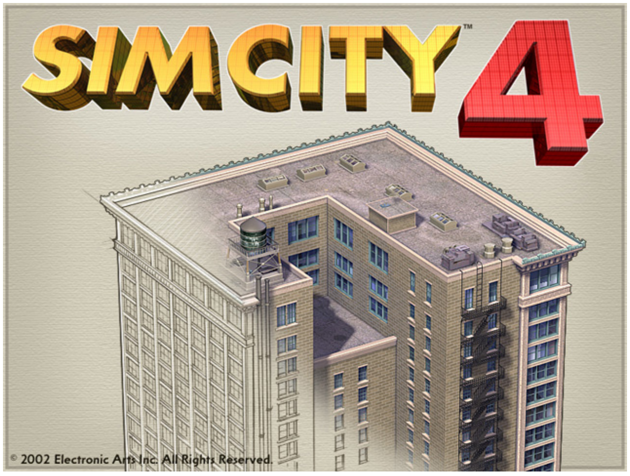

Figure 1. SimCity Digital Building Screenshot (http://simcity.ea.com/).

6 THE DIGITAL WORLD

It is expected that in the future age of Petabytes and Yottabytes and the next new generations of computing devices, not only the Built Environment will be able to be constructed digitally. Both the natural and built environment will 'exist' into a Digital World that will allow humans to improve providing the necessities for human life and civil societies, including energy, shelter, food, water, and air, and the infrastructure for commerce in more efficient and renewable ways than today. The Digital World will help to address the scientific, engineering, economic, social, and political aspects in an integrated and comprehensive way, sustaining the environment and the natural cycles of which life depends.

In a Digital World not only built but also natural environments will be considered. With the currently available computing technology, not just physical structures, but also landscaping elements such as trees, foliage and water (which are still quite rudimentary and do not convey a real-world feel) are part of alternate virtual reality worlds (e.g. Second Life, www.secondlife.com) where more and more people have a second "life" in Internet. Objects can be imbued with physical properties so they respond to gravity, inertia, propulsion and wind from the weather system in second life virtual reality worlds (Khemlani, 2007).

Second Life, a 3-D virtual world entirely built and owned by its residents which was opened in 2003 and has grown explosively to reach a total of 6,647,675 people from around the globe inhabiting its digital and "natural" environments is a sample and a trace of the advances that will come when construction projects stakeholders' developers become interested in create or participate in these digital environments not only from a leisure but from a professional perspective. For example, collaborative creation, where the same set of objects can be constructed with several other users, at different times or simultaneously are existing functionalities in virtual reality worlds over the Internet that are being exploited only for leisure by common people around the world. These and other functionalities related not only to artificial but also to natural environments "existing" digitally into a Digital World will surely alter dramatically the way humanity address scientific, engineering, economic, social, and political aspects, sustaining the environment and the natural cycles of which life depends.

7 USING BUILT, NATURAL AND DIGITAL ENVIRONMENTS

In construction, the ultimate 'proof' of the value and soundness of a formalized concept or method is in its application in practice (Fischer, 2006). In this sense, construction sites and project offices should be the better research laboratories where new methods, concepts and knowledge should be proved. It is well know, however, that the rush and problem solving nature of the work at construction sites makes them hostile environments to carry out formal and ideal research projects where particular factors can be isolated to study their effect in pro-

[3] http://www.futurecity.org/home_intro.shtm

[4] http://simcity.ea.com/

ject outcomes. Digital Realities, Digital Built Environments and Digital Worlds massively available shall lead to overcome these limitations, impacting in how research in construction is carried out today.

Figure 2. Second Life Online Digital World (www.secondlife.com).

This impact could for example, finally lead to the end of the era of drawings as the main medium of storage and communication of construction industry information due to new ways to carry out design, build and operation of construction industry projects based in the interactions (e.g. simulations) among built, natural and digital environments. Another impact could be related with objects that, in reality, are interconnected by nature making it difficult to manipulate them once they are placed. These objects could replaced by objects in digital environments connected in models developed by experts, where they could be manipulated in ways that are not common today, extending current research contributions. Digital environments shall promote the development and application of research thinking within construction projects environments, linking industry and academia, and transforming ideas and information from research into practical solutions, contributing to research, education and practices that will produce new technologies, methods and leaders needed to create a truly sustainable, global built environment.

Digital environments could lead research and practice to go beyond current underlying assumptions and expose them to broadly based critical scrutiny. The built environment continues to be fragmented, under-resourced and explored from the limited perspectives of individual disciplines or interest groups within the construction / property industry. Using built, natural and digital environments shall contribute to reverse or diminish these problems dramatically.

8 CONCLUSIONS

According to Alvin Toffler (2006), much like during the industrial revolution, we are transforming again the way in which human beings work, play and think. The construction industry, even lagging behind the rest of most of the industries, is not unaware of the forces and opportunities of change leading this transformation. The Digital Reality, Digital Built Environment and Digital World concepts introduced in this paper constitute an important part of the forces and opportunities of change driving progress in Civil and Environmental Engineering not only through a transition process, but that promise to advance the state of profession through emerging new paradigms.

It seems that there are larger amounts of people and institutions that are grappling with the same overall concepts and ideas presented in this paper than in the past. Added to this is the existence ever increasing of power-users rolling ever larger amounts of data into digital design and construction models who are finding that getting the right data at the right level of detail, and presenting it well-purposed for the task at hand is the key to gaining value in implementation in large and small construction projects (Sawyer, 2006). These trends are clues that make us envision that the digital reality, digital built environment and the digital world concepts presented in this paper are more than mere speculation, but a plausible medium to long term reality.

When information becomes more than just support, the logic that regulates production and goods interchange does not apply anymore (Toffler, 2006). It is clear that the digital reality, digital built environment and digital world concepts described in this paper go beyond acting merely as support in construction, but promote a greater unity and more rapid renewal of relevant broadly based explanatory frameworks related to the built environment, providing new insights and understanding for application in practice, education, and policy development.

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