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THE COMPUTER AS A CATALYST FOR NEW EDUCATIONAL PARADIGMS IN ARCHITECTURE

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Today computers are used in architectural practice to execute repetitive and routine tasks more efficiently. As a consequence, the use of computers have become quite common if not commonplace in the CAE (construction/architecture/engineering) industry. Certain efficiencies have been realized through the use of computers, particularly when the users of these systems are well trained and are motivated towards efficient drafting.

The greatest gains in the field have been realized in drafting and rendering areas. Once the design is completed, particularly in the design development or working drawing stages, CAD tools can be used to represent the conceived design with great deal of accuracy and detail. Even during the development of the design concept, three-dimensional rendering tools are used to visualize designs for the benefit of clients and designers alike. Such tools are rapidly becoming standard in the building design industry.

The design process itself, however, has remained essentially unchanged. Computer tools for drafting, or for visualizing, have been inserted into the design process as mere substitutes for the manual forms of those tasks, leaving the rest of the design process essentially unaltered. As a result, the benefits realized in making these tasks more efficient are counteracted by the loss of time and effort, when the new technology is interfaced with the conventional process: namely data input, data output file access, etc.

Similar developments can be observed in the realm of architectural education. While computers are becoming more and more commonplace in the design studio, the pedagogic methods used and curricula in which these methods are embedded remain as they were. Similar difficulties, as those encountered in the industry, are not difficult to imagine in the educational context. While the systematic documentation of these experiences is rare, some evidence supporting this point is available.

On the other hand, the mere introduction of computers into the field leads inescapably to new opportunities. For example, the initial motivation for CAD software in engineering design was to make the process of structural design more efficient. Soon, however, it was realized that the engineering design process itself had to change in profound ways. Due to increased accuracy and computational power, factors not previously taken into account could now be considered in design. Safety factors, for example, could be lowered, without risking structural failure. Finite element analysis techniques allowed designs that were more specialized, and therefore, utilized building materials more efficiently, and so on.

A similar development can be envisioned in the field of architectural design. As we are able to represent and retrieve designs more accurately and with greater speed, designers will tend to restructure their own design processes. They will tend to adapt previous design ideas to current design problems more effectively. They will incorporate the consideration of larger sets of solution alternatives in their designs. They will be able to evaluate preliminary designs more rapidly and along many different dimensions, opening the way to integration of other technical consultants' concerns into the early stages of design. Ultimately, they will be able to do fewer routine and mundane tasks manually, like multiplying and dividing in the course of mathematical proofs.

The difficulty with this proposition, we believe, is not the hidden dangers that computerization of design holds for us; but rather, it is the lack of computer based tools that allow us to forge ahead into these new modes of design. Worrying about the inherent ills of computers in design is akin to the almost superstitious fear of machines and modern gadgets. In this paper, we are not interested in considering these issues. Rather, we are interested in fully exploring the consequences of having these advanced CAD tools integrated in the design process. We are interested in assessing the impact of the next generation of these tools on the design process, particularly on design education. In order to do this, we take an evolutionary view of the paradigms of design education and the historical context within which design knowledge exists.

A BASIC MODEL OF LEARNING

In discussing the evolution of the educational process, we need a basic model that can structure our discourse. We envision the simplest structural relationship that could exist between the teacher and the student (**Figure 1**). The teacher possesses knowledge of a particular domain that the student does not have. They

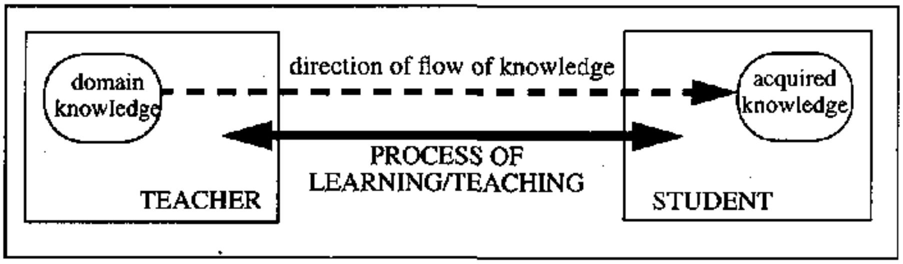

Figure 1. A basic model of learning/teaching, showing the flow of knowledge.

engage in a process that is called 'teaching' from the perspective of the teacher and 'learning' from the perspective of the student. We consider these to be reciprocal concepts and include them in **Figure 1** as a singular structural relationship. As a result of this interaction, the domain of knowledge possessed by the teacher is acquired by the student. Even if this acquisition is partial or that its form leaves some things to be desired, for example learning with understanding as opposed to rote-learning, we still claim that learning/teaching has occurred.

While this model is almost axiomatic, it glosses over some important educational issues, the least of which are not the questions of the type and extent of learning. There are other aspects of learning which have to do with the form and nature of the interaction between the parties (*i.e.* didactic *vs.* practice based learning) and the form of the domain knowledge (*i.e.* cases *vs.* theory). To consider these issues further, let us now review the various educational models used in educating architectural students, over the centuries.

PARADIGM SHIFTS

Historically, the process of knowledge transfer from expert to novice has evolved as a function of our increasing domain knowledge. While this has been a gradual process, there have been watershed moments in our conception of architectural design, as with the *Ecoles des Beaux Arts* and the *Bauhaus*. These moments can be characterized as those of 'paradigm shifts' (*à la* Thomas Kuhn) highlighting the important differences, between the periods before and after.

We characterize the pre-*Beaux Arts* modes of design education (*i.e.*, pre-18th Century) as those based on educational models where design is seen as the practice of building. The *Beaux Arts* period (*i.e.*, the 19th Century) amplifies models of education reflecting an understanding of design patterns. In the *Bauhaus* period (*i.e.*, the 20th Century) we observe design education relying on models of design arising from universal principles. In the following sections we will provide a historical perspective by reviewing the nature and content of architectural knowledge during these periods.

We will also argue that computers and their potential impact on the design process (which are briefly stated in the 'Premise' section) constitute a force behind one such watershed moment which is pregnant with new paradigms of design education. We will examine this issue in the final section of this paper.

Figure 2 is designed to summarize the various elements of the educational models prevalent during these periods using the basic two part knowledge structure shown in **Figure 1**: namely, the teacher and the student. As we review each period, we will repeatedly refer to **Figure 2**, in order to illustrate the concepts that we present in the text.

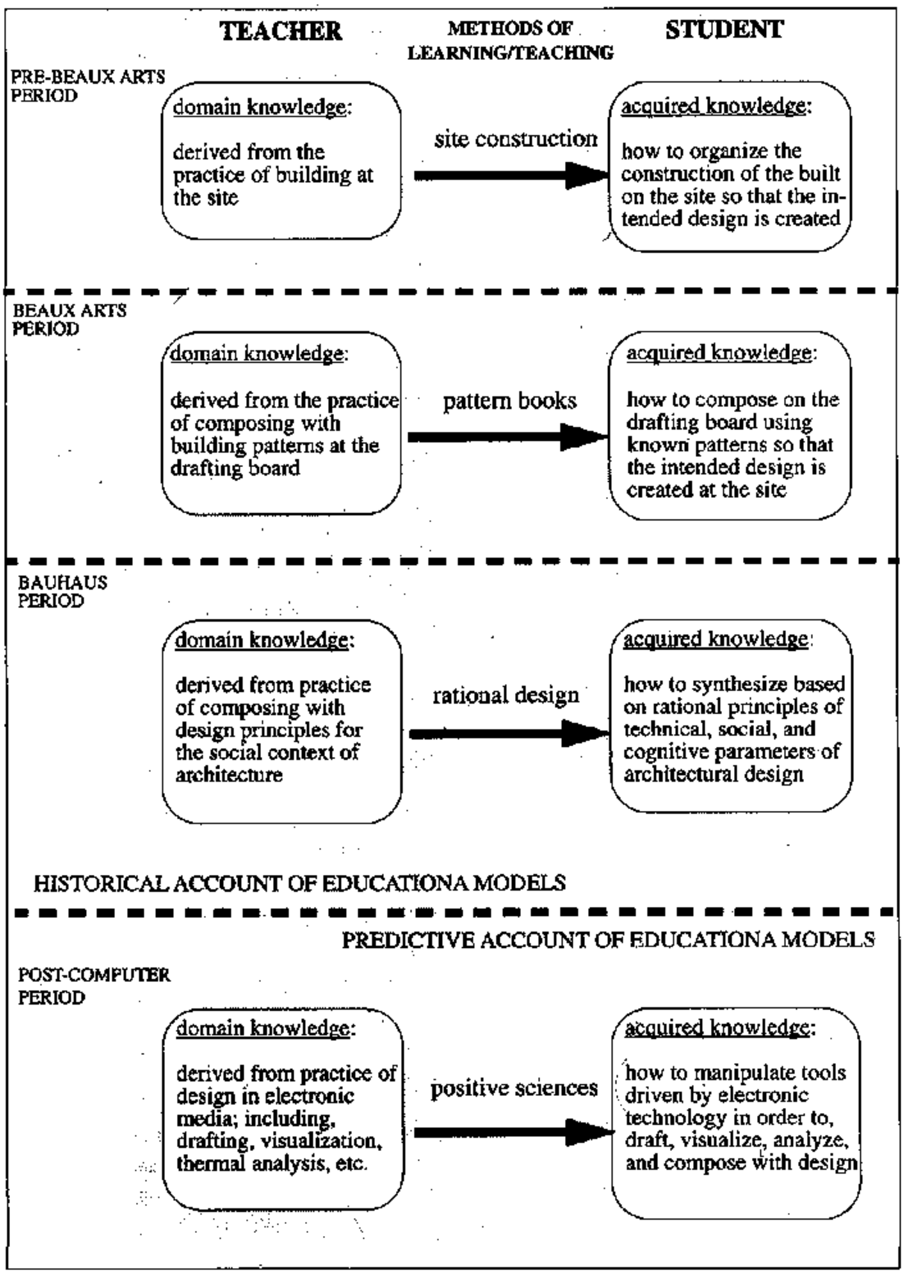

Figure 2. Models of architectural education, based on knowledge transfer between teacher and student.

The Pre-*Ecoles des Beaux Arts*

The documentation of the schools of thought which have given rise to particular models of architectural education are rare and have gained momentum only relatively recently. The interest in this area is largely due to the popularization of education in general.

As a result of repeated rediscovery of social and democratic principles since the Renaissance, the Western world has established institutions of higher learning accessible to those other than just the political elite and the clergy. The early 'institutes' established during the Renaissance, in Italy and elsewhere, are the predecessors of the later better known institutions of higher learning, like the *Ecoles des Beaux Arts* or the *Bauhaus*.

The instruction in these institutes of higher learning was a direct consequence of the models of knowledge prevalent at those times. While there were significant treatises of architecture based on the rediscovery of the antiquities, such as those by Vitruvius and Alberti, the notion of education of the architect was based on that of the masterbuilder. The student learned as an apprentice under the mentorship of the 'master', very much like modern coaches or trainers who produce performers like athletes, actors, and musicians.

The knowledge imparted to the student was derived from the practice of building at the site (**Figure 2**). The knowledge of how to locate and orient buildings with respect to cardinal directions and cultural directives, how to proportion elements of construction, how to regard sub-soil conditions and water tables were all derived from trials and errors in the construction site. In turn, students were expected to gain knowledge by actually witnessing the process *in situ* and then applying it themselves.

This clearly was a function of how scholars of the day regarded not only architecture but the totality of human knowledge about the natural sciences and human cultures. The forces attributed to spiritual, cosmic, and worldly phenomenon were taken into account as buildings were planned and constructed. Many cultures still have building traditions that go back to such conceptions of architectural knowledge, such as *feng shui* in China and the Far East.

The *Beaux Arts*

A distant offspring of the French Revolution, this school of higher learning was officially established in Paris in 1819. This marked the beginning of a new era in architecture as was the case in many other segments of the society coming out of the Napoleonic period. In a macroscopic sense the *Ecole* is the true beginning of Modern architecture: fresh, progressive, and uninhibited by its predecessors. The *Ecole*, however, based its program on the principles of 'idealism', especially Aristotelian and Neo-Platonic idealism, as was the case with its immediate predecessors (*Academie des Beaux-Arts and Academie Royale d'Architecture*) and its distant predecessors (Antiquity and the Italian Renaissance) rather than on 'realism', 'naturalism', or 'materialism' which are closer to the agenda of the Modern Movement. Thus the education of the architect emphasized pre-ordained patterns and symbols of idealized designs as part of its agenda in lieu of learning by doing at the site.

Unlike the ancient modes of learning, which consisted of practice under a master builder, the *Ecole* identified the academic setting as the place for learning. The student learned to make buildings abstractly; without actually building them (**Figure 2**, '*Beaux Arts* Period'). A new role for the architect emerged: the master draughtsman. The crafted product of the architect, now, was the drawing.

In educational terms this meant that the knowledge embodied in the experience of building had to be translated into an abstract and symbolic form. Instead of the touch and feel of bricks, stones, and wood, the architect's building palette included composite patterns of lines, colors, and shapes leading to simulations on paper and in the mind. This transformation was accomplished through carefully prepared 'pattern books' articulating the language of the new architecture. This language was classical, borrowing heavily from antiquity and transforming them into kits of parts from which certain building types could be created.

All in all, the practice of architecture followed clearly prescribed rules about style, process, and scope. These rules were adhered to in education as well. The learning/teaching process was centered around pattern books and building types that could be created from them. Practice was envisioned as the production of the drawings that depicted the buildings to be constructed by others at the site. Just as the architect was removed a step away from the concrete objects of their creative efforts, so was their education at the Ecole.

The *Bauhaus*

Bauhaus established at Weimar in 1919 was in spirit a reaction to the *Ecole* and its teachings. Similar to the emergence of the *Ecole*, it derived its impetus from a powerful political upheaval in Europe, during the aftermath of the First World War, especially in Germany where this upheaval was felt most intensely. Its objectives were also to establish a new and fresh start for architecture which was engulfed in 'decadence' and mindless copying of historical patterns.

A primary aim was to alter, once again, the role of the architect. The architect had been designing, for more than a century, from pattern books, derived from historical patterns with little or no heed to contemporary social, economic, and industrial conditions. This elitist relationship with respect to society and its current problems had to change. This required the establishment of a new basis for the architect's relationship not only towards society and the professions but also towards his/her own knowledge base. What would constitute the foundation of design, if there were no pattern books?

The answer was in the principles, derived rationally and without heed to history or custom, which governed the relevant ingredients of architecture: social, cultural, economic, technical, aesthetic, and perceptual. Practitioners and educators of the *Bauhaus* were interested in discovering the unshakable principles of perception, for example, which governed the appreciation of compositions. They aspired to find modular systems that would both provide standardization and allow variety in design. They appreciated the behavioral patterns of use in buildings and set out to discover ergonomic principles of planning and design. They rejected surface decoration as an insincere and esoteric expression of taste. Instead they sought to find a new aesthetic for building based on the honest expression of the functionality of buildings and their process of construction. Materials were to represent their true nature and character. A new theology based on the technological advances of the day was established as a foundation for architectural design.

This was yet another layer of abstraction from both the process of building at the site and the process of designing through patterns (**Figure 2**, '*Bauhaus* Period'). Now the knowledge base acquired during the architect's education consisted of principles of design, derived from patterns of design, representing actual buildings. As these layers of derivation increased in number, so did the magnitude of the architect's removal from his/her concrete domain of practice.

This, no doubt, had to be reflected in the educational process. Students now had to design based on the immutable principles of a rational design process. They then had to verify the performance of their designs, not only with respect to these principles but also with respect to patterns of well understood building designs and ultimately with respect to the realities of the construction site. This presents a very large set of areas of expertise for the architect (perhaps one that explains the proliferation of areas of specialty in today's practice) and extreme demands on his/her ability to coordinate these areas of expertise.

THE FUTURE

What the future of architectural design holds then is the challenge of how to deal with complexity and multi-disciplinary design criteria. The old models of the architect's knowledge (*i.e.*, construction of the building at the site, composing with pattern books, or even designing from rational principles) are inadequate for meeting this challenge. Today, the building problem reaches far into many dozens of building specialties with dozens of design experts involved with any given building. The traditional process of design delivery does not take into account this ever growing complexity, nor does it fully accommodate the cultural, economic, legal, and ecological demands placed on buildings.

As in many other aspects of our present society, we try to find solutions to the problem of complexity with the aid of automation and computer assisted systems (**Figure 2**, 'Post-Computer Period'). Last two decades of intense work in CAD has produced many tools to assist designers in this task. While the present impact of this flurry of activity on the design process is somewhat small, its potential impact is significant.

Aside from the well accepted and considerably advanced tools of drafting and visualization, a new generation of computer tools for the designer are emerging. These include sophisticated systems to assist in the analysis, synthesis, and simulation of designs as well as the management of data storage, transfer and communication. The 'CAD paradigm shift' is right around the corner. As was the case in the earlier paradigm shifts, a brand new technology and all that it offers in terms of human achievements is ushering in a new way of designing.

There are several important pedagogic objectives underlying this paradigm shift:
1. learning the use of the tools
2. understanding the logical underpinnings of the functions performed by the tools, and
3. developing new tools or improving existing ones to reflect advances in these underpinnings.

Learning the Tools

A primary purpose of education in any technical fields is the introduction of the student to 'the tools of the trade'. In CAD, this includes tools of visualization, drafting, programming and feasibility analysis, layout generation, solid modeling, thermal analysis, lighting analysis, acoustical analysis, structural design, standards checking, costing, facilities management, and virtual reality applications. With such a wide variety, their introduction in the classrooms faces definite challenges. One challenge has to do with the difficulty of narrowing down the field to a small and meaningful set. The other is to find a set of tools that provide a good user interface facility. This is also a two pronged issue: one is the interface between the tools and the other is the interface between the tools and the designer within the design process.

In both categories of interface, CAD industry has a long way to go. Similarly, educational programs in architecture have to find strategies for overcoming these difficulties. A plausible approach is to select tools with the intent of demonstrating their relevance to design rather than trying to be all inclusive. For example, the design studio or similar hands on courses (such as, design modeling type courses) can become 'laboratories' within which CAD tools are introduced. A basic modeling software coupled with a visualization and drafting package can serve very well in most design studios where the focus is on conventional design. In a specialized design studio (such as one dealing with systems integration or urbandesign) other tools are also essential (such as performance analysis and GIS type applications, respectively).

The emergence of the new educational paradigm will be realized at a minimum through the use of commercially available packages and well trained faculty (both in computation and architectural design) as well as staff. It is important to note that maintenance and upkeep of hardware and software have an ever increasing importance in the success of CAD based education.

The Logic of Computer Applications

Most of the things that computers allow designers to do, outside of drafting and visualization, have to do with systematic generation and analysis of designs. These include thermal analysis, structural analysis, statistical analysis, layout generation, shape grammar interpreters, financial analysis, and standards conformance analysis applications. Underlying each of these are algorithms that carry out a set of logical or procedural operations.

A curriculum that merely teaches students how to use these algorithms without teaching them their logical basis cannot lead to true education. It is paramount that students understand why certain results are given by the computer system, how these results are likely to change as a function of changes made in the input, and how to interpret the results in making design decisions. All of these point to the necessity of understanding the logic underlying the algorithms that they use. If sizing a beam, the student must understand the relationship between the size of the beam and factors like the live loads assumed, the lateral bracing system and its role in holding up the building, and the construction of the floor slab supported by the beam. Otherwise, the student will not be able produce a successful structural design. Similarly, a lack of understanding of the relationship between reverberation times, the materials of construction, the proportions of the space, and the functions it will accommodate can only lead to a poor acoustical design, regardless of the sophistication of the computer tool available to the designer.

As a result, the curriculum of the future, designed to accommodate the computer as a key tool in its delivery, must also provide a set of didactic subjects dealing with the full range of topics that are represented by the CAD tools, not to mention the overall professional objectives of the educational program. These subjects must be delivered in the conventional sense, *i.e.*, explaining the first principles of physics, chemistry, or economics, for example, from which they have arisen, as well as the methods and techniques essential for the understanding of the computer algorithms used in their implementation.

Improving the Tools

A curriculum not equipped with a mechanism for self improvement, however advanced in its contents and inclusive in its scope, is doomed to fail. Thus, the emerging CAD applications for architectural education must be seen as evolving concepts. Mechanisms must be in place to allow the development of new tools and improve existing ones. As existing tools are put to use, better ideas of use and usability are bound to come up. Designers, particularly creative ones, will discover ways in which existing tools fail or succeed. This will be the impetus for improving them. Designers will also find ways of putting these tools to new and even unintended uses. These experiences can lead to the development of entirely new sets of design assistance tools.

Another motivation for the generation of new tools is the advances that occur in the logical underpinnings of the various professional domains cited in the earlier section. It is a foregone conclusion that new methods for the analysis and generation of designs will emerge; and as these come into use, new tools will have to be developed to make them available to the designer.

Some of the tools that are emerging in the field for reasons similar to these include: software designed with the usability issues as the starting point, shape grammars, generators and interpreters, visualization-simulation-virtual reality applications, advanced database applications, and new and advanced artificial intelligence applications.

These tasks of CAD software development, normally, fall outside of the architect's area of expertise. They require deeper knowledge of computer science and software engineering than what architects possess. However, these are not tasks that can be placed solely in the hands of the computer scientists either. They require a true collaboration between the architect (or designer) and the software engineer (or computer scientist).

MANDATES FOR COMPUTATION IN DESIGN EDUCATION

Following from the considerations cited above, the new educational paradigms, taking their mandate from the computerization of the design process, have to fulfill certain 'objectives' and realize these ends within the framework of certain *rationales*.

A principal objective is for students to gain hands on experience and practice with the new tools. Just as in the introduction of the slide rule and the hand held calculator to disciplines that perform mathematical calculations, the introduction of the computer must be based on formal training on the tool, directly. This is to learn about the functionalities that are provided by the tool as well as to gain experience with the ergonomic and cognitive parameters of the user interface features.

In the case of the slide rule and the calculator, as users gained skill with the use of the tool, educators were concerned about the potential misuse of these tools. They were concerned both with the loss of the understanding of the mathematical operations performed by the tools as well as an exclusive reliance on the tools. Thus adjustments were made in curricula to make sure that students did not end up lacking a true understanding of the mathematical operations while warming up to the use of the tools.

Similar concerns are relevant in the case of CAD. As designers learn to generate perspective drawings, for example, they need to know enough about the underlying logic and techniques of perspective drawings so that they can properly set their parameters, such as the vanishing points, picture plane, horizon line, and so on. Thus, curricular features teaching students about perspective drawings cannot be abandoned, just because they learn how to generate perspective drawings with the computer. Such problems with other application areas (such as structural, thermal, acoustic, electrical design analysis) are even more critical and more obvious. Thus, the second objective of the curricular paradigm we are describing here includes a full menu of theory courses and related didactic subjects.

Table 1. A curriculum illustrating the computerized paradigm of design education.

SEMESTER	DESIGN	TECHNOLOGY	DESIGN SCIENCE	DEPARTMENT ELECTIVES & HUMANITIES	UNIVERSITY ELECTIVES
ONE	Introduction - Computation	Calculus		History	Writing
TWO	Introduction - Drawing	Physics	[illegible]	Architectural History I	
THREE	Design - Composition	Statics		Drawing II	ELECTIVE I
FOUR	Design - Construction I	[illegible]	[illegible]		ELECTIVE II
FIVE	Design - Construction II	Materials and Assemblies	Computer Modeling I		ELECTIVE III
SIX	Design - Site and Soils	Soil Mechanics		Architectural History II	ELECTIVE IV
SEVEN	Design - Arch Programming	Structures II	Psychology of Habitation	DEPT ELECT I	
EIGHT	Design - Systems Integrat'n	Total Building Performance	[illegible]	DEPT ELECT II	
NINE	Design - Urban Design I		[illegible]	DEPT ELECT III	ELECTIVE V
TEN	Design - Urban Design II		[illegible]	DEPT ELECT [illegible]	ELECTIVE VI

LEGEND: CURRENTLY OFFERED WITH CAD — TO BE OFFERED WITH CAD

The third and the last objective of the new curriculum model is the allowances for the evolution of tools or the discovery of new uses of existing tools as a function of changing demands in the field. All tools that attempt to provide power to users are necessarily limited in terms of flexibility. A hammer, for example, that does not include a nail extraction end is designed to provide a better performance for nailing nails (for example, the finishing nail hammer with the rounded head to supplement the flat one). Yet, tools are routinely used for purposes that they were not intended for in the first place. A hammer is a good door stop, if it is heavy enough, or if the nail removal end can be wedged in under the door.

When these new uses for existing tools become prevalent enough, existing tools are transformed into other specialized states or forms. Conversely, entirely new tools may be developed to fulfill the new functions attributed to existing tools, as in the case of the rubber wedge door stopper. The emergence of new tools is often justifiable, when the proliferation of newly attributed function tends to reduce the power of the existing tool for all of these new applications.

A Menu of Courses

In fulfilling these objectives a variety of different curricular programs can be used. Here we provide only one such curriculum, which constitutes an example derived by and large from the 5th-year undergraduate curriculum at the Department of Architecture, Carnegie Mellon University. This serves as a professional degree program in architecture.

In this particular instance, the computer assisted instruction is done in the courses shown in the shaded boxes. These courses are integral with a range of topics involving hands on design as well as other didactic subjects, such as those listed under technology, design science, and humanities columns. However, not all of the topics are suitable for CAD assisted learning or need to be so. As long as there is balance of both CAD assisted and manually delivered courses in a curriculum, the goals of a successful education can be satisfied through the new educational paradigm.

CONCLUSIONS

In concluding we offer several convictions of ours, that can be offered to the reader in their simplest form. Their justification, we hope, can be found in the text that preceded.

First, we consider computation as a technology that possesses all of the requisite potential to usher in a new paradigm of design education in architecture, rather than as a simple substitute for manual design tools.

Second, we conjecture that computation can and will have impact on design, only if its tools are developed by architects and computer software engineers, jointly. Preferably, those engaging in this activity will have both areas of expertise at a very high level.

Third, there are three specific strategies which are necessary (perhaps not entirely sufficient) to realize this emerging paradigm shift in architectural education:

(1) adapting existing courses (especially in the design studio and drawing and modeling courses) to the new order of the day,
(2) using existing as well as new courses to provide the non-computational, theoretical foundation of the subjects that are modelled through CAD tools, and
(3) to be diligent in seizing on new opportunities to create new applications and new courses that embody these applications in the cause of furthering architectural education.

A graduate program, preferably at the Ph.D. level, is invaluable to implement this last strategy.

MİMARLIKTA YENİ EĞİTİM YAKLAŞIMLARI GELİŞTİRMEDE BİLGİSAYARIN KATALİZÖR OLARAK KULLANIMI

ÖZET

Günümüzde bilgisayar bir çok meslek dalında kaçınılmaz ve vazgeçilmez bir araç haline gelmiştir. Bilgisayarın bir çok mesleğe getirmiş olduğu büyük yenilik, geleneksel çalışma yöntemlerini aşarak yeni ve verimli çalışma olanaklarını ortaya çıkarmasıdır. Mimarlık ve mimarlık eğitiminde de bu gelişme er ya da geç oluşacaktır.

Tarihsel bir çerçeve içinde ele alınırsa, mimarlık son beşyüz yıl içinde iki büyük aşamadan geçmiştir. Bu aşamalar, *Ecoles de Beaux Arts* ve *Bauhaus* gibi eğitim sistemlerinin kalıplaştırdığı yeni tasarım yöntem ve yaklaşımlarının etkisi altında

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oluşmuştur. Bilgisayar yardımı ile tasarım da, bu tarihi gelişmelerle aynı önemde olabilecek yenilikleri mimari tasarıma getirmek durumundadır.

Böyle bir oluşumu, sakıncaları olan ve önlenmesi gereken bir gelişme gibi görmektense (ki böyle bir görüş tamamen geriye dönük, verimsiz bir tutuma yol açacaktır) gerekli hazırlığın yapılıp ivedilikle eğitim ortamına davet edilmesi gereken bir yenilik olarak görmekte yarar vardır. Bu hazırlık, mimarlık eğitim programlarında üç türlü yeniliği gerektirir.

Birincisi, tasarım eğitim ve yöntemlerinin bilgisayarca düzenlendiği, ancak tasarımcı tarafından yönetildiği bir eylem haline getirilmesidir. Kuşkusuz bu uygulama stüdyo çerçevesi içinde gelişmelidir. İkincisi, tasarımı destekleyen teorik ve bilimsel bilgilerin yine bilgisayar yardımı ile iletilen ve stüdyo ortamından ayrı, onu destekleyici bir şekilde sunulmasıdır. Üçüncüsü ise, mimari tasarım ve anlayışına uygun bilgisayar yöntemlerinin tariflenmesi ve bunları destekleyici araçların geliştirilmesi için yüksek lisans seviyesinde derinlikli çalışmaların yapılması olmalıdır.

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