INFORMATION TECHNOLOGIES IN CONSTRUCTION: A PERSONAL JOURNEY

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ABSTRACT: The paper presents an informal summary of one person's journey of four decades in the field of using information technology in civil engineering and construction. This survey is not followed by any prediction of the future but, less ambitiously, by a list of issues to be addressed so as to face the future with confidence.

1. INTRODUCTION

This Workshop comes exactly 40 years after I took my first computer programming course. This coincidence prompts me to use this occasion to sketch my personal journey in the application and adaptation of information technologies to the construction industry, and to summarize my observations. I illustrate this journey with the aid of the wonderfully accurate contour map, *Integration of Construction Computing Islands*, kindly provided by Matti Hannus (Hannus, 1996).

As an engineer involved in design research, I would expect that analysis be followed by synthesis; as a knowledge engineer, I would expect that diagnosis be followed by prognosis. Therefore, I would expect an examination of the past to lead to projections and predictions of the future. I refrain from doing so; I have a dismal, documented record of making predictions that did not materialize and not predicting momentous changes that did occur (Fenves, 1971; Fenves, 1983). Therefore, I conclude more modestly by sketching some of the key issues that must be addressed in order to face the future with confidence and a degree of unity.

2. THE PAST: A PERSONAL JOURNEY

2.1 The 1950's

The period 1956-1960 was one of very rapid development for computer applications in civil engineering and for me personally. For my MS thesis, I wrote a machine-language program for what later became known as fully-stressed design (Fenves, 1958). On a summer job, I wrote my first production program, in assembly language, for the analysis and detailing of reinforced concrete bridge piers. At the request of Professor Nathan M. Newmark, I became Secretary of the newly formed Committee on Electronic Computation of the Structural Division of the American Society of Civil Engineers (ASCE), and served on the Program Committee for the first two ASCE Conferences on Electronic Computing (ASCE, 1958; ASCE, 1960). Lastly, I began to teach a course on *Computer Methods in Civil Engineering* while still a graduate student.

2.2. The 1960's

Upon completing my PhD in structural dynamics in 1961, I was looking for something meaningful to do. On a consulting basis, I had written a number of frame analysis programs, carefully reusing my subroutines, but without much generality. By the beginning of the 1960's, there were several fairly general matrix structural analysis programs, but they required tedious numerical input and were geared to very large problems motivated by the aerospace and defense industries. I knew I wanted a program as general as possible, with decent user input, and one that would solve small problems as efficiently as large ones.

One of the momentous events in the history we are tracing was the appearance of Professor Charles Miller's COGO (COordinate GeOmetry), a problem-oriented language by which a surveyor could communicate with the computer in a language, albeit stilted, that he or she would use in giving instructions to a colleague (Miller, 1961). That fired me up and I resolved to do "something like that" for structural engineers.

I had the good fortune of teaming up with Dr. Frank Branin at IBM for a summer and together we developed a network formulation of elastic structural analysis, suitable to serve as a basis for a general analyzer of structures ranging from plane trusses to space frames, which we presented at the 3rd ASCE Conference on Electronic Computation (Fenves and Branin, 1963). We later found very similar formulations developed independently by Langefors in Sweden, Hall in Australia and Lind in Canada. Armed with this formulation, my colleagues R. Logcher, S. Mauch and I developed STRESS (STRuctural Engineering System Solver) in 1962-63 (Fenves et al., 1964). STRESS became commercially available on the IBM 1130 and the CDC 1604 and quickly began to penetrate the structural engineering community. One of my colleagues characterized the impact of this development as "STRESS made the cost of analysis irrelevant in making design decisions". STRESS and its successor, the STRUDL subsystem of the ICES system, set the tone for structural analysis programs well into the 1980's.

While I was at MIT in 1962-63, the first time-sharing system, Project MAC, was introduced (Corbato et al., 1962). My colleagues and I asked its developer what it was to be used for. His reply was: "for rapid debugging of batch programs". We looked at each other, went back to our offices, and in short order produced a time-shared version of STRESS, with commands interactively interpreted and completed or corrected by the user as needed until the SOLVE command caused the analysis proper to be executed.

Still in the 1960's, I made a lateral move within "Engineering Design" and a first bridge to "Construction" on Hannus' landscape. In writing my book on *Computer Methods in Civil Engineering*, I came across decision tables (or tabular decision logic) as a concise representation of collections of if-then rules (Fenves, 1967). In 1966, I presented a paper at the 4th ASCE Conference of Electronic Computation on the tabular representation of design standard provisions (Fenves, 1966). This was the starting point of standards processing, an area of information technology that has been active since then, but which did not produce an impact comparable to that which our work achieved in analysis. In a previous paper, my colleagues and I have speculated on the reasons for this mismatch (Fenves et al., 1995a).

In 1967, my late colleague L. Richard Shaffer and I developed, as part of a technology transfer demonstration project, a time-shared system providing STRESS, COGO and a comprehensive construction planning, monitoring and accounting system to practicing engineers and contractors (Froemming and Fenves, 1969). The three applications were not integrated, but the support facilities for communication and data management were fully shared. This temporary "floating bridge" did not outlast the project, but did serve as a model for a number of commercial timesharing services for the construction industry.

2.3. The 1970’s

After moving to Carnegie Mellon University in 1972, I began to undertake a series of fruitful collaborations with colleagues in the Department of Architecture that are still continuing. In particular, my colleague Charles Eastman and I began to build the foundations of a causeway intended to link engineering and architectural design. The major concern of the decade was database management, and we made several steps towards conceptual data models that used spatial information as a “glue” to link non-spatial information of interest to architects and engineers (Eastman and Fenves, 1978). This causeway eroded to the point where it does not show up on Hannus’ landscape, largely because relational databases and primitive “objects” associated with CAD systems respectively satisfied the immediate needs of engineers and architects working on isolated islands. For the majority of organizations and cooperative ventures, the “DXF-ferry” on Hannus’ map was sufficient to provide whatever interchange was needed.

2.4 The 1980’s

The first half of the decade was the era of expert systems and knowledge-based design, prompted by the general interest in bringing AI technologies into all application fields, including construction. Among other explorations, my student and subsequent colleague, Mary Lou Maher, and I produced HI-RISE, a KBS for generating structural configuration designs (Maher and Fenves, 1984). My other student and still a colleague, Jim Garrett, and I combined standards processing and knowledge-based design to produce SPEX, a KBS for standards-compliant design (Garrett and Fenves, 1987). Both of these systems had strong influence on the research community, but neither had the comprehensiveness and ruggedness needed to be used directly in practice.

The middle years of the 1980’s witnessed two internal developments at Carnegie Mellon University which have had a strong bearing on the journey. In 1984, the Department of Civil Engineering established Computer-Aided Engineering (CAE) as a distinct specialization area for graduate study and research, dedicated to the study and control of engineering processes with the same rigor that our colleagues apply to the study and control of phenomena (e.g., earthquake effects or groundwater contamination). Then in 1986 the University established the Engineering Design Research Center (EDRC), an interdisciplinary center addressing design across all engineering domains, sponsored by the National Science Foundation. These two events provided a direct focus for our efforts and brought us in close contact with like-minded colleagues in other engineering and allied disciplines, from whom we learned a great deal.

In the period 1986-1991 my colleagues and I embarked on a pilot project sponsored by EDRC, the Integrated Building Design Environment, that was intended to chart the “terra firma” that may link the isolated islands of architecture, structural and foundation engineering, and construction planning. IBDE combined seven expert systems into a tight, vertical integration. IBDE was intended to be an experimental testbed, not a prototype of a production system (Fenves et al., 1984). Within that constraint, IBDE served its purpose of sketching some of the surface features of the large valley connecting the three peaks.

2.5 The 1990’s

In the present decade my colleagues and I have continued to explore the emerging landscape of the "Coastline of the 2000 Building Product Model" shown on Hannus' landscape. The distinguishing feature of our work is that we are primarily concentrating on the early, conceptual phases of building design, where most of the critical design decisions are made, where collaborative exploration by project participants of alternatives is most fruitful, and where tradeoff between objectives and constraints of individuals participants can be best resolved (Fenves et al., 1995b).

3. TOWARDS THE FUTURE

What of the preceding narrative is relevant to the future? Or to the theme of the Workshop, *Construction on the Information Highway*? I will attempt to present some personal reflections on some key issues we need to address in order to face the future with confidence.

3.1 What is in a name?

Professionals, as other people, like to characterize themselves and their field of endeavor by short, meaningful names. Self-identifications such as "I am in structures" or "I am in soil-structure interaction" quickly characterize a professional within civil engineering. What is the name of our endeavor? I mentioned above that in 1984 we designated our specialization area in civil engineering as Computer-Aided Engineering. That was not a particularly fortuitous self-designation. We did consider the term Computer-Aided Design, a well-accepted term in Electrical and Computer Engineering, but rejected it because in our view it only focused on one engineering activity or process, and because the acronym CAD seemed to be pre-empted by Computer-Aided Drafting. A term that has surfaced since, "Computational Science and Engineering", is by contrast too broad.

The term "Use of Information Technologies in Construction", the motto of W78, is too wordy, and the passive word "Use" disguises the fact that the available and applicable information technologies invariably need to be adapted and extended to serve any application field, such as construction. The German term "Bauinformatik" probably captures our collective activities the best, but is untranslatable into English. These are not idle musings; the existence of a distinctive and descriptive term is one of the manifestations of a mature discipline.

3.2 Language of discourse

If we are to be recognized by our peers, we must describe our work in a form that is respected, particularly in academic circles. It is a sad fact of life that, in engineering at least, academic respectability is based, first, on attributes of mature disciplines and, second, on established formalisms of the physical sciences of mathematics. Mathematical models using, say, fourth order partial differential equations seem to be automatically treated as more rigorous than models using algebraic equations only. If you don't use equations at all, as in this paper, you are immediately perceived as being "soft". Again, these are not irrelevant academic self-examinations.

For external respectability, and even more so for internal communication conciseness and expressiveness, we need to develop and collectively subscribe to a "language" of nouns and verbs or, mathematically, operands and operators, that can rigorously describe what we do. That is an absolute prerequisite for orderly growth, and for the prevention of needless duplication and re-invention. My colleague, Nick Perrone, has stated the problem succinctly 30 years ago: "In every other discipline, each generation stands on the shoulders of the preceding one; in computer applications, we are all stepping on each others' toes". The situation has not improved much in the intervening years.

3.3 The role of IT research

Whatever terms we use to describe ourselves, we do share a common objective, which is to support and augment all participants in the construction industry, in the most creative and proactive sense, in the performance of their individual tasks and even more so in their synergistic collaboration, striving to design, construct and operate better constructed facilities in less time and at lesser cost.

The difficulty with the above statement of objectives is that it is too ambiguous or, conversely, not rigorous enough. Research leading to better understanding of cementation processes leading to "better" (e.g. more durable, faster maturing) concrete or better understanding of human physiology leading to "better" (e.g., more comfortable) indoor environments all contribute directly to the goal of "better" constructed facilities and, indirectly, to more creative and satisfying performance of the respective design participants involved.

The fundamental distinction that I see is in the kinds of knowledge that information technology research brings to bear on the shared objectives. The knowledge we contribute happens to be in the form of product and process models, tools and representations serving individual participants and teams in the construction delivery process. What does, or should, differentiate us from our colleagues in, say, concrete technology or human physiology is the nature of our research. This research should aim to establish a common shared "scientific" understanding of why product and process models are needed, how they are used and, most importantly, how constructed facilities and their delivery may be made "better" by the proper application of appropriate product and process models, both those presently available and those yet to be discovered.

3.4 Role of technology transfer

Lastly, to make a significant contribution towards the objective stated, we need to develop and invent a better mechanism of technology transfer. When one of our colleagues invents a new additive that makes concrete "better", the additive does not immediately go from the research laboratory to the contractors' product catalog. It is understood that there is a long research and development process until the new product has been improved, tested, approved and otherwise "ruggedized" for commercial production and use. What we lack most is a similar technology transfer mechanism whereby "laboratory scale" IT tools and representations are re-manufactured for production use. Until such a mechanism is put into effect, we will continue to step on each others' toes and will continue to see our bridges linking islands of automation wither and disappear.

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