THE PERCEIVED IMPACT OF COMPUTERS ON THE TEACHING OF DESIGN - GOALS AND REALITY

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Abstract

The actual and potential impact of computers on design education is an issue of growing concern for students, faculty, and practitioners. The assessment ranges from very positive to negative. On first sight, the complexity of reasons for and against computers in design seems overwhelming. This paper attempts to isolate reasons for the various attitudes and find a method to judge the impact of computers on design education rationally by identifying goals and comparing them to reality.

Part One establishes facts: the human and financial investment that universities have made in CAD, based on results from publications and a national ACADIA survey, and the investment of architectural firms in CAD, based on recent national and regional in-depth studies.

Part Two examines goals of the use of CAD in the design studio. For better analysis, goals are divided into two extreme categories: tool independent and tool dependent. Tool independent goals are born out of the need to improve the existing design education, independent from technological development. Tool dependent goals are tailored to the alleged capabilities of new software and hardware and to pressure from the professional community. The actual definition of goals for design education will lie somewhere in between.

Part Three examines the reality in the design studio. It tries to determine the place of the computer in the design process from a student's view, and an educator's view. The last section is dedicated to the testing of the developed theory against actual studies.

135
Introduction

Educators and professionals have established computers as an important factor in the teaching and practicing of architectural support and technology courses. Traditional computer tools are less established in the design studio and in the conceptual and creative phases of design. This paper attempts to address the reasons and to propose the development and use of autonomous and intelligent computer tools to make a positive and visible impact on the teaching of design.

With the establishment of computing as an important branch of science, it has become a fast growing field, changing constantly and rapidly. This development is described with the paradigm shift from problem solving approaches towards knowledge-based approaches - or with the shift from traditional towards more autonomous computing in design. Traditional computer tools help students and educators to represent their ideas more precisely, possibly in shorter time, and ideally lead to the testing of more feasible alternatives before reaching a final design decision. Autonomous and intelligent tools fulfill the above functions as well but in addition they have the potential of becoming knowledge-based design tutors and partners. Programs of this kind, based on recent hardware developments and practical applications of Artificial Intelligence (AI) techniques to the design process, do presently exist only in research environments but will enter architectural teaching within the next few years [Schmitt87a]. The implications are far-reaching and worth considering before major investments in human and material resources are made. It could be a fundamentally wrong decision to spend scarce resources on training thousands of students and design professionals to act according to the capabilities of current computers rather than concentrating on basic research to develop intelligent and autonomous programs that understand humans. The problem, then, consists of two parts: should universities and the profession further invest in traditional computing environments, and if they do, how can the shift towards more autonomous computing be facilitated in the future. The following is a systematic description of our experiences and some suggestions. The findings in this study are based on these sources:

1. The 1986/87 NAAB Annual Statistics [NAAB87]
2. The ACADIA 1986 CADD Activities Survey [Bollinger86] in which all architecture schools in North America were surveyed. Sixty-eight out of one hundred and one responded.
3. A study on 256 architectural firms and architects in the Pittsburgh area. All participants were interviewed by telephone and responded to 26 CAD related questions each. The study was carried out in 1984, 1985, and with a smaller sample size in 1986.
4. Interviews with approximately 100 students and faculty at UCLA, the University of Manitoba, the University of Michigan, the University of Arizona, Harvard University, and Carnegie Mellon University.
5. A nationwide survey of 451 architecture firms, selected from ProFile, the official directory of the AIA. 215 firms responded to 13 questions in a questionnaire [Stoller87].

Although a careful effort was made not to over-simplify the results, a few critical problems remain. The sample size, in particular with students and faculty, is limited, the information was gathered over the course of three years, and the set of criteria is not complete.
1. **Part One: Human and Financial Resources**

The decision to introduce computers in the design studio is still a daring one. What makes computers so different from all other teaching and production tools used in design? The answer is threefold:

1. Computers require a substantial investment in human time and skill, and a new approach towards design teaching. Relatively few architects can teach, practice, and keep up to date with the ever-changing technology.
2. Computers require a significant capital investment without clear quantifiable and predictable benefits for the institution. They pose a financial risk that can strain departmental and university budgets.
3. Computers are not a proven technology for the design process. Originally developed for information processing and large numerical problem solving, they have only recently adapted to the mainstream applications of architectural design.

Why, on the other hand, have almost all architecture schools introduced computers and computing in their curricula? In 1986, 68 architecture schools offered on the average 0.8 required and 4.6 elective courses involving computing [Bollinger86]. Again the reasons are at least threefold:

1. Computer technology offers an extraordinary challenge and rewarding benefits to the architect's desire for exploration. This phenomenon becomes obvious in observing students, faculty, and professionals dealing with the new machines.
2. Computers can - if employed wisely - improve the creativity and productivity in the architectural design and production process. They can result in financial savings and in a growing attractiveness and prestige of the institution that offers computers for use in design education.
3. Architectural research in computer aided design is one of the most exciting new research areas and bears the possibility of fundamentally changing the way in which the multi billion dollar construction industry operates. It may be the key to a new and better built environment.

With these preliminary remarks, the following sections will concentrate on the human and financial impacts of computers in design.

**1.1 Human Investment**

In 1986/87, 17411 architecture students were enrolled in North America, educated by 1812 architecture faculty [NAAB87]. The number of faculty involved in computing rose from 140 in 1984 to 213 in 19861. A critical question is: what do these faculty teach - design or computers, or both? And how does this substantial influx of new ideas change the traditional design process? A growing percentage of the advertisements for faculty positions include the request for proficiency or at least literacy in computing which shows that computer skills are becoming a valuable asset for architecture departments. The universities are in

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1 The numbers are based on 86 responses out of 101 schools [Bollinger86]. This corresponds to an average of 3.1 computer faculty per responding school. Relating this number to an average faculty size of 18.1, the ratio would be 17% in 1984 and almost 30% in 1986. However, as only 68% of the schools responded, the known minimum percentage of architecture faculty involved in computing is 8% in 1984 and 12.5% in 1986.
competition with industry searching for professionals with similar capabilities and offering higher salaries. Architectural professionals with several years of computer experience are still rare. Their decision to become involved with the new technology was made years ago at a time when computing was not yet accepted as a mainstream architectural skill. The risk they took is now being rewarded. Administrators are taking a similar risk now in hiring these architects. The potential positive impact of this decision may not be felt immediately. Administrators will have to trust the predictions made by architectural researchers concerning the fundamental improvements caused by using computers in design. In the absence of truly future oriented commercial programs that deliver the promises made up to twenty years ago [Negroponte70], they are not in a particularly enviable position. With the exception of a few research oriented universities which attract sizable funding, any research must be funded internally. In addition, architects with computer skills often request and receive higher salaries than purely design oriented faculty which may lead to internal tensions and the formation of factions. Similar observations hold true for professional firms: having experience in CAD is of advantage for the student after graduation. Both the chances of finding an acceptable job and of a higher than average salary increase. Based on the different studies mentioned above, the following generalizations can be made:

1. The investment in CAD related human resources is increasing steadily in education and in the profession. Starting salaries for Assistant Professors and for architecture graduates with CAD experience can be higher than the average starting salary. In both cases, however, the expectations are higher. The faculty member with CAD experience is expected to bring in research money and thus carry part of the higher salary. The professional with CAD experience is expected to increase productivity in the office significantly, thus justifying the higher salary.

2. Due to the quality of the present architectural software and hardware, many architects with CAD experience end up as CAD specialists in the departments, or as CAD operators in architecture offices. The long term impact of loosing touch with the day-to-day design activity in the university or the office environment is unclear at the moment; well defined career examples do not exist in either case. It seems safe to assume that CAD experience will be an increasingly valuable asset in the future.

3. The advent of more user friendly or even autonomous programs will somewhat reduce the client CAD experienced architects have now, but judging from the present state of research, it will be at least three to five years before these programs will have significant market penetration and impact. At the moment, architecture faculty must spend a considerable amount of time explaining and maintaining the new tools.
1.2 Financial Investment

Despite the drop in cost of computer hardware in recent years, the average price of an acceptable CAD workstation including software is still the equivalent of one year's tuition and fees in a very expensive university (approximately $16,000). This includes a 32 bit workstation with high resolution color screen, multitasking operating system, input and output devices, various software programs, and the capability to function as part of a network. This means that faculty using the capital intensive equipment will normally have to give more attention to the new tool than to the traditional representation tools, which may influence their attitude towards design.

In hardware, major decisions must be made concerning flexibility and upward compatibility. Therefore, machines based on the 80386 and 68020 microprocessors operating at a speed of at least 16 to 20 MHz are preferable over the older 80286 and 68000 processors operating at 6-12 MHz. Random Access Memory (RAM) needed for serious, interactive design work, exceeds the present DOS barrier of 640 k. Core memory should be in the neighborhood of 2-4 MB. Local hard disk storage depends on the number of people using the machine, but should not be less than 40 MB per person. Graphics capabilities include a resolution of at least 1024 by 1024 pixels, color (8 planes deep), and preferably all transformations built in as hardware operations. Machines of this calibre are still expensive, but guarantee not to be obsolete within a couple of years. They are also the prerequisite for computer aided design work not impeded by unacceptable hardware limitations.

On the software side, the decisions are even more complex. A multi tasking operating system, for example Unix, is recommended for design work, including a good window manager. The actual application software would ideally be an integrated package that allows the handling of the complete design process, from conceptual design to working drawings and post occupancy evaluations. No such package exists at the moment at an acceptable price and level of user friendliness. Some high end commercial packages, combined with special hardware, are beginning to address these issues (Intergraph, ARC, Computers 4 Design).

Taking a more realistic attitude, commercial programs such as AutoCAD are a viable alternative. They offer the needed 2D and 3D drafting and transformation capabilities, primitive shading methods, and a built-in programming language (AutoLISP, a subset of Common LISP). This allows the program to function as an interactive, graphic programming tool. CAD programs should also support add-on programs from third-party software developers, an important issue for cost, energy, and any kind of quantitative analysis. The fact that programs like AutoCAD were originally written for small personal computers and at the present do not take advantage of the new processors' capabilities will eventually impede their usefulness and require new program developments. It is recommendable to acquire one kind of expandable program that is capable of fulfilling several needs rather than buying a range of incompatible programs. This will facilitate the teaching and the learning of computer aided design software. Ideally, the program would consist of a flexible core into
which various modules are connected, using the identical building representation language.

The third factor to consider in assessing the financial investment is the maintenance of the hardware and software. This issue plays a part also in the human investment. In general, it is preferable to maintain and update one set of software, which speaks strongly in favor of a networked, multi-user and workstation based system. In our experience, the maintenance of hardware and software is becoming easier over time, but still requires the full time attention of one support staff person for a typical architectural studio cluster.

In summary, the human and financial investments for the new design environment are significant. Dedicated professionals, educators, and support personnel are necessary to make the system work. The time they spend with the teaching, learning, and maintenance of the system necessarily is subtracted from other activities. The advent of autonomous and easier to learn software will have a positive effect, because it will reduce the time spent with the technicalities of the system. Architectural office and design automation has not yet reached the level of efficiency achieved in other service oriented fields, and will not reach this level before software and hardware are available which are as efficient for design as they now are for business applications.

2. Part Two: Goals

What are the goals we try to achieve by heavily investing in personnel and computers? What are the potential benefits? The history of computers and of architectural education and the profession offer some hints. An argument often used is that architecture cannot stay behind the other professions in embracing the new technology without losing its competitiveness. While this is not really a goal, it is one of the strongest reasons. Three different goal directions are identifiable. The first and highest goal is the improvement of our built environment and the quality of architecture; this is a tool independent goal and requires more fundamental research. A second possible goal is to explore the capabilities of existing hardware and software to discover new design solutions and to stimulate creativity. A third goal is introducing computers in the design process is to accommodate the growing demand from the professional community to educate architects who are able to efficiently use the new technology.

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2 In an article in PC Week of September 14, 1987, page 55, Jim Leake describes the true annual cost of a $5,000 PC, amortized over three years in a company with 100 machines and 300 users, with $7,647. The components are $1,667 for hardware, $1,200 for software, support, $1,200 for salaries, $300 for maintenance, and $1,800 supplies. Source: Nolan, Norton & Co.
2.1 Tool Independent Design Education Goals and Tool Dependent Considerations

One of the strongest needs in today's design education is to integrate a design process and a building industry characterized by growing fragmentation. Design studios and support courses often have little or no connection in content or aims. The split between technology and design directions within departments is often quite deep. To use computers as an integrating medium to produce coordinated and eventually better architecture is therefore a desirable goal. In this context, the development of the last five years has been positive: in the beginning, there were numerical programs that only analyzed particular aspects of a building once the structure was completed or the design entirely finished. These programs, often on main frames, were subsumed by programs that included at least a graphical front end. In the next generation, drafting programs included provisions to extract data and to analyze them separately or even within the same program. Today interactive research design programs can give the user much needed feedback on the performance of various design parameters [Flemming86c]. With the next software and hardware generation, autonomous programs should be able to optimize a building design according to a set of multiple criteria, thus giving the user a complete performance prediction and more control over the design outcome.

A second tool independent goal is to develop better presentation and representation for design. With the attempts to formalize several aspects of the design process [Akin86a], it became clear that representation of design is a key to the understanding and thus to the improvement of design. Solids modeling, for example, is one, but not the best way to represent design in its entirety, because it only addresses the geometric nature of design. Performance alone is not a sufficient representation of buildings because it often neglects the aesthetic aspects. Present computers excel in representing and simulating qualitative characteristics of design, but are less efficient at representing the quality of a building. There is a definite need to explore this issue in depth, and results from Artificial Intelligence research, in combination with new programming approaches, such as object centered programming, are encouraging [Schmitt87a]. These new programming approaches are a serious attempt to find an abstraction that is more applicable to represent the interactions between geometry, functions, performance, and aesthetics of a building. Better representation of design also means better presentation of design ideas, because thoughts, facts, and particular features of design can be highlighted, exaggerated, or de-emphasized if they are contained in a general representation of the building.

The third tool independent goal should be the maturing of programs to become design aids and design consultants. This will allow better presentation of design ideas and stimulate creativity. It eliminates considerable guesswork and dead ends and may lead to better design solutions faster. Autonomous programs, heavily equipped with design knowledge and decision aids, will be an appropriate vehicle. Research in this area is moving slowly, often due to resistance from traditional designers and programmers who see this area as the last human resort of design freedom. Without moving towards this goal, however, future design programs will remain glorified drafting packages.
Tool dependent considerations are based on the acceptance of today's technology and on the use of particular hardware and software to its fullest potential for design education. The results are often astonishing, if the emphasis is on the principles of design rather than the application of perfect tools. The inherent danger is an over-simplification of architectural forms and in the worst case the exclusive dealing with toy design problems.

A second tool dependent consideration is to get the available technology to students as fast as possible. A reason behind this goal is the assumption that, whatever software and hardware is selected, it will be obsolete in a few years, consequently the most important thing is to get started somewhere and somehow. This very pragmatic consideration is often supported by software and hardware producers through extensive grants. These grants are normally intended to make students and faculty familiar with the brand name and build up future customers, but they can be of benefit for both sides.

For education, tool independent goals are most important, because they aim at improving the process and the quality of design without being restricted in theory or reality by the limitations of machines or programs. If eventually reached, tool independent goals will have caused the most fundamental changes to the process of design.

2.2 Requests from the Design Profession

A third major factor in the decision for the introduction of CAD in the design studio is the potential pressure applied by the professional community. Should it be a goal in the introduction of CAD to accommodate these requests? The pressure is usually production oriented and includes requests for computer drafting literacy and the basic understanding of computer software and hardware. In other cases, the capability to modify and customize existing programs is required. Few professional architects ask for graduates who are able to write entirely new programs or even develop architectural research. These interests normally come from very large firms. In most cases the requests are not for design automation but to expedite the drafting and working drawing production process for purely economical reasons. In deciding which computer hardware and software to introduce into the studio, advice from the professional community can be very helpful. Real life experiences with equipment or software are invaluable to avoid costly mistakes. However, universities should not expect too much from the professional community in terms of software and hardware advice, because the goals of an institution and the goals of practitioners will always differ significantly. Practitioners look as much for advice from the universities as vice versa. Therefore, while a goal of the introduction of computers in the design process should be to satisfy the needs of the design profession in principle, it is not the role of the universities to become training centers for particular hardware and software configurations. The often criticized unwillingness of universities to teach practical problems only, while concentrating on underlying principles, will in the long run benefit the profession more than one-dimensional, completely applied
3. Part Three: The Reality

The reality of computers in the design studio is characterized by pragmatic decisions. The overwhelming majority of programs belongs to the class of traditional, algorithmic drafting and analysis packages. Autonomous design programs or design automation packages are practically non-existing in today's design studios. The following sections show that there is a wide gap between many students' and educators' expectations and the capabilities of traditional computer tools. within the student and faculty population, three main groups exist: the enthusiasts, the indifferent, and the opposed. Their views will be represented separately. The last section describes the attempt to learn from this experience and to apply the findings to actual design studios.

3.1 A Student's View

From our experience, the majority of students are heavily influenced in their attitude towards computers and computing in design by the very first teachers they have. Students' assessment of the potential of the new tools range from complete opposition to overenthusiastic acceptance, with between one and two thirds being indifferent. Students' attitudes are important because they produce the most accurate evaluation of the new tools: they must use them, but they have no financial interest in a particular technology, and they do not have previous knowledge they may want to maintain or defend.

Students who are most interested in getting a well paying job after graduation are normally quite positive towards using computers in design. From talking to architects, they are often influenced by the profession's goals (see above). These student's arguments are:

- Computers are interesting and help to develop design ideas faster.
- Computers allow the production of fast perspectives.
- Computers help organization in design.
- Architectural offices use them, so we must know about them.

Students who are indifferent towards the new technology are so for good reason: they have not seen tremendous improvement in the quality of design or in the time spent to finish a design by using computers. There are few role models of excellent architects using CAD as a design tool. They may also be influenced by faculty with a wait-and-see attitude. It is important to understand these students, because they are a valuable group to test the quality of teaching and technology. These students can be convinced to get involved in computers only if:

143
• The software is user friendly and easy to learn.
• The software is fast and flexible enough to allow real time design exploration.
• The software is a real help in preparing attractive presentation drawings.

These students are normally not interested in:
• Any problems involved in getting, installing, and maintaining the software.
• Any hardware configuration, as long as it performs well.

Their attitude towards autonomous programs and design automation is positive if it will improve the design exploration process. A problem is, though, that it is difficult for these students to understand the implications of a technology they do not even know.

A third group of students is outright hostile towards computers in design, in particular towards design automation. Their main argument is that the curriculum does not leave enough time to get involved in CAD. They are also influenced by peer opinions and faculty or professionals with negative attitudes towards computers. Their main arguments are (some of them taken literally from faculty evaluation sheets, if the same argument appeared several times):

• No time, too much other pressure.
• Computers have not done anything yet to improve architecture.
• Designers and computers cannot communicate
• Computers are slow, rigid, and restrict the design exploration process.
• The purpose of a school of architecture is to teach design, not computers.

To teach a design studio which includes this last kind of students can be very difficult. Our experience has been that the general opinion of students towards computers in design will not change in classes with one third of the students objecting to computers, but that the working atmosphere and the results are better in classes composed of students with indifferent and positive attitudes. In these cases, the indifferent students normally become more optimistic, whereas the enthusiasm of the previously optimistic students is somewhat reduced. We therefore recommend not to force students into CAD studios or assign them randomly. We also do not recommend to compose a studio solely of computer enthusiasts. The right mix is one third of very interested students and two thirds of students who are indifferent towards CAD, but who are good in design.
3.2 An Educator's View

Interestingly enough, the educator's view and opinions are not too different from the students'. The three groups: enthusiasts, indifferent, and opposed are more outspoken in their arguments and more difficult to convince otherwise in any direction.

Some enthusiasts believe that design is merely a problem solving and rational decision-making process and that computers are the ideal vehicle to be applied to this process. In extreme cases, anything in design that does not fit in this mold will be ignored or dealt with "later". Enthusiasts are often found with tool dependent goals (see above), or professional productivity goals. Not always do enthusiasts have the deepest knowledge of the field. Once their knowledge grows, the enthusiasm is normally turned into a more realistic view. Given the chance, the enthusiasts will thoroughly modify the teaching of design studios. Their attitude towards autonomous programs and expert systems is mostly realistic.

The second, indifferent group of educators takes an attitude of wait-and-see. They have not seen tremendous improvements in the teaching of design or in the design product since the introduction of computers. Similar to the equivalent student group, they are the critical people to convince and therefore fulfill an important function.

The third group is that of the absolute opponents to the use of computers in the design studio. Again, their criticism, if constructive, is essential. The arguments reach from:

- Unnecessary waste of time and money.
- The best architecture was designed without computers.
- Students get distracted from other important fields of study.

Their reaction, when confronted with the possibility of more intelligent, autonomous programs in the future, ranges from even stronger objection to a slightly more positive view.

3.3 A Professional's View

The professionals fall into three groups as well. However, their arguments for and against computers in design are different from the other groups.

The enthusiasts have experienced or believe in economical windfalls with the introduction of computers. The most frequently quoted arguments are:

- Increase production without increasing staff.
- Same production with less staff.
- More control over the design and budget process.
- Higher accuracy in drawings, facilitated editing.
- Higher profile with clients and colleagues.
Enthusiasts seem to stand by their opinion for some length of time even if they have to accept sacrifices in reaching their goals. However, they are very interested in hiring students with CAD experience.

The indifferent group is much smaller amongst professionals than amongst students and educators. A certain polarization has taken place - as a practicing architect, it seems that one must have an opinion for or against computers. The interest in autonomous and intelligent programs is greatest in this group. Members of this group feel that it makes little difference if an architectural student has CAD experience or not, but normally they will not hold it against her or him if they do.

The third and last group, considerable in size but decreasing, opposes computers in design. This group consists of architects who tried the use of machines and failed, and others who do for some reason not plan to invest in this technology. The arguments most often heard are:

- Too expensive.
- Not enough work.
- No good software.
- Too busy to learn the new technology.

The overwhelming reason for objection to computers is of economical nature. The argument "too expensive" or "no clear financial benefits" is a standard reason for objection. Interestingly, the danger that the equivalent educator and the student group see, i.e., the limitation of design freedom, is seldom an issue with the professional group. Age, experience, and different priorities may explain this fact.

3.4 Applications

To explore the validity of the previous statements and to substantiate some of the claims, we propose to look at actual design studios. Nine students, ranging in their attitude from enthusiasts to indifferent participated in the studios which took place in fall 1986 and in spring 1987, using AutoCAD and MegaCAD on five IBM ATs. The computers were equipped with color screens of 640x480 pixels resolution and 20 MB hard disks. An 8 color E-sized plotter served as output device. The studios consisted of interrelated modules, each with a particular focus. In the first studio, the emphasis was on occupancy considerations and the final project was the design of a school of architecture. The second studio concentrated on the study of architectural language.

Module One introduced the students to programs and computers - with the exception of the enthusiasts they had no in-depth knowledge of the software. After a very steep learning curve in the first week, all students were roughly at the same software knowledge level at the end of the second week. Little progress was made in the remaining weeks in exploring special program features.

Module two consisted of the analysis of an existing Fine Arts building and of Mies van der Rohe's Crown
Figure 1: Top: The College of Fine Arts at Carnegie Mellon University, presented as the result of extensive analysis. Norman Larson.
Bottom: Two ways to analyze and interpret a house by Adolf Loos. Studio of Ulrich Flemming.
Hall on the IIT campus in the first studio, and of the analysis of Adolf Loos buildings in the second studio. The purpose was to discover and to explore the computer's power in dealing with repetitive elements of varying size, and with the representation of architectural language. The results were excellent in both cases, the only problems occurring with storage capacity and redraw speed (up to one hour). The products were analytical slide shows with explanatory text for both buildings, as well as a set of large pen plots of the two buildings (see Figure 1). The analysis of existing buildings was most rewarding for students and faculty, as it involved a relatively easy mapping process between the object and its interpreted representation. Other positive findings were the three-dimensional capabilities of the computer and its strength in dealing with repetition, symmetry, and scale.

Module three included the preliminary design of the school of architecture in the first studio, and the design of a writer's pavilion in the second studio. The first studio stressed the development of alternatives, and the selection of the best solution after an evaluation based on analysis according to several criteria [Flemming86c]. Although a prototype of a semi-autonomous interactive evaluation program was available, it was not heavily used. This module was closest to the traditional design studio context; the students were not required to use the computer for the actual design drawings (the enthusiasts and some other students did anyway). The results were mixed. From a design standpoint, the enthusiasts did not produce the best solutions. However, they attracted the most interest from the jurors (carefully selected according to the three groups of computer opposing, indifferent, and enthusiastic faculty and practitioners). The possibility to evaluate the early design according to different criteria with intelligent programs was unanimously praised, the results, however, were judged independently. The second studio focused on the design of a writer's pavilion in one of the architectural languages explored in the previous exercise. Students relied heavily on the perspective capability of MegasCADD. For presentation, the files were transferred and plotted in AutoCAD (see Figure 2, bottom). The hardware and software limitations became obvious in this project. User interface, screen size, and execution speed could not live up to the student's and instructors' expectations.

Module Four emphasized design and presentation. By this time, the indifferent group had moved to a much more positive attitude towards the use of computers in the design studio, while the enthusiasts were noticeably more realistic. The limitations of hardware and software became more obvious in the design stage (the above request for more powerful machines and software is a result of this and earlier experiences). The more experienced design students dominated the field and creatively compensated the sometimes missing software knowledge (after the first week, the learning curve flattened immediately, due to the overwhelming other requirements). The most positive impact was felt in producing site plans and three dimensional representations (see Figure 2, top). The anticipated plotter bottlenecks in the last two nights before the final jury did not occur. The final jury, again selected from the previously described groups, commented as
Figure 2: Top: Axonometric view of the architecture school design. Alexander Biagioli. Bottom: Perspective tour through the writer's pavilion. Norman Larson, studio Ulrich Flemming.
expected, with the exception of one previously opposing member, a senior design faculty member, who declared himself convinced of the power of this particular design approach in the conceptual design phase. The results of the studio were as good or better as the traditional design studios. This observation is based on an anonymous evaluation of all design projects by all design faculty members.

4. Conclusion

The decision to introduce computers in the design studio is for good reason a daring one. Not only does it have impact on the teaching of design, but on the careers of students and faculty, and on the future of the profession. Three equivalent groups exist in the three populations: the enthusiasts, the indifferent, and the strongly opposed. The strength of the groups varies over time and with the different backgrounds. The only clear trends are:

- The acceptance of computers in design is growing throughout the three control groups.
- The time factor is most important for the student and for the professional group, but for different reasons: students are under too much pressure from the other courses, professionals are under too much pressure from their clients. In both cases, the enthusiasts expect major time savings from the new tools.
- Little is known and little has been thought about the impact of intelligent or autonomous programs or their impact on the teaching of design.
- The strongest interest for intelligent programs lies in the indifferent group within professional architects.
- The financial impact of introducing computers in the design process is of highest concern in the professional group and least important in the student group.
- The student group identifies most easily with the tool independent and the professional goals.
- A certain intellectual fear is strongly developed amongst the opposing groups, most strongly amongst the educators.

The impact of computers on the teaching of design is as complex as the groups that judge it. Extensive de-mystification and explanations of the true capabilities and dangers of the new tools is still necessary. The acceptance will only grow if the goal of creating better architecture with the help of computers is achieved.

In conclusion, the lessons learned point towards several possible avenues for future enhancements in the use of CAD in the studio. One of them is the "SM" approach: more memory, more pixels, more color planes, more MIPS (million of instructions per second), more data base capabilities [Mitchell87a]. With time and financial resources, these hardware and software oriented problems will be solved which in turn will reduce the importance of tool dependent considerations. A second avenue leads toward the development of a new teaching methodology for architectural design, with the new tools as active partners. This approach will delegate some teaching responsibilities to computers, supplied with the instructor's and other architectural experts' knowledge.
5. Acknowledgements

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[Stoller87] Stoller, Adam. 
Session Introduction
Charles F. Morgan, University of Florida 155

"Study Drawings in Architectural Design: Applications for CAD Systems"
Daniel M. Herbert, University of Oregon 157

"A Fractal Studio"
Chris I. Yessios, Ohio State University 169

"Aspects of Rules and Language in Design Decisions"
Robert E. Johnson and Yasser Mansour, University of Michigan 183

"Graphic Standards: IGES and PDES in an AEC Environment"
James A. Turner, University of Michigan 195