EDUCATING FOR THE UNKNOWN: PRESENT COMPUTER EDUCATION FOR FUTURE DESIGN PRACTICE

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ABSTRACT
The penetration of computing and computer-aided design into current and future architectural practise is examined and the implications for education discussed. It is argued that computing is part of the working environment in which both education and practise exist and that the content of education needs to be reinterpreted in the context of this new environment.

INTRODUCTION
Almost 25 years ago, Jonathon Barnett wrote in Architectural Record that

"not too far in the future architects would be able to receive engineering data and evaluation of functional characteristics almost instantly, at any stage in the design process; and specifications and working drawings of the finished product could be produced with great rapidity using computerized technology... Ideally, the architect or urban planner would be free to give his full attention to problems of design, use and appropriateness."
(Barnett, 1965, p 150).

This expectation that computers will tremendously enhance the process of design in the near future, and thereby revolutionise the practice of architecture, has been voiced countless times in the past three decades. What Jonathon Barnett wrote in 1965 we could write with equal conviction nearly a quarter of a century later. The revolution remains in the future; contrary to the expressed intentions of practitioners, design uses of computing form a very small proportion of all computing undertaken in architectural practice. This divergence between expectation and actuality arises from the limitations of current systems compounded by a narrow understanding of the nature of computer methods within the present generation of practitioners, even amongst those firms that appear to be making successful use of computers. The general perception within the profession is that the necessary skills of graduating architects in computing are straightforward mechanical extensions of existing drafting skills, and they exert influence on schools and professional accreditation bodies to subscribe to this view.

This is the first theme of this paper: that the existing practice environment is not the one we should prepare graduates for. It is argued that the full potential of computing in design will only be realised with the creation of different models of design processes which derive from the nature of the medium, rather than being transferred from experience with conventional media, but that there is as yet no mature paradigm which can be adopted.

Such a paradigm will not arise out of practice—it must be developed in the schools. This our second theme: that we must produce a new paradigm for the teaching of drawing and design.

This paper also presents the pedagogical implications of this lack of a mature role for computers
in design practice. It is argued that the essential task is to give students a theoretical understanding of the nature of the computer medium in design rather than skills in particular current systems, and that such understanding is best supported through a structured exposure to very simple design tasks where the designing takes place "on the computer", and where the characteristics of the medium can be exploited, rather than the modelling of more complex designs initially developed via conventional media. This is our third and final theme: there is a need for a unifying model of design appropriate to the computer medium.

FIRST THEME: THE CURRENT ENVIRONMENT

The current environment in practice and teaching is characterised by novelty and, it is thought, rapid change. First, novelty. Most CAD vendors and software houses are less than ten years old, and most architectural firms using computers have invested in them in the very recent past (Wagner, 1985). The commercial world has had thirty years to develop computer methodologies and integrate computing into commercial practice. The architecture profession and the schools are still struggling to find the right place for computing, and a coherent body of experience is just beginning to emerge.

Second, rapid change. To say that innovation is rapid in the computer industry has long been a cliché. Particular machines and particular programs rarely have a lifetime of more than a decade. Architectural computing is itself one of the fastest changing sectors of the industry. Microcomputer-based CAD, for example, transformed computer use in architecture in the mid-1980s, and we can expect another sea-change before the decade is out. Over the long period that students are in architecture school the nature of architectural computing could change substantially from when the student takes a computing course to the time he or she graduates. Much more than specialists in the other technology-orientated components of the curriculum, computing educators must try to second-guess the future and provide courses that will prove useful to students three to five years after they are taken. Our own experience is illustrative: five years ago we taught Fortran to students doing their first computer course, and we taught it on the university's mainframe. Now we introduce students to computers through graphics on our own microcomputers.

We should be aware, though, that we are just leaving a very particular and unusual phase in the history of architectural computing. We illustrate this with evidence provided by a series of surveys, the first conducted by the AIA in early 1982 and published in the AIA Journal, another by Architectural Record in early 1985, and, most recently, a survey by Progressive Architecture in mid-1987 (Anonymous, 1982; Wagner, 1985; Doubilet, 1987).

The surveys report that 30% of their sample used computers in 1982, 72% in 1985, and 87% in 1987. All three surveys relied on self-reporting. Since there is much more motivation to return a survey form about computing if the firm uses computers than if it does not, we might expect these rates to be somewhat inflated. The inflation effect can be gauged by comparing two survey results from the United Kingdom, undertaken in mid-1987. The least reliable was a self-reported poll of a small number of individual architects carried out by the Building Centre in London, which reported a penetration rate of 62% of firms with computing facilities. The second surveyed all 5,000 British practices, and was undertaken by the Royal Institute of British Architects (RIBA) (Howard, 1988). It obtained replies from 1,927 practices, a very high response rate. The penetration rate found was substantially lower, at only 47% of practices. Assuming a similar over-reporting rate in the American case would give a true penetration closer to 60% in 1987.

From this data it is nonetheless possible to build up a picture of the pattern of penetration of computing in American architectural practice. The progress of technological innovations
through time follows a characteristic logistic or S-shaped curve. We used the method of Fisher and Pry (1971) to fit a logistic to the three data points for computer penetration into practice given in the American surveys (curve A in figure 1). This provides an optimistic view of computer use. The second curve in figure 1, curve B, is based on the assumption that the pace of change indicated by the surveys is reliable, but that the absolute rates are inflated, and the real rate in 1987 was actually 60%. The curve stays the same shape but is shifted so that the 60% point occurs in 1987 instead of curve A's 1983.

![Graph of computer penetration](image)

**Figure 1. Penetration of computing into architectural practice in the USA.**

The 90% level of penetration is conventionally taken as the saturation point. Curve A indicates that saturation has already occurred. The interesting point about this exercise is that even if curve B is a more realistic depiction of the state of practice, saturation will still be achieved by mid-1990. The same procedure was carried out for the penetration of CAD into computing in practice. The surveys reported that, of those using computers, some 12% used "graphics" in 1982, 35% did "two-dimensional drawing" in 1985 and 53% "used CAD" in 1987. When this penetration of CAD into architectural computing is combined with that of computing into practice, the two logistics (one optimistic (A), one more reasonable (B)) of figure 2 are generated. The two curves are much closer to each other than the previous pair because drafting penetrates computer use faster than computer use penetrates practice. They imply that drafting systems will have saturated practice somewhere around 1992.

![Graph of CAD penetration](image)

**Figure 2. Penetration of computer drafting into architectural practice in the USA.**

The speed of penetration of innovations is usually measured by the take-off time, which is the
time taken to proceed from 10% to 90% penetration. The take-off time is about nine years for computing in general and seven to eight years for CAD into architectural practice. These are typical of the take-off times of innovations in other industries (Terleckyj, 1977). For comparison, the take-off time for facsimile usage by British construction contractors and consultants, which also follows a classic logistic curve, is projected to be eight years, 1981 to 1989, with 80% saturation at the time of the survey in 1987 (Howard, 1987). Thus, although we often remark on the rapid uptake of computing in recent years, the rate is in fact normal for innovation diffusion. As Reyner Banham provocatively noted, architecture “has tended to believe itself in the throes of major revolutions when confronted by technical innovations that other crafts and disciplines have taken in their strides” (Banham, 1984, p 268).

The important point revealed by these curves is that we are just leaving the period of most rapid growth, the middle linear portions of the curves. The current practice environment is therefore an unusual one, characterised by what is to the architectural profession an explosive penetration of the new technology. This rapid penetration has created strains within the profession, and, as we shall discuss below, strident calls for students who can operate the new technology. It has also left firms bottom-heavy in computer-knowledge: the young graduates know much more about computing than their employers.

The surveys indicate that almost all architectural offices in the USA will have computers and computer-aided drafting systems of some sort within the next four years. But although every office may have a computer, the number of architects who use one is and will remain quite small. The offices surveyed by us (Radford, 1988) in Australia and Kemper (1985) in the USA still only have about one workstation for every five to ten architects, others far fewer. The office of Skidmore, Owings and Merrill in Chicago has probably the largest investment and largest commitment to the use of computers as a part of the design process. All technical staff are trained how to use the firm’s CAD system as a part of the induction process when they join the staff, irrespective of whether or not they are expected to use the system in their initial activities. Further, there is a climate of expectation that computers will be used on work. Nevertheless, initial design ideas are still predominantly worked out in pencil on paper, and the firm has about a one to five ratio of workstations to architects. Where the computer systems contribute to the process of design is in extending the use of the model of the building set up in the CAD system. By re-using descriptions of the design for different purposes, extending it into the structural and services engineering domains, design really progresses on a much broader front than is common. Decisions are made with much more complete descriptions than in traditional design. The major value of CAD is seen as integration and the continuing propagation of information from early to post-construction stages, rather than its characteristics as a design medium.

In other firms the picture is one of just dabbling with design aids. A typical mid-sized firm with a large CAD system does not do much design work done on it directly (“something that I’m working on; I want designers to be in there and I’m training two of them at the moment”), but it is used for 3D sketches and massing exercises as feedback after the design is done. In another firm, although used for presenting designs, the system is not used for design itself:

"Apart from 3D work, we don’t use it as a design tool. People still sort things out with 6B pencil on detail paper, they don’t sit down in front of a blank screen and start trying to design a building. Maybe that’s where other practices go wrong." (Radford, 1988, p 12)

A third firm, too, is not trying to design on the system, since the mechanics of the operation occupies a large amount of time and attention and inhibits the creative process, but does refine designs through its use: "No one in our office has found that he or she can conceptualise on it. It will take a generation to do that" (reference omitted for anonymity). But if the design is sketched out on paper first, it can be developed on CAD, and it is then possible to transfer from
design drawings to working drawings much faster.

This impression of dilettantism in the design uses of computing is supported by the survey evidence. As shown in tables 1 and 2, most firms have used computers to automate their office functions. Design computing is attempted by a very small proportion of firms. The most recent (1987) survey is complicated by its division of responses as originating from small (1-9 members), medium (10-49) and large (50+). The most common activities of small and medium sized firms were specification writing and office management, the least common were design activities.

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Table 1. Most common applications of computers in architectural offices. Percentage of respondents reporting those applications. (Sources: Anonymous, 1982; Wagner, 1985; Doubilet, 1987)

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Table 2. Most common design applications of computers in architectural offices. Percentage of respondents reporting those applications. (Sources: Anonymous, 1982; Wagner, 1985; Doubilet, 1987)

The 1987 survey also reveals a marked difference in computer use depending on firm size. Larger firms use computers for more applications than smaller ones, and make more intensive use of their computers. The very large firms, those with 50 or more staff, also use their computers differently to small and medium-sized firms. If small and medium firms have used computers primarily to automate the mundane but essential functions of office management, in the manner of any small business, the largest firms have used them to automate the documentation process.

Several important points emerge from these surveys. First, firms with computers are using them to do more tasks. Second, by far the most computer applications were and still are in the areas of office and project management. Computer-aided design activities were very uncommon as late as 1985, and even in 1987 were only undertaken by a small minority of firms surveyed (remember that about 90% of American architectural firms fall into the "small" category). Yet the most common perceived advantage of computers mentioned by computer users in 1987 was the ability to investigate more design options (mentioned by 55% of users). Almost twice as many firms said that computers enhanced the design process as actually used computers to enhance it.
SECOND THEME: A NEW PARADIGM

This mismatch between expectation and reality is reflected in education. The pressure on what to teach is being driven by the perceived needs of the profession via the professional associations. The requirements of the profession are imposed upon the schools through accreditation criteria.

In Australia, the Royal Australian Institute of Architects (RAIA) draft accreditation policy quite emphatically equated CAD with drafting:

"The RAIA expects all graduating students have abilities in the use of techniques of systems drafting together with computer aided design".

This kind of statement reflects confusion of direction. Systems drafting is concerned with documentation, computer-aided design with the synthesis of designs. Do the authors mean computer-aided drafting? If they do mean design, what do they mean by abilities in computer-aided design? Systems drafting is a well understood and useful technique which can be taught as a skill which one is "able" to execute. Computer-aided design is an open-ended replacement of traditional media in design with computer-based media.

The National Architectural Accrediting Board of the USA puts forward a better statement on the importance of the new technology:

"Certain issues of emerging importance in today's society cut across the four areas [of the architectural curriculum] and need to be emphasized in the school's educational programs because of their far-reaching implications for the future of architecture. For example:

— By means of the computer, architects and others are fomenting a quiet revolution in the ways buildings and their technical systems can be designed, in ways designs can be evaluated in terms of performance and cost, and in the ways buildings can be managed and operated — as well as in how offices carry out the work of design and how they manage their practices." (NAAB, 1983, p 8)

American schools have not been keen to "emphasize" computing in their curricula, notwithstanding its "far-reaching implications". In 1982 about one-half of American schools offered computing. Three years after the publication of the NAAB criteria, only 65% of schools offered computing. Only in one-quarter of architectural schools was some computing mandatory (Bollinger and Hinton, 1986; Kalay, 1986). This is a quiet revolution indeed. Part of the problem, of course, is simple cost. Architecture schools are not capital intensive like medical or even engineering schools. Acquiring the computing power sufficient to make computers available to every student at any time would be a huge capital investment for any school, and one with a very short lifespan. In structures or environmental sciences laboratories it is quite feasible to use equipment ten or twenty years old. In a computing studio the situation would be ludicrous. CAD educators can never afford all the desired copies of programs, and writing software in-house is time-consuming and rarely successful. Even more important is the problem of staff resources. Most schools are dependent on two or three technical specialists who often spend much of their time just keeping the system running and acting as trouble-shooters rather than as instructors and researchers.

The NAAB Criteria go on to mention computing five times. The graduating student should:

"understand techniques of analysis including such visual tools as diagrams, charts, models and drawings; also quantitative and computer-based tools applicable to
architecture;... (p. 12)
- be aware of emerging technologies of graphic presentation;
- understand the types of communications media generally used in architecture, including computer-based techniques of graphic presentation;
- be able to convey the essentials of the building or project design by such means as orthographic drawings (plan, sections and elevations), oblique and perspective drawing, freehand drawing, computer-aided drawing and photographs;... (p. 15)
- understand the basics of computer usage in the process and some illustrative areas of application, including design, documentation, financial management, word processing and information storage and retrieval. (p. 21)

Both the American and the Australian policies seem to indicate an awareness of the importance of computing without grasping just how the technology relates to the way architecture will be practised by the graduates of schools of architecture towards the end of the century. The change to computer technology is only part-way through and its implications are not fully understood, any more than in banking, telecommunications, manufacturing industry and other fields. The policies imply that computing can be regarded as a separate class of skills. We should prefer them to make reference to computing as a part of the working environment within which both practice and education exist.

All architectural educators are caught between satisfying the profession's need for immediately employable graduates and producing individuals with a critical, liberal education. Computing educators must balance calls for CAD-system operators, essentially high-technology drafters and button-pushers, to man the systems increasingly found in architectural offices against the need to provide students with a sound theoretical base in CAD systems. Since the most common uses of computers in large architecture firms are for production documentation and management, and the least common are for design aids, the profession interprets 'CAD' as 'computer-aided drafting'. Yet drafting is a small component of the architectural curriculum, and academics interpret 'CAD' as 'computer-aided design'. The profession's demands are quick cures for the immediate problem of computer saturation. Education's intentions are to plan for the long-term, for the profession of the next century.

In teaching CAD it is not enough to simply teach the technicalities of the medium. The essential (and fortunately the most interesting) part is to reinterpret the process given the different medium, to approach familiar tasks in different ways drawn from the characteristics of the medium.

This reinterpretation is a necessary corollary to the notion of computing as being part of the working and learning environment in the late twentieth century and implies that the task of matching education to the technology is one to be undertaken by all educators, not just a few specialist teachers in computing and computer-aided design. The act of drawing is closely linked to the act of design, as a medium of communication to others, and as a means of articulating design ideas for reference back to the designer. Each medium of drawing has its own characteristics. Drawing and modelling via computer systems is different to the equivalent process using conventional media, two of the most important differences being the increased structuring of information in the drawing and a corresponding decreased ambiguity in the representation. The enhanced structuring of information helps in describing the designed artifact to others, particularly for production drawings and linking design to computer-aided manufacturing, but the reduction in ambiguity may impede the exploratory process of the early stages of design. The teaching of design drawing with computer systems should examine the ill-understood relationship between designer and medium and emphasise the different nature of computer graphics in design.

The greater richness and variety of operations possible with a CAD system compared with
manual drawing techniques necessarily requires greater awareness of the medium while it is being used. A study of the kinds and extents of knowledge used by mechanical engineering designers (Whitefield, 1986) suggests:

"Most clearly raised is the problem that the knowledge required to operate the CAD system appears to interfere with the application of the knowledge required to make domain decisions. Various aspects of CAD contrive to increase the need for drawing knowledge and thereby reduce the domain knowledge the designer is able to apply. Moreover, the designers using drawing boards operated in a more breadth-first manner.

Some evidence on design (eg. Jeffries et al, 1981) suggests this is characteristic of more skilled activity... Rather than unburdened, the designer is further hampered by the demands of CAD system operation, because producing a drawing via CAD is a more complex and demanding task."

What appears to be happening is not the simplification of design through the application of technology to a point where the design process ceases to be interesting, as suggested by Cooley (1980), but the addition of another set of knowledge requiring more rather than less skilled designers.

The essential task is to give students a theoretical understanding of the nature of the CAD medium for drawing in design rather than skills in particular current systems, and that such understanding is best supported through a structured exposure to very simple design tasks where the designing takes place "on the computer", and where the characteristics of the medium can be exploited, rather than the modelling of more complex designs initially developed via conventional media. One architecture student describes his experience thus:

"The experience was as frustrating and as ultimately satisfying as learning a new language. You spoke not with hand, board and T-square but with hand, mouse and keyboard. What needed to be learnt was the syntax to string together command instructions to achieve a particular transformation or computer action.

You began to get things done only after you had mastered the command syntax, thus you abandoned the inappropriate hand drawing methodologies. In time, computer drawing even begins to influence your design process. You begin to use the strengths of the system of transformation, replication and revision and avoid graphic solutions that are better suited to manual drawing techniques, eg quick, fluid lines and abstract concept drawings.

(John Ubaldi, Architecture III, University of Sydney)

In the forty or so years that the social and environmental sciences have been seriously taught in architecture schools, their integration with the design studio is still tentative and incomplete. The same holds true for computing. Specific courses labelled "computing" are only a part of the role that computing should have in an architectural school today. They imply a specialist view, looking from the discipline out at the world of architecture. Computers should instead play a pervasive role, appearing in sundry places wherever the models and methods they allow are appropriate. In these situations their use is subservient to the teaching aims of the course, yet the effort required to learn how to use a particular applications program means that too often the tool dominates the purpose. The classic case is the perennial cry for computers in the design studio, where the experience of many schools is that using production drafting systems has simply meant less time for design since so much is diverted to learning how to use the system.

Part of the difficulty in implementing computers in a pervasive role in education is the lack of any coherent or generally accepted model of design and the relationship between design and design media which can draw together the various strands of education in the field.
THIRD THEME: A UNIFYING MODEL OF DESIGN

The best form for such a unifying model is not yet clear and here we shall only put forward a brief summary of one approach which we find useful. At this stage we seek only a conceptual framework in which the diverse aspects of an education in architectural design programs—construction, structures, aesthetics and more—are linked to descriptions of design purposes and the operations that can be made on those descriptions in a way which is appropriate for the characteristics of computer-based design media.

The use of language as an analogy to design has been adopted by both architectural historians and theorists (for example Zevi, 1978, and Summerson, 1985) and by those specifically interested in formulating computer-based design system (for example Štíný, 1975; Oksala, 1979 and Coyne et al., 1989). In the linguistic analogy, the physical parts of buildings are equated with words and collections of words and the way those parts can fit together is equated with the syntax of a textual statement. The composition of parts which constitutes the form of a building is interpreted by an observer as having meaning in terms of function, constructional validity, cultural reference and so on in an analogous way to the interpretation of a written statement by a reader. The attraction of this linguistic model to us in working with computer-based design media is that it can be applied to descriptions of designs as well as designs. For example, when applied to drawings it is the compositions of lines and shapes which are equated with textual statements, and syntactic operations concern the organisation and transformation of those lines and shapes. It is a characteristic of computer-based media that the nature of syntactic operations is more apparent than with traditional media.

In this model, an interpretation is a statement about a design or design description which belongs to some other language (Mitchell, 1983). Interpretation, then, is concerned with mapping between different kinds of descriptions. A “language of lines” has interpretations in terms of an architectural plan; a “language of architectural plans” (Oxman, Radford and Oxman, 1988; Radford, Oxman and Oxman, 1988) has interpretation in terms of functional performance and social significance (Broadbent, 1969). Unlike traditional media, computer-based design media allow these mappings to be made explicit by supporting multiple linked descriptions of the same design. A common example is the association of a database entry as an explicit interpretation of an object drawn in a CAD system. A more sophisticated example would be the association of an adjacency diagram (an abstraction concerned with planning) as an interpretation of an arrangement of spaces (an abstraction concerned with room areas and configuration).

There is a significant body of work in the field of shape grammars (March and Štíný, 1986) which operates entirely in the syntactic realm. A grammar system consists of a set of vocabulary elements, a set of rewrite rules, and a start state, and can be implemented directly in a computer system. Flemming et al. (1986) have demonstrated the utility of such a formulation in studying the language of the Queen Anne style houses of a part of Pittsburgh, and there is pedagogical value in so doing. Hillier and Hanson (1984) have developed a space syntax for the description and analysis of settlements and buildings, which is now being employed widely in the analysis of urban redevelopment areas in Britain and Europe. Less formally, the ideas of syntactic operations map well on to the compositional characteristics of computer modelling systems in terms of transformations and the parameterised instantiation of prototypes.

An extensive discussion of the linguistic model is beyond the scope of this paper (see Coyne and Radford, 1988). The point we wish to make here is that there is a two-way relationship between model and medium: on the one hand, the effective use of computers as a part of the environment in which design education takes place requires a unifying model of design in which their role is clear, and on the other hand the existence of computers as a medium able to support many different kinds of design descriptions and operations makes the development of


Howard, R. (1987) "IT is a Big Hit", *Building* 11 September, p. 88.


Wagner, W.F. (1985) "Results of a RECORD survey: How firms with computers are faring—and what are the non-users waiting for?", *Architectural Record* June, p 37.
