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Toward an Integrative Approach to Form and Process Design in Architecture

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Abstract: Technology is now changing architecture; in the emerging context, we see transformation in both process and product. The architect is now freed to create here-to-fore unaccomplished curvaceous form, additionally, new service areas are emerging in the information-age frontier marketplace. However, project delivery methodology is shifting from the traditional design-bid-build model, to an integrative collaborative design-build model where, often, the architect is not the project leader. Information technology, which refers to the use of electronic means to expand the limits of individual and organizational rationality, has traditionally been used to support the design process. A key characteristic of information technology is that, in addition to individual tasks, it can also support inter-task coordination, which is central to successful design. The intention of this study is to present a view of design based on 3 underlying functional elements: conception, development and implementation and propose a corresponding three-stage model of the design process. This model suggests a framework for the use of information technology to support the design process, further, this model supports the notion that proper coordination and communication among the design stages is central to the achievement of high quality in construction and a successful design process. The nature of the design process is dynamic and unfolding however, as design at each stage requires specialized knowledge and information from architecture, engineering and construction and any stage may necessitate the intervention of another stage for corrections, enhancements or revisions. As a result, continuous communication among the architect, the engineering team and the construction designer is central to the design process.

Key words: Design information, construction, process, design medium, architectural project, integrative approach

INTRODUCTION

Technology is now changing architecture, in the emerging context, we see transformation in both process and product. The architect is now freed to create here-to-fore unaccomplished curvaceous form, additionally, new service areas are emerging in the information-age frontier marketplace. However, project delivery methodology is shifting from the traditional design-bid-build model, to an integrative collaborative design-build model where, often, the architect is not the project leader. We now see a diminution of the architect as fiduciary-agent for the owner and certain unknown risks are inherent in the emerging impact of technology in architecture. Thus, in the context of technology disruption and increasing specialization, the architect must clarify practice values and professional ethics as a prerequisite to evaluating contemporary vision and mission.

During design, when products are symbolically represented, designers employ support technology only. In that process, implementation technology is a series of assumptions that will not be tested until the construction starts. Before the construction, designers rely on available information, on their own knowledge and on the knowledge of specialists in order to make assumptions and abstract designs on how the product will be constructed. If common, matured technology is chosen, no special emphasis is given to study and document in detail the construction process or the construction materials and their properties. However, if the design proposes new or special construction techniques or materials, careful planning and detailed design are required. In such a case, the design of the construction becomes an inherent part of the design itself. In either case the constructability of the proposed design depends entirely on the assumptions of the designers during the design process. The right assumptions on the implementation technology during the design process improve design efficiency significantly, while they resolve implementation issues early in the design process. On the other hand, incorrect assumptions about the existing implementation technology can easily deteriorate the design process into a utopian exercise.

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The transfer of information from design to construction is carried out by drawings, specifications and sometimes models. Information technology opens new horizons in linking design with construction and facilities management. At a first step of automation, the drawings, specifications and models can be provided in an electronic form for facilitating access, inquiry and search. Subsequently, as long as this information of the design documents is electronically available, it can also automate the manufacturing of components and their assemblies. Thus, ICT can be employed for both support of the design process and the implementation of the design.

Contemporary project delivery methodologies, interfaced synergistically with evolving technology, are enabling the reconnection of design and construction industry disparate factions into a cohesive knowledge network. Information technology is empowering architectural firms in the areas of communication, management, organizational structure, building modelling (both representational and simulation) and creation of complex geometry for innovative sculpturesque forms. Architectural design is being transformed from the traditional segmented linear design process, which focused on the physical building artefact and autonomy of the designer, to a holistic life cycle process which decomposes design autonomy into a collaborative team with bi-lateral knowledge exchange between owner, architect, engineer, design specialist, builder, craftsman and machine resulting in Integrative-Architecture.

ICT IN ARCHITECTURE-GENERAL ASSESSMENT

The research indicates that we are at the threshold of a disruptive period in the design process, further, the general impact of ICT in architecture cannot be assessed at the elemental atomic level, or isolated islands of the traditional process of architecture (i.e., drawing production or modelling), rather a comprehensive generalist assessment is necessary to gain meaningful insight into long-term evolutionary trends in architecture.

Early 20th century architectural theoreticians (i.e., Gropius and Le Corbusier) promoted adoption of technology in architecture. This was in blatant contrast to many 19th century architects who, in general, were suspicious and sceptical of technology advancements in architecture. Thus, we see engineers design and build 2 of the most famous structures of the 19th century, the Eiffel Tower and the Crystal Palace. Theories of the Modern Movement were dominated by industrial design concepts espoused by the Bauhaus The Modern Movement was particularly interested in the industrial design and production techniques of the boat, plane and car industry (Mostafavi and Leatherbarrow, 1993).

However, the Modern Movement (i.e., 20th century architectural theory) focused on technology relative to the product of architecture and the mechanization of manufacturing, not the process of architecture.

Early architectural computing technology theorist focused on the ‹rationalization of the design process. These concepts were found to be controversial by those in design who maintain the validity of the ‹intuitive element of the design process.

The term automated design preceded computer-aided-design (CAD), the early vision of architectural theorist was to submit a design brief to a computer with spatial requirements, relationships and environmental constraints and then generate bubble diagrams. These would then be turned into dimensioned plans, rationalized for construction and would proceed to production drawings. This synthetic design process proved unrealistic since only a few design factors could be quantified (Howard, 1998). Architecture without Architects (Rudoffsky, 1964), focused on the natural design process and the rationalization of architecture.

Notes on the Synthesis of Form (Alexander, 1964), remains a milestone in this early computing visioning for the use of computer programs to rationalize the design process.

Alexander (1964) theorized that early design decisions often are falsely pigeonholed rather than being properly analyzed at their most fundamental independent subsets. Thus, he envisioned the ability of the computer to decompose the design process into hierarchical layers, whereby individual elements would be analyzed and synthesized at their most elementary atomic level.

Many theories of early computing theoreticians have not been realized due to the limitation of hardware memory and processing speed. Hence, a narrow perspective of the design process and heretofore-limited hardware, software and Internet capability has been our predecessors in architecture. The 1970’s and 80’s brought a shift in the focus of architectural computing, the theoretical rationalized design process was abandoned.

ICT’S IMPACT ON PROJECT DELIVERY METHODOLOGY

The design and construction industry is very mature, highly fragmented and is slowly entering a new era via the communication age. Architecture, that is both design and construction, is becoming increasingly complex, specialized and interrelated. New project delivery methodologies (i.e., various forms of design-build) are replacing the traditional project delivery method (design-bid-build). This transformation has occurred over the past decade, primarily in the private sector. Many have felt this would not transfer to the public sector, however, governmental agencies are increasingly pursuing design-build project delivery. Thus, as in other related industries, architecture is experiencing shifts in fundamental process. Data obtained from the Design Build Institute of America indicates that in 1985, traditional design-bid-build project delivery accounted for 87% of all non-residential construction, in 2000 it accounts for 54% of the market, with other collaborative-integrative project delivery methods being responsible for 46% of the market, thus, we see a dramatic shift in project delivery methodology (Susan Williams, 2000).

HUANG DESIGN PROCESS FRAMEWORK

Huang (1997) has established the theoretical framework for the decomposition and re composition, of the design process using a new process model he terms Interorganisational Information Systems in Design (IOS). Huang's premise is the electronic marketplace will ultimately offer a transparent seamless relationship between the design, procurement and construction process. Central to this concept is a centralized database, a 4D model which resides on an extranet site for data sharing and team collaboration. Castle has documented the manifestation of the emerging IOS framework in the construction industry via extranet sites, which he terms Computer Project Networks (CPN's). Further, Castle has documented the influences of ICT on the emerging firm model relative to management, organization and the worker (Castle, 1999). We have shown the recent exponential expansion of e-commerce and based on the projected exponential capabilities of the computer, must acknowledge the looming reality of continued reconfiguration of the design process and mechanisms for project delivery.

COMPUTING TECHNOLOGY EVOLUTION

Common database systems: The first aggregated systems were hierarchical systems, which stored information in organizational chart form. However, these systems are limited to certain types of informational relationships. The next database systems were the network models, which addressed the problems associated with hierarchical systems. Nevertheless, they also have problems, the greatest of which is inflexibility. Every program that uses a network database has to state explicitly where all the information is stored and how to access the information. Consequently, if a new program requires that the underlying network design change, every program using the database could potentially be affected. This causes major problems in large installations, when several teams are working on several projects at once and each team has its own list of changes to the database, which would affect each of the other teams.

Relational databases: These offer the most significant potential for achieving a fully integrated system. This early concept was the forerunner to today's parametric modelling software's, which are based on data independence.

Machine intelligence: It occurs when robots become capable of applying knowledge in order to respond to various environmental situations, using vision systems, range and proximity sensors and contact sensors. A machine may not be creative, but it has total recall and its mind does not wander.

Expert Systems (ES): These are computer programs that use specialized symbolic reasoning to solve difficult problems well. They use specialized knowledge about a particular problem area (such as geological analysis or computer configuration) rather than just generate purposed knowledge that would apply to all problems, use symbolic (and often qualitative) reasoning rather than just numerical calculations and perform at a level of competence that is better than that of non-expert humans. Expert systems apply heuristic reasoning (rules of thumb) rather than algorithms (precise rules) to general good but not necessarily optimal answers.

Technology Evolution continues to influence architecture and manufacturing, major phases are as follows:

- Past First major milestone commercial computing.
- Current Second major milestone Distributed environment Interactive computing
- Future Third major milestone Machine intelligence.

EVOLUTION OF (CAD) TECHNOLOGY AND DESIGN PROCESS

The evolution of Computer-Aided-Design (CAD) technology is as follows:

- The development of drafting systems led to the emergence of engineering work stations.
- Development of computer-controlled manufacturing systems made possible their interconnection and their linkage to production scheduling and control systems.
- These developments made possible, in turn, the lowest level of CAD/CAM linkage-the downloading of data from design to manufacturing.

- This fuelled the development (limited to date) of higher levels of integration that would allow 2-way communication between design and manufacturing and the automation of process planning using design data.

In manufacturing Computer-Aided-Design (CAD) and Computer-Aided Engineering (CAE) have significantly improved the design process. CAE enables a design to be tested to ensure that it does not violate any mechanical, heat, stress, or other engineering capabilities. CAD and CAE offer the have brought substantial gains over the traditional blueprint drafting method of design in the following areas:

Product flexibility: New products can be designed and therefore introduced more quickly.

Modification flexibility: Existing product designs can easily be altered to meet particular customer needs.

Design access: Designs can be stored and accessed far more easily on a computer than on study.

Quality: Designs can be tested for performance before being run and any required changes to upgrade the quality of the product can be easily made. This also saves time and money because it removes the necessity to actually produce the product or a sample only to find it is flawed.

Productivity: With the technology flexibility and information-storage capability, the productivity of design engineers in manufacturing is enhanced significantly. In fact, in many cases: increases of output per draftsman range between 200 and 6,000%, depending on the specific application, with averages of between 200 and 500%.

CAD and CAM have done a great deal to improve the design and manufacturing functions. Integrated Systems (IS), the emergent model in manufacturing, now interfaces design and manufacturing team members during the product design phase. Prior to the IS model, little communication existed between design engineers and manufacturing-engineering designed the product and then threw the drawings over the wall for manufacturing to make the product. This manufacturing model was very similar to the linear design-bid-build model we find in architecture.

Currently, machine intelligence (Artificial Intelligence-AI) is not a factor in the mainstream practice of architecture. Artificial Intelligence is beyond the scope of this research, however, it is included here to give the reader a breadth of the long-range implications of IT in architecture. Also, I have already introduced early computing theorist concepts regarding the rationalization of the process of architecture (i.e., Chris Alexander-Notes on the Synthesis of Form 1964). The philosophic question of the age-old question regarding the issue of rational vs. intuitive design is beyond the scope of this study.

KNOWLEDGE INFORMATION PROCESSING

Emerging technology, enabled by supercomputers and parallel (dual) processors (i.e., 5th generation computing) will focus on knowledge information processing as opposed to data processing. Artificial intelligence systems help performs a variety of knowledge-based tasks requiring human expertise. They configure computers, provide repair consultation for steam locomotives, interpret geologic data, control gas processing plants, manage investment portfolios and analyze corporate bad debts, etc. Anywhere human expertise is needed, machine intelligence will play a role.

These applications also have enormous potential for altering the economies of scale for manufacturing, management and professional work. The potential comes from the fact that once constructed intelligence systems can be cloned at low marginal cost. Thus, the economic of knowledge or know-how itself are altered. A second economic benefit comes from the fact that knowledge systems can tutor to humans.

Many detractors would argue against the contention that artificial intelligence will be a major development of information technologies. But what these detractors overlook is that this technology is only in its infancy. The rather striking successes businesses have experienced over the last few years can be attributed to a few basic concepts. Yet these successes have had 2 effects, which will allow us to harvest much greater yields from machine intelligence in the future. First, machine intelligence has helped spark research into the way humans think, which is producing insights to further develop the technology. These successes are now attracting private research funds from companies interested in reaping benefits from the technology. Also, machine intelligence is a cornerstone of the Strategic Defence Initiative and considerable defence related research funds have been committed.

A FRAMEWORK FOR THE ARCHITECTURAL DESIGN PROCESS MODEL

We propose a view of design based on three underlying functional elements: conception, development and implementation (Fig. 1) and propose a corresponding

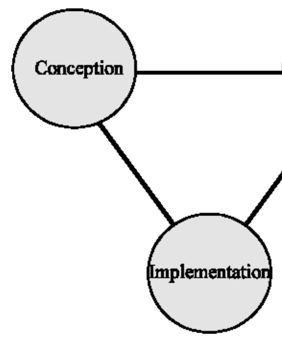

Fig. 1: underlying functional elements

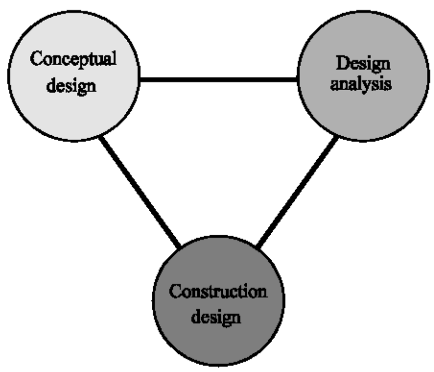

Fig. 2: Three Design phases

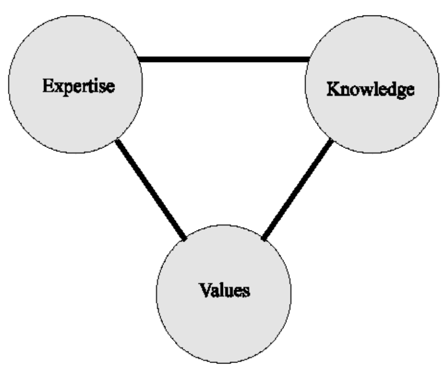

Fig. 3: Input of Design Participants

three-stage model of the design process (Fig. 2). This model suggests a framework for the use of information technology to support the design process, further, this model supports the notion that proper coordination and communication among the design stages is central to the achievement of high quality in construction and a successful design process.

The emphasis on the three functional elements follows from a structural/rational perspective of the design process. An externally constrained, evolutionary perspective suggests that the design process is driven by environmental constraints that are the final arbiters of its quality (Astley And Van, 1983). The identification of the three stages (i.e., conceptual, design development and construction design) is subject to the dynamic and unfolding nature of the design process and therefore it is not meant to imply a simple sequential relationship.

Thus, the architect, the engineering team (structural, environmental, mechanical, electrical engineers) and the construction designer (who is in charge of the construction process) are the major design participants, who contribute their expertise, knowledge and values in the design process (Fig. 3). Expertise includes the vision of the design participants that produces creative ideas and solutions.

Then we try to formalize the concept of a natural process flow from conceptual design to design development to construction design that suggests a build-up of increasingly restrictive constraints imposed by the relations among the three stages. The nature of the design process is dynamic and unfolding, however, as design at each stage requires specialized knowledge and information from architecture, engineering and construction and any stage may necessitate the intervention of another stage for corrections, enhancements or revisions. As a result, continuous communication among the architect, the engineering team and the construction designer is central to the design process.

In large design projects, the need to coordinate and manage the communication and negotiation between the design participants introduces a major source of complexity. The owner, often in the form of programming requirements, initiates conceptual design. The architect studies different design alternatives at the conceptual level with direct references to precedent, style, objectives, social issues and individual feelings, maintaining frequent interactions with the owner. Formal design intentions emerge from this process and they act as internal constraints throughout the design process. The power to define internal (intuitive) constraints sets the conceptual designer apart from the other participants in the design process (Fig. 4).

The architect, in the traditional linear design-bid-build process, is the leader and principal contributor in the conceptual design stage, but the technical support of other disciplines is needed to address issues related to design feasibility. Project design criterion must be clearly established, What if questions arise continuously during this stage requiring expertise on engineering decisions, constructability and maintenance. As a result, engineering and construction expertise is essential for a conceptual design that will need few revisions at the subsequent

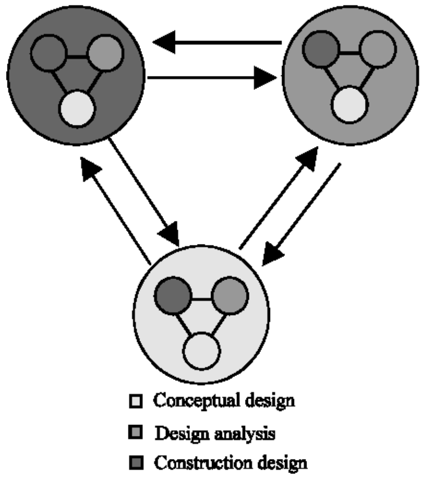

Fig. 4: Dynamic knowledge Exchange

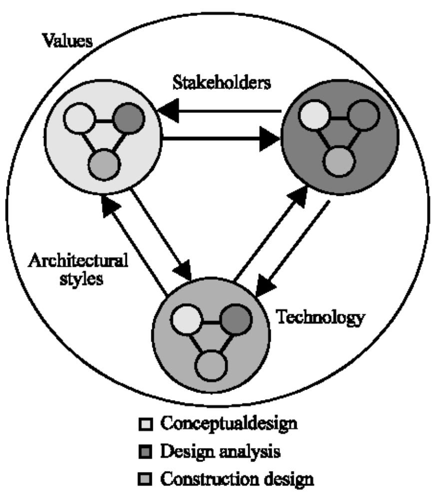

Fig. 5: The differences in the underlying tasks have important consequences for the choice of appropriate support tools at each stage of the design process.

design stages. Design changes during the construction design stage require architectural and engineering expertise input. The architectural and engineering experts should understand construction, resource planning and project control and should ensure that decisions taken at this stage do not compromise the aesthetic and engineering integrity of the building and that they do not eventually cause problems with maintainability. All three-design stages involve problem solving. The nature of the underlying tasks is markedly different for each stage, however, resulting in different appropriate methods of inquiry (Churchman, 1971).

Conceptual design is creative, unstructured, more an art than a science. Design development involves solving a more structured set of problems and requires the coordinated effort of different areas of expertise. In construction design the major decisions involve the planning, coordination and supervision of several structured tasks and are of a managerial nature.

Therefore, we describe conceptual design as the most individualistic stage, however, we now see this phase of design becoming more collaborative and integrative. Design development typically involves a team effort and construction design is usually organized along a hierarchical chain of authority. These differences in the underlying tasks have important consequences for the choice of appropriate support tools at each stage of the design process (Fig. 5).

THE USE OF ICT IN THE DESIGN PROCESS MODEL

This model suggests a framework for the use of information technology to support the design process. Fundamentally, transparent communication among the design participants is central to a successful design process (Until the 19th century, an interdisciplinary designer was typically responsible for all stages of the design process, eliminating the need for communication among the different stages.). Communication between the conceptual design and construction design elements is necessary to assure the constructability of the conceptual design without compromising the aesthetic and functional integrity of the building. Communication between different stages requires translation between the corresponding representations. Expert advice, facilitated by emerging ICT, at critical points in the early design phase can facilitate quick and informal communication with the other phases, while formal communication between phases requires a more rigorous translation process. Thus, emerging ICT offers a transparent management environment where all stakeholders, (i.e., community, users, financiers, etc.) an opportunity to be an integral part of the design and construction process.

Design is the conscious and intuitive effort to impose meaningful order. A particular technology describes the transformation of available resources to design goals. In this context, technology determines the cost benefit characteristics of this transformation, i.e., the amount of inputs required to produce a certain output. Existing technology also establishes a frontier of feasibility, setting certain limits that cannot be exceeded regardless of the amount of available resources. Hence, the impact of introducing a new technology is 2fold: it can improve the cost-benefit characteristics of the transformation of resources to design goals and it may shift the feasibility frontier, thus allowing the achievement of design goals previously unattainable.

In the design process, technology supports individual design tasks, as well as the coordination of different tasks. Support technology in the conceptual design stage provides visual representation and performance analysis. In the design development stage, support technology facilitates visual representation and provides tools for engineering analysis and design detailing. In the construction design stage, support technology deals with material brands, construction techniques and tools for the planning and management of construction.

Information technology, which refers to the use of electronic means to expand the limits of individual and organizational rationality (Bakos, 1885), has traditionally been used to support the design process. A key characteristic of information technology is that, in addition to individual tasks, it can also support inter-task coordination, which is central to successful design. For example, information technology can be used to translate representations between different stages in the design process, thus facilitating inter-stage communication.

The balance between the design stages changes to reflect external considerations imposed on the design team. This balance is typically determined by the requirements placed on the different elements of the design process by the external stakeholders and by environmental, organizational and technological considerations. Finally, the design participants who negotiate critical technological uncertainties are likely to assume roles of increased relative importance (i.e., increased value in the process chain).

Discussion of the proposed integrative architecture model: So while Integrative Architecture is about the machine, it is equally grounded in the humanistic quality of informal relationships and knowledge networks between process participants in architecture. Knowledge exchange, enhanced with emerging information technology, is occurring between owners, architects, engineers, builders, users, suppliers, manufacturers and machines (Fig. 6), resulting in Integrative Architecture. Thus, the proposed Integrative Architecture model views the future architecture practice as a balance and harmony between generalist and specialist, formal and in-formal communication networks, intuition and rationalization, designer and builder and man and machine. Thus, the reconnection of modern day disparate factions, (i.e., owner, architect, designer, engineer, builder, craftsman,

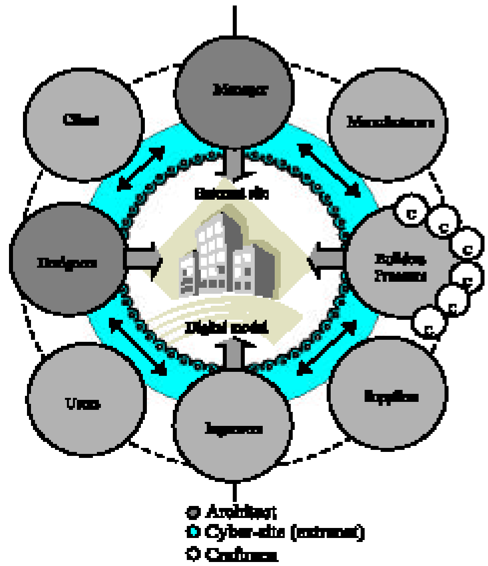

Fig. 6: Integrative architecture

users, suppliers, manufacturers and machine) is enabled via informal relationships and bilateral knowledge exchange in the digital environment. Integrative Architecture can be seen as a reference framework for interorganisational relationships and communication networks. The Integrative architect is a component of a dynamic knowledge network of collaborative contributors that offers the ultimate expression of technology, adaptability, craft and creativity. Organizational restructuring is a prerequisite for congruent technology adaptation, hence, emerging new inter-organizational forms of collaborative project delivery methodology are viewed as necessary enablers to leverage networked digital collaborative integration tools that enable project leadership.

During the Renaissance, we saw the decomposition of architecture into 2 factions, design and building. Integrative Architecture is a return to the pre-Renaissance comprehensive integrative vision of architecture as design and building. However, in great contrast to the historical architecture process via the master-builder, where the designer-manager-engineer and builder were embodied in the single individual, the emerging architecture process is a collective body of knowledge and specialty skills found in many individuals.

The Design process model in this study, demonstrates the importance of communication among the design participants. Differences in the representations used during the different phases of the design process create obstacles to such communication. Understanding the functional role of these representations and the potential applications of information technology will substantially improve inter-phase communication.

Construction quality depends not only on construction design and on quality control during construction, but on the conceptual design and design development phases as well. These phases should pay attention to feasible construction techniques, taking into consideration the available resources and technology. As a result, proper interaction between the different phases of the design process is central to the quality of construction.

Computers have opened new frontiers in support technology. The capability of computers to store, retrieve and manipulate data allow quick alternative representations and feasibility studies of objects based on large sets of data.

This is achieved with computer-based process technologies that support individual design tasks. Computers can also facilitate the exchange of information between the different phases of design, providing the basis for further explorations on engineering, detailing and construction issues, as well as improving the communication among the designers, the owner and the users.

Coordination technology supports the coordination of multiple tasks with a set of common goals. Computer-based process technology and coordination technology, combined, constitute the information technology defined as the technology focusing on the use of electronic means to expand the limits of individual and organizational rationality. Advanced computer-based support technology, for example, allows efficient electronic representation schemes and provides access to electronic data banks for design information which facilitates the study of alternatives, leading to a more complete design. Advanced computer-based coordination technology can contribute to improved communication among the different individuals and groups participating in the design process and can overcome the communication barriers that disrupt the process.

CONCLUSION

Architecture is being transformed via an emerging knowledge network that is empowered by evolving information technologies and management strategies. This knowledge network enables sophisticated problem solving and heretofore, unaccomplished performance and physical Forms.

We think that technology cannot be separated from design intentions and the creative process. Design intentions drive the selection of appropriate technology, while the available technology determines the feasibility of particular designs and thus affects the process and the outcome of design. To the extent that state-of-the-art technology can contribute to the design process, it should result in better design. Advanced computer-based support technology, for example, allows efficient electronic representation schemes and provides access to electronic data banks for design information that can facilitate the study of alternatives. Furthermore, several individuals are typically involved in the design process with different responsibilities and expertise. Barriers to communication in these settings can often disrupt the design process.

Information technology contributes to improved communication among the different individuals and groups participating in the design process. Advanced manufacturing technology can improve the cost and quality of the final product and emphasizes the importance of resolving implementation issues early in the design process.

Designers should thus try to understand the nature of the technology that will be employed in each design step. Cost-benefit analysis should be carried out and the designers together with the owner and the users should carefully consider the implications of the selected technology, both during construction and during the life of the designed artefact. New contract typologies are emerging, resulting in in-formal relationships that encourage knowledge exchange and collaboration, thus enabling fusion, in lieu of fission, of architecture factions. Old model views of architecture are no longer sufficient, a re-evaluation of the role of the architect and new ways to think about architecture are needed in the current ICT disruptive context. This is what I have tried to do with this study.

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