A Dialectic of Process and Tool:
Knowledge Transfer and Decision-Making Strategies in the Building Delivery Process

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ABSTRACT

The building delivery process has traditionally been regarded as a discrete and sequential set of activities. This state of affairs is the result of a historical evolution driven by many factors, one of which might be the necessity to organize the activities for the purpose of establishing a professional fee structure that is commensurate with the scope of work and level of accountability or responsibility. However, within the context of rapid changing technologies, production processes as well as knowledge explosion, the existing framework no longer seems effective or capable of meeting the increasingly complex demands associated with the creation of the built environment.

The capabilities of decision support tools are expanding but they still fall short of anticipating or challenging the very logic of the rather static processes they are supposed to support. This paper examines the necessary conditions under which significant structural changes in the building delivery process can evolve and the related implications for future development of decision support tools. It also explores hidden potentials of existing tools and propose enhancements to facilitate effective knowledge transfer and process management.

Key Words

building delivery process; computer-aided design support tools; knowledge transfer; adaptive-iterative approach; tradition and innovation

INTRODUCTION AND BACKGROUND

Origins of the Building Delivery Process

The act of building can be seen as an integral part of the civilization process, and in a functional sense, an activity in response to man's basic need

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for shelter and protection from the adverse elements of nature. Created through processes of indigenous communal participation, the traditional habitats often demonstrate a remarkable sense of unity and clarity of implicit tendencies and/or explicit intentions within the relevant cultural context. Examples of such integrated habitats can still be found today and in some developing countries, they still represent the only mode of building delivery (Mahdavi 1989, Dunkelberg 1985).

With increasing differentiation in social structures and the distribution of resources (building materials, energy, *etc*) through improved communication and transportation systems, the building delivery processes have become overtly complex for any individual or single community to master and execute effectively. Therefore, specialist professional communities have emerged, in the attempt to assign due responsibility for contributing their specific knowledge. Whilst this might seem a rational step toward addressing the increasing complexity involved, it also inevitably and fundamentally transforms the originally integrated process to one of fragmentation and compartmentalization. This in turn necessitated the development of communication channels that have primarily focused on the exchange of documents that record ideas, decisions and perhaps most importantly, the stipulation of responsibilities amongst the parties concerned. The quest for more efficient methods has gradually evolved into a *circulus vitiosus* whereby advances in communication and dissemination technologies continuously struggle to cope with unprecedented rate of informational growth globally, while continuing (if not intensifying) the trend toward process disintegration.

Notwithstanding this general observation which applies to most established building industries in the world, the extent of its *de facto* manifestations in different communities can be as diverse as their traditional political and socio-cultural structures.

HOMEOSTASIS OF TRADITION AND INNOVATION

Prefatory Remark

There have been efforts to increase the efficiency of the application of information processing/management methods in the building delivery process. However, it appears that these tended to pursue incoherent and sometimes diverse directions. On the one hand, there is the growing concern and sensitivity of the "human element" in the process of delivering adequate built environments but lacking the resolve to systematically structure a process to realize the implementation pragmatics. On the other, there is the discipline and effective structuring of the process but insufficient integration of the human factors and long-term ecological concerns.

This incoherency may be one of the reasons why an initial euphoria in the professional community concerning the value and prospects of information technology was followed by a certain frustration. Thus, it seems appropriate now to develop an epistemological view of the potential and limitations of the novel information technologies and the conceptual problems of their integration in the building delivery process. It is critical for this purpose to understand the historical background and the nature of the complex forces and conditions that affect the development, introduction, and effective integration of new design/construction support tools. The search for new directions should reflect not only on marginal strategic advances in isolated areas of the building delivery process but in terms of an overall rethinking of the dynamic and complex conditions which regulate the evolution of the process and the emergence of tools.

Value of Tradition

Traditions represent important means of transfer of cultural information. In the context of building traditions, this statement has a twofold relevance:

- the code of building tradition contains essential information on environment (topography, micro-climate, *etc*) and resources (energy sources, availability and properties of building materials, *etc*) accumulated over long time periods. The environmental responsiveness of traditional buildings clearly demonstrate this point (Mahdavi, 1989).
- traditional building codes transfer also in direct informational sense significant cultural messages. In its double role as the context and the representation of inter-individually respected system of values, beliefs, and preferences, the built environment provides a spatial realization of explicitly formulated or implicitly existing sense of cultural identity (Lévi-Strauss, 1980a).

The Necessity of an "Iterative-Adaptive" Approach

It is well-documented that a total disregard of the existing building traditions has adversely affected the socio-economic fabric of many countries, particularly in the "developing" world (Mahdavi, 1989). These negative developments are commonly the result of drastic (often unprepared or ill-prepared) changes in the economical context and the structure of the building delivery process.

The detrimental effect of these changes lies commonly either in their past which often surpasses the maximum environmental/social adaptability rate or in their disintegrating effects on the underlying social structures.

The above reflections should not imply the "sacredness" of existing traditions or the undesirability of change. In fact, as it will be discussed below, a rigid adherence to the inherited traditions can occassionally negatively impact the problem solving process. What should be emphasized here is rather the necessity for careful cross-disciplinary preparatory studies, substantial modeling efforts and a feedback-sensitive step-wise realization of modification and restructuring programs in highly complex social communication/production systems. This careful strategy has been specified in human ecological terminology as an "adaptive-iterative" approach (Mahdavi, 1993a).

Tradition as Hindrance?

The importance of individual and collective learning processes for the cultural development is well established. However, in anthropological and ethological studies, references can be found regarding an occasional antagonism between learning and judicious behavior (Lorenz 1977, Lévi-Strauss 1980b). This phenomenon manifests itself in the inability to liberate oneself from certain behavioral patterns that have resulted from long-term training procedures. A sequence of actions may have initially evolved as the result of insight in some relationship patterns and their associated necessities. However, after numerous repetitions, this sequence might turn into an unreflected (quasi-automated) and, in a sense, irrational routine. As long as the context, in which the behavioral adaptation has occurred is unchanged, this sequence might function successfully. However, the slightest change in the context might result in a total collapse of the behavioral routine and thus jeopardize its rational problem solving capacity.

It is noteworthy that the lack of a rational approach behind the development of the human culture and its artifacts can be demonstrated even in engineering design domain where one usually expects a "hard-core" rational problem solving strategy.

This demonstrates the negative consequences of the fixation on existing solutions for the development of new, functionally more efficient designs. A similar rigid attitude can be observed also occasionally in the way design support tools are developed and applied. Conventional (widely accepted) application modi might retard the tool development process and hinder the exploration of the potential of the newly introduced tools.

In this context, it is worth noting that sometimes, significant discoveries are made by individuals who were not specialist in those fields. For example, the second law of thermodynamics was discovered by Robert Julius Maier who was a physician and not a physicist. The syphilis virus was identified by Schandinn who was neither a bacteriologist nor a pathologist but a zoologist (Lorenz, 1987). A building which for many architecture historians marks the beginning of modern architecture, namely the crystal palace in England was designed by Josef Paxton who was not an architect but a rail-way engineer. These observations help explain the valuable effect of inter-disciplinary cooperation in introducing novel approaches in dealing with design problems.

ON THE DIALECTIC OF PROCESS AND TOOL

Standpoint of the Hypothetical Realism

The relationship between the outside world and the various cognitive representations thereof is an old epistemological discussion. In particular the role and reliability of man's perception apparatus has been subject to controversial debates. In the context of a hypothetical realism, it has been emphasized that concurrent sensory information (*eg,* simultaneous visual and acoustical perception) principally does not contradict each other. This observation has been used as an argument for the existence of perception-independent extra-subjective reality. Furthermore, it has been argued that the cognitive apparatus can provide reliable representations of the extra-subjective reality because it is itself the product of a co-evolutionary process. In other terms, the mechanism of cognitive apparatus has resulted from and tested in the context of what it represents.

Communication, Consistency, and Evolution

The assumption of an extra-subjective reality as a common point of reference has been shown to be very effective in communication. It has provided a stable system of measures and proofs for regulation of inter-individual communication process including the comparative evaluation of various representations of reality. It appears that the conscious and "reflective" cognitive processes at the individual level (*eg,* in the course of problem-solving activities) derive their contributive significance toward collective design/production activities on the basis of underlying cultural frame of references. This implies a reduction of the theoretical degree of freedom at the individual level, since in order to achieve collective relevance, individual cognition must refer to an underlying system of insights/rules which possesses a higher level of inertia. It appears as though the collective "thinks" itself through (is "present" by) individual cognition. This collective frame of reference is a product of a co-evolutionary process in the course of which human society has evolved within an ecological context. This gives a picture of triple-evolutionary process with significantly different temporal dimensions and different degrees of freedom as well as levels of inertia.

Appearance and Survival of Tools

Given theoretically higher degrees of freedom at the individual cognitive process, technological innovations such as new information technologies may evolve continuously. However, the "survival" of technological innovations in developing more efficient tools in dependent on the degree of their dissemination and application. In certain cases this might be simply the ease of integration in the existing process. In fact, it seems that many tool-makers consciously try to minimize any structural interference with the procedure to avoid acceptance problems. The process in which new tools are meant to be integrated must maintain cross-individual and cross-professional communication and thus shows some resilience toward structural changes. Thus the somewhat improved tools are not necessarily introduced and applied in a manner that would take advantage of their true potential. For example, the introduction and/or meaningful application of innovative information technology tools into the building industry has suffered under an attitude that uncritically accepted the premises of the existing building delivery processes.

To exemplify this point, the predominant factor in the decision-making process in practice is still based on cost, more specifically initial or capital cost. However, building costs is not a good indicator of building value. Yet, traditional processes often ignore the operational and occupancy implications while emphasizing first cost despite the fact that tools are available for evaluating cost benefits of a performance oriented approach to the building delivery process over the life cycle of a project. It is well acknowledged that decisions at the early project phase can have significant impact on subsequent alternatives and design solutions. But the unwillingness to invest in preliminary investigative design studies in order to keep costs low would invariably result in remedial or even abortive work, thereby increasing the overall costs towards the end of the project phase. The range and nature of existing design support tools that are being applied in practice clearly reflect this scenario, whereby they are almost exclusively developed for the back-end of the design and construction process. It is therefore of strategic advantage in reassessing the relative importance of early conceptual design within the whole and to allocate adequate resource towards this stage of work, and to utilize the potential of computer-aided information processing tools to support a more comprehensive design/construction strategy.

Process and Tool Co-evolution

Most existing design/construction support tools demonstrate deficiencies caused by their rigid adherence to the structure of the existing building delivery process. However, occasionally tools have the *a priori* intention or the *a posteriori* effect of introducing new procedural alternatives. In these occasions and given "favorable" conditions (strong qualitative advantages of new tools, the dynamic logic of competition, insight in structural problems of existing processes, *etc*), a true co-evolutionary development can occur in that the critical evaluation of the shortcomings of the existing process implies the need for enhanced tools and the introduction of new technologies triggers reevaluation of and improvements in the existing structure and process (hierarchy, labor division, decision making process, economical and environmental orientation, *etc*). Significant qualitative progress toward advanced knowledge-transfer mechanisms in the building delivery process are not likely unless efforts are made to provide the necessary conditions for a positive co-evolutionary cycle of process and tool dialectic. Examples of these efforts are discussed below, focusing particularly on the design phase of the building delivery process.

Existing Processes and the Unexplored Tools Potential: A Didactic Example

To demonstratively explore the potential of existing computer-aided simulation tools to support the architectural design process, fourth year students in the Department of Architecture, Carnegie Mellon University, applied scientific analysis and quantitative data to conventional design processes in a design studio. Envelope design and daylight studies were the focus of the experiment. To go beyond the rather inefficient existing traditional methods of analysis, the computer was introduced as a design support tool by which design decisions could be quantitatively evaluated.

Students were initially given existing simple house layouts from which more detailed massing models and floor plans were created using CAD tools (Figure 1). Students assigned individual functions to the spaces and designed the building envelope taking essential lighting requirements into consideration. During the decision-making process, a daylight simulation tool provided quantitative feedback as to the visual performance of the actual state of the design. A second simulation tool was applied simulataneously to determine the hourly sun position as well as solar radiation intensities. Together, these two programs provided sufficient information to support the envelope design in terms of daylighting requirements (including appropriate shading strategies). It was expected that the students apply the resultant data or "feed-back" to their design processes and to make the necessary modifications until a satisfactory state of design was reached (Figure 1).

Due to the general attitude of students in most architectural schools, there is a certain degree of skepticism toward the use of rational decision-making support tools. This is partly due to the "schism" between design studios and the science/technology sequence. This lack of communication or integration leads to the situation where students perceive the act of design (as it occurs in the course of a design studio) and the process of knowledge transfer within the science/technology courses as separate and unrelated entities.

In order to counteract this perception, in the experiment described above, the notion of "enigmatic" houses was utilized. It was communicated to students that the sketches they received were from actual buildings designed by twentieth century master architects. However, the names of these architects and additional information on the buildings (*eg,* detailed plans, views, photographs, *etc*) were provided only upon project completion. This opened an indirect way (without formal "indoctrination" sessions) of communicating the message that technical design knowledge and the creative design act should not be seen as antagonistic issues. In other terms, the design studio was used as a motivation field to encourage the students to integrate rational means into their design processes addressing simultaneously issues of function, appearance and performance. This approach created a sense of "suspense" as the students were speculating on the potential deviation of their own solution as compared to the original solutions.

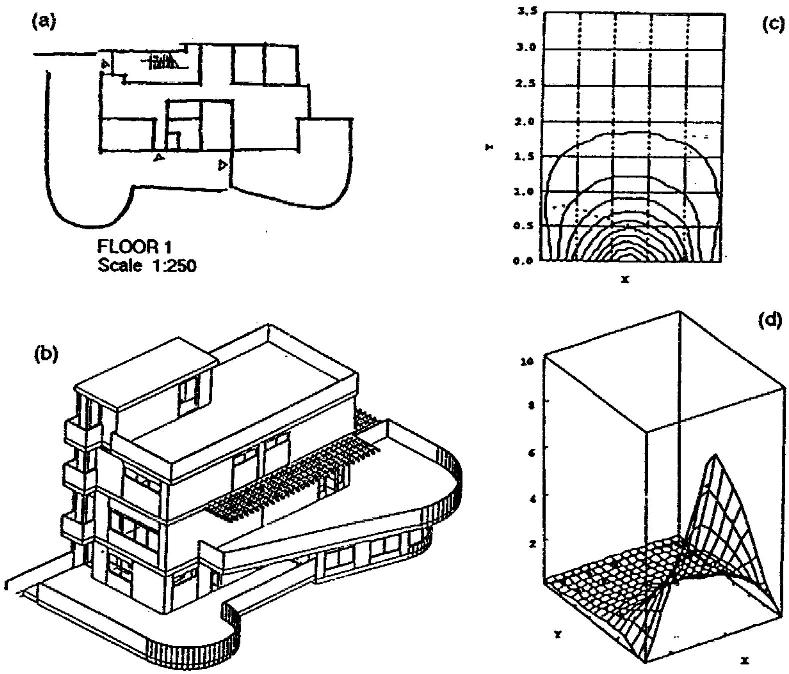

Figure 1. Sample of Studio Results
(a) A schematic plan of "Haus am Ruperhorn" by Brüder Luckhardt (1928) as presented to the students
(b) 3-D representation of one student's design (Stefan Grgurevich)
(c), (d) Graphic results of daylight distribution studies

Thus, although they were asked explicitly to utilize simulation tools, they did not limit themselves to responding to the predefined technical criteria but rather integrate those requirements into an overall sound architectural synthesis.

The students' comments show their understanding of the intention to use the simulation program as a support tool rather than as a design generator. Overall, they agreed that the exercise helped in enhancing their design functionality. Using simulation as a means to measure the design against "objective" evaluation criteria helps in decision-making and reduces the risk involved in a total reliance on intuitive design decision-making while maintaining the creative opportunities available along conventional design routes.

The use of computer support tools can also help in building "heuristic" knowledge. For example, students involved in this experiment commented that as their designs progressed and in the course of application of the simulation tools, they were able to develop an understanding or "feeling" of the interrelations of the relevant design parameter due to feedback provided by the computer-aided analysis tools. This not only made the program deficiencies tolerable, but allotted a more efficient use of time. Computer support tools, in this sense, serve the motivation for understanding the dynamic pattern of the design parameter. This motivation coupled with the opportunities of the integration of rational means of analysis into conventional design processes allows critical processes to be taught with multiple pedagogic effects.

Support tools are currently utilized around the accepted design process and standards, emphasizing a notion of design activity as the production of drawings and documents. Computers are not thought of as a tool to a more efficient design process as a whole. The current design process has seldom been creatively exposed to the innovative potential of computer-aided design support tools. As a demonstrative step in this direction, in the studio experiment described above, the focus was not the application of computers for the support of the conventional design methods. The studio approached rather a more holistic and innovative view in which issues of geometrical representation and drafting activities did not play a major role. Rather, parallel evaluation and feedback via the simulation programs encouraged innovative interaction modi with computer-aided information processing as the dominant design process support tool.

Innovative Processes and Old Tools : The CBPD Case

The demonstrative "Intelligent Workplace" project at CBPD (Center for Building Performance and Diagnostics, Department of Architecture, Carnegie Mellon University) has adopted and responded to the importance of a total building performance approach to the project delivery process (Figure 2).

The building is conceived as a "live-in laboratory" where effective integration of state-of-the-art building systems will be demonstrated. From the outset, a fairly exhaustive search for the most innovative building systems and their performance capabilities in US and Europe was conducted. Periodic brainstorming design sessions were held to explore various design potentials, involving leading researchers and practitioners from building related disciplines, utility company representatives as well as product manufacturers who are members of the Advanced Building Systems Integration Consortium (ABSIC), a university-industry collaboration based at Carnegie Mellon University. Such exercises have been beneficial in assembling a knowledge base of concepts, critical research findings on building and occupant related issues, and innovative building systems. The process also raised many pertinent questions, especially with regard to new ideas of system integration for better performance, energy and ecological conservation, and the need to evaluate these options at the conceptual stage.

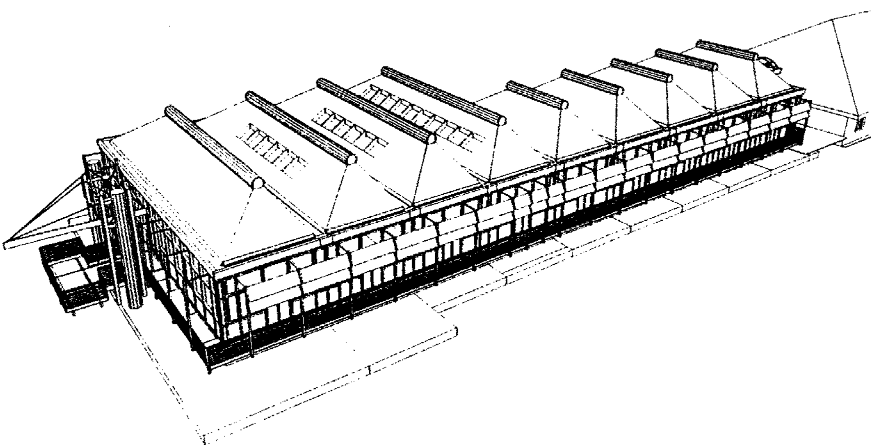

Figure 2. The proposed CBPD "Intelligent Workplace", a rooftop extension to an existing building at Carnegie Mellon University campus

In the evaluation and application of numerous existing design support tools, experience has shown that many of them are somewhat inappropriate and ineffective in supporting integrative design approaches. For example, it was proposed that a dynamic shading device should be provided as an integral part of the enclosure system, intelligently controlled according to daylight availability and illuminance requirements in the workspaces for the purpose of studying daylight-artificial lighting interface concepts. None of the lighting design simulation tools was able to model this design feature adequately. Another design intention was to determine the feasibility of natural ventilation under favorable external climatic conditions (rather than fully depending on mechanical systems for space conditioning). However, the energy simulation program used, namely, DOE-2 (one of the most comprehensive energy analysis tool available today) does not cater for the natural ventilation option. Interestingly, the genesis of the DOE-2 program itself reflects partially the bias towards the HVAC-based thermal conditioning practice in non-residential buildings in the United States.

Apparently, most existing simulation tools are principally developed for decision verification rather than conceptualization and generation of potential solutions (Mahdavi and Lam, 1991). They have been developed with the assumption that substantial amount of information is made available so that verification can be conducted. Hence, they cannot support conceptual design analysis where specific and detailed information may not be available. Routinely, information is accumulated throughout the design process. In other terms, the existence of an already comprehensive design model is prerequisite for starting the evaluation cycle using most existing simulation tools. However, the development of the design model itself cannot be supported by these tools. To address the inadequacy of tools in dealing with innovative building design processes suggested, concerted efforts have been directed at CBPD toward developing new computational environments. For example, in order to support an integrative notion of the building design process, a "multi-directional" or "open" simulation environment (as opposed to the conventional mono-directional approach) is under development (Mahdavi, 1993b).

EPILOGUE

As a collective activity, the building delivery process relies heavily on the effectiveness of communication structures and means. Initially, it was expected that the application of innovative information technologies would qualitatively enhance the information transfer processes within this process. This has not occurred, at least not to the expected extent. To facilitate better understanding of this circumstance, a critical review of the status quo and in-depth conceptual reflections on the complex relations between process evolution and tool development is presented. It is concluded that significant qualitative progress toward advanced knowledge transfer mechanisms in the building delivery process are not likely unless efforts are made to provide the necessary conditions for a positive co-evolutionary cycle of process and tool dialectic.

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