USING CAD TO TEACH ARCHITECTURAL DESIGN

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ABSTRACT

A CAD program with solid modeling capabilities was used as the primary instructional media for a graduate level architectural design studio. The objective of the studio was to enhance design education by use of the CAD tool. A series of projects were designed to utilize CAD most effectively without sacrificing complexity and depth of educational content. The experiment identified several pedagogical advantages of CAD for design education and also some problems that have to be resolved to take maximum advantage of these tools.

INTRODUCTION AND OBJECTIVES

CAD can be a powerful tool in teaching architectural design. It is clearly more useful then simply a means to increase productivity or generate more accurate and sophisticated presentations.

Two primary goals of an architectural design studio are:

1. Increase the students' understanding of geometric form and how it can be manipulated,
2. Help students learn to utilize the knowledge base available for solving architectural problems.

CAD has the potential to enhance the satisfaction of both these goals by providing new ways to visualize and manipulate form and by allowing the use of highly interactive knowledge bases (Miller, 1987/88). This paper describes a one semester experiment that was designed to introduce a sophisticated CAD tool as a primary resource for a graduate level design studio in order to explore that potential. Successful introduction of CAD should take advantage of its potential without disabling the existing resources utilized in the traditional paper based process. CAD tools must coexist with traditional tools, each used for its most appropriate purpose and all working together to achieve the studio's basic goals (Miller, 1987/88). Each tool used by a student designer to represent a design is a different way for the student to reflect upon the evolving project, gain new insights and apply new knowledge. Since the time constraints of design studios are quite rigid, the experimental CAD studio was structured to emphasize CAD and the particular impact it had upon the educational experience. It's relationship to other media was important but the use of CAD tools was considered the highest priority.

The use of CAD by novices commonly results in a decrease in design productivity. More time is devoted to learning how to use the new tool than to the design task. The experimental studio was designed to explore how the act of learning the CAD tool could also be educationally valuable. To compensate for the expected decrease in productivity, design studio projects of limited scope can be offered. However, an important benefit of using computers should be an increased ability to deal with more complex problems. Thus, the experimental studio was designed around problems that were typical of advanced studio assignments, and a strategy to compensate for the productivity loss was developed.

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We viewed this experiment as only one step in a long range strategy towards fully integrating CAD into design education. This initial studio was designed to test a number of concepts and provide us with directions to explore in future years.

CAD SYSTEM, SETTING AND PARTICIPANTS

The studio utilized Worldview, a program developed at the SUNY/Buffalo Department of Architecture. It is a true solid modeling program, although it does have some important limitations. The main features of Worldview are:

1. Extrusion, rotation and translation of 3-dimensional objects.
2. All drawings reflect changes made in any one drawing.
3. Unlimited number of views of each object.
4. An unlimited number of windows available on the screen at one time.
5. The availability of instancing so that the change to one object can be reflected in duplicates of the object.
6. The availability of overlays so that any amount of information can be abstracted from the total model and viewed separately or superimposed.
7. Three dimensional data on any project can be shared by any number of users in library files.

The limitations of Worldview with respect to solid modeling, are that it lacks:

1. hidden line removal,
2. a paint program to render surfaces,
3. union and intersection operators for 3-dimensional objects.

The hardware used in the studio changed from the first half to the second half of the semester. In the first half of the semester, six Tektronix terminals operating off SUN workstations were available. By the second half of the semester, a new version of the program was developed that ran directly on ten SUN workstations. Optical mice were used for data entry which precluded tracing drawings. Two plotters were available, one for small size single colored drawings and one for large multi-colored drawings with pen options.

The facilities for the semester were almost ideal. The paper and pencil studio was practically adjacent to the computer laboratory. Priority access to the equipment in the lab was established for the studio and the students generally had full use of the equipment during studio hours. There was enough equipment available so that there were few problems obtaining access to terminals. However, construction in the laboratory and equipment breakdowns did cause intermittent access problems.

The II students chose to take the studio primarily because of their interest in CAD. Ten of the students had some previous experience with computer aided design. Those who had previous experience with Worldview, had used an earlier version which was much more less sophisticated than the current version. Even with this experience, all but one of the students would still be classified as novices with solid modelling.
THE EDUCATIONAL PROCESS

The studio was organized into four progressive phases:

1. learning how to use the tool,
2. modeling as observation,
3. modeling as knowledge representation,
4. design synthesis.

Each phase introduced new concepts and methods and an increasing level of complexity in CAD modeling. Each phase was designed so that there was transferrable knowledge to the next, in terms of both skills learned and content. The subject matter was urban multi-family housing designed for access and use by people with disabilities. This topic was selected both because of the expertise of the primary studio instructor and because of its appropriateness for CAD application.

The project offered several significant opportunities and challenges for the application of CAD tools. On the one hand, the design of housing involves the development of repetitive elements that fit together in an additive manner. Technical information is readily available and can easily be adapted for use in an interactive knowledge base. Creating variation in the design of such housing is a key aesthetic and programmatic goal that makes simple repetition an inadequate response. Also, the urban context and scale demanded that buildings fit carefully into the surrounding context. Since the project focused on housing that was accessible for disabled people, existing precedents had to be rethought and modified and expert knowledge consulted. In summary, the project offered both good opportunities to use the power of computers and also demanded a sophisticated level of manipulation of form and application of knowledge.

The first project (3 days) was basically an exercise to become familiar with the CAD concepts, commands, user interface and hardware. The assignment was to draw LeCorbusier's Dom-ino concept. A drawing and step by step procedure was provided to the student, but they were free to select views of the model and develop their own presentation format.

The second project (2 weeks) was a visualization exercise in which students used solid modeling to learn through observation. Each student found an outstanding example of multi-family housing that was interesting from an architectural perspective. From the 10 to 12 examples collected, six were selected and assigned to teams of one or two students. Each team generated a solid model of the project by estimating dimensions from documentation found in the school library. The model was then manipulated to represent the formal qualities of the building. Emphasis was placed on experimentation with presentation methods that combined CAD and hand techniques. The model was not necessarily a complete representation of the building. The students were encouraged to explore fragments or abstract characteristics of the building. A number of presentation techniques were utilized including unusual perspective views, collages of images, photo-reproduction techniques that allowed the removal of hidden lines and hand painting of computer plots.

The third project (4 weeks) was the development of "Library of Spaces". Through library research, information was collected on the design of typical spaces in dwelling units. This information was then transferred into a graphic 3-D CAD knowledge base which could be accessed interactively. This exercise had several objectives. The first was to ensure that the students understood the dimensional constraints in housing design. The second was to begin the development of a shared knowledge base to be used in future projects. The third objective was to develop "building blocks" for use in the design process, thus capitalizing on the additive nature of the housing design process.
Teams of one to two students were assigned a room type. Each student identified the types and sizes of furniture used in that room and developed a typology of design layouts for the space. The library included 3-dimensional models of furniture and layouts for each of the principal options in the typology. All of the layouts developed were combined into one read-only file. The students could copy the files into their own work space and manipulate them at will. Prints of the whole library were available. Conventions were established for drawing spaces in the library so that all looked relatively the same in terms of presentation technique.

The major project was a competition project (8 weeks). The objective was to complete a housing proposal for an urban site in Syracuse, New York. The programmatic requirements were very general, however there were strict rules for the use of the site. The basic requirement was that the housing be adaptable for use by disabled people; thus, an emphasis was placed on accessibility features. In examining the site context, we discovered that the impact of the surrounding buildings was great. A landmark work of modern architecture, I.M. Pei’s Everson Museum, was on an adjoining block and a major development project was planned on another adjoining block -- a convention center/hotel complex. Within the confines of the block allocated to the project was a large parking garage to serve the convention center. This presented a major constraint on site planning. Vehicular access to the site was restricted greatly by traffic patterns.

The major project started with the development of a solid model of the site and its context and an analysis of the site and program implications. Urban design studies and massing models were then developed. After each student had settled on a basic urban design approach, apartment units were designed using the library of spaces. The competition required a minimum of three different types of apartments. Students then began working on the detailed building design including structure and circulation schemes. Finally, attention was given to elevations and special accessibility features.

RESULTS

The Dom-ino project was a very useful way to introduce the Worldview program. As novices, the students tended to use the default views provided in the program. They let the program dictate their visualization. After a critique, the students immediately began investigating alternative views and, in the process, learned more about the Dom-ino design. It became very clear from this initial project that giving criticism and assistance with drawing was much different using CAD than paper and pencil. It is difficult to give a critique on a CRT screen. The size of the image in a multiple window format is very small, so zooming is required to see any detail. This means that the instructor must wait for the screen to refresh and a sense of the whole can be easily lost. Students should be ready with printsouts before criticism is offered but this can reduce the spontaneity of informal crit sessions. Another problem facing the instructor is learning how well a student has learned the program. The Worldview program is complex and sophisticated. Concepts such as instancing and relocating points in a 3-dimensional coordinate space are not easy for the novice to understand. Printsouts themselves are not always useful for identifying difficulties and lack of understanding. Unfortunately, errors were manifested by corrupted files and incredibly distorted drawings, often beyond salvage. The perspective generation capabilities of the program resulted in a high level of redundancy within presentations. Using a paper and pencil process, it is difficult to squeeze one perspective drawing out of a hard pressed student. When any number of perspectives can be easily generated, the students have to learn how to select drawings to include in their presentation. Otherwise they may waste a great deal of time plotting and finalizing unnecessary views. Presentations can become unclear and confusing without careful editing.
The students had a difficult time beginning the second project. There were many false starts and slow beginnings. Since each building was very different, the instructor could not describe a generic model-building process. Each student had to identify the best way to build their own model. As they started to develop them, it became apparent that there were still some concepts in the use of the program that not all of them had grasped. For example, a wall can be represented as a double line or single line. If a double line is used, the inside of the wall can be treated as an edge of a room or the wall can be separate from the room plan yet be drawn directly over the edge of it. A decision to draw the wall one way or the other results in constraints in how the model can be utilized and analyzed at a later date. With a single line wall, the building envelope cannot be separated from the floor plans or structure. With the first type of double line wall, the envelope of the building can be separated from the floor plans but it will have no thickness. In the second type of double line wall, the envelope can still be separated from the floor plans and it can also retain its thickness as an independent object. Students had to plan their model carefully in order to utilize it effectively for analysis purposes.

This case study exercise forced the students to study the buildings very closely (see Fig. 1). They had to understand how the building was constructed and how it could be represented. They could not cheat in representing it because the computer demanded preciseness. They were able to uncover methods used by the designers to create variation and formal complexity and they began to discover the "decision tree" behind the design. For example, several of the buildings were designed with a "root" dwelling plan upon which systematic operations were applied to create variations. To construct the model most efficiently, the students discovered the "root" plan and then applied graphic operations to it in order to generate the variations. In this way the designer's thinking was made explicit and reconstructed.

Although learning how to model the building took valuable time away from the analysis task, it was very useful for learning how to utilize the CAD program and how to systematically plan the construction of a model. It also helped the students to better understand the properties of the forms that they were manipulating, perhaps even more than the analysis task itself.

A conventional understanding of a building is that it is all one object. The model building and decomposition process shatters that perception and helps the students perceive the building as a complex organization of many objects and voids. Modeling void is a difficult concept for many students to grasp. However, design educators know that it is fundamental to the development of good architecture. Solid modeling through CAD enables students to better understand how void can be designed. One can easily draw void and solid as two separate entities, bring them together, or separate them instantly.

Those forms that were most difficult to model were often the most interesting from an architectural point of view. Architects such as Aldo Rossi, Frank Lloyd Wright and Ricardo Bofill blend one object into another, create complex compositions intertwining solids and voids, and generate subtle variations that can often take intense study to grasp. From a 3-dimensional scale model or drawing it is easy to overlook the lessons to be learned from such manipulations of form, but, using the computer model, the level of precision required to create the representation and the potential for applying shape operators to increase efficiency in model building demanded more careful observation and reflection.

Using a conventional physical scale modeling method, the same project would have taken three times as long. Not as much would have been learned and the exercise would have been more literal and less precise.
Fig. 1  Case Study Analysis

Fig. 2  Library of Spaces - Kitchens
In particular, the logic of the design would not have been made as explicit. Although a good instructor could probably have conveyed the same amount of knowledge without using the old modeling technique, the latter allows a student to learn more on their own with less guidance and formal lecturing.

Development of an interactive graphic knowledge base is a powerful way to encourage use of empirical knowledge and precedent as part of the design process (Miller, 1987/88). Often in design studios, predesign research is considered by students to be peripheral to the project objectives. Even more often, the data collected are not effectively put to use during the design process. The third assignment -- the Library of Spaces -- was approached with enthusiasm. Students recognized the usefulness of the exercise since they knew it would have direct application to their major project. The emphasis of the major project on accessibility for disabled people encouraged a focus on ergonomics which was sustained through the rest of the semester. The typology encouraged a focus on convenience, cost effectiveness and explicit judgement about trade-offs between user preferences.

Development of the Library required a large time investment, not only on the part of the students, but also on the part of the CAD laboratory staff. A system of transferring files from one user workspace to another and organizing the library files had to be developed. Many unanticipated problems were encountered since the program had never been utilized for sharing data bases constructed by novice users. The class met as a group with the laboratory staff to work out conventions for drawings and learned about the process of sharing information in digital form. The time investment in the library must be viewed as a one time cost. Future classes can make use of the same knowledge base but devote more of their efforts toward manipulating and applying the knowledge rather than initial entry of data (see Figs. 2 and 3).

From an educational point of view, the use of the computer knowledge base is much preferrable to a paper and pencil approach. The drawings were easily modified. Fixtures could be moved independently as opposed to paper and pencil where an entirely new sketch must be made each time a piece of furniture is relocated. The greatest benefit, however, comes from the ability of the students to utilize the drawings directly. Redrawing is minimized. The elements of the building with which the users interact most intensively become a part of the design right from the start. This results in more attention given to the issues of furnishing, convenience and user needs than would otherwise be the case. In paper and pencil mode, room layouts are often left to the very end of the project. Even when the instructor emphasizes these concerns at the beginning, they are often neglected as the design progresses through further stages of development. Successive editing of furniture and fixtures occurs as a designer shifts attention to other issues. With solid modeling however, furniture and fixture layouts remain part of the design at all times and the building design evolves around them.

The competition was intended to focus on the accessibility elements of housing design, however the site chosen demanded considerable attention to urban design concerns. Thus the two primary issues of the project centered on issues of greatly different scales. To address the urban design issues, a site analysis was conducted using both computer modeling and paper and pencil studies. The site was very large and open. There were new buildings proposed for both the block on which the site was located and a major adjoining parcel. The imageability of the site was low. It is currently a large parcel of urban renewal land occupied by a vast sea of parking. Thus, it was difficult for the students to understand how the proposed project would relate to the rest of the city. Materials were gathered from previous urban design studies of the area and video tapes and still photography were used to capture its visual character. Building sizes were estimated and developed in the site model as simple rectangular solids. The model of the context allowed views of the CBD and from the street to be taken from any vantage point. Students were able to fit their own urban design proposals into the site model and view results from any angle.

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Other studies of traffic circulation, pedestrian access and open space (eg. figure/ground diagrams) were completed. These were not implemented through computer aided design because they were essentially 2-dimensional drawings that could easily be developed by drawing on copies of the site plan.

Direct digitizing of video taped views of the site would have been a great enhancement to this process, especially for views taken from a high rise building in the CBD. However, the equipment we had available did not allow the capture and storage of video images.

The development of dwelling unit plans was approached by most students by direct utilization of the Library of Spaces. Each student decided on a mix of appropriate room types and sizes in a dwelling unit. Selecting from the Library, they built crude room layouts (see Fig. 4). Using paper and pencil, they made an overlay sketch of the crude plan, adding architectural features and adjusting sizes so that the rooms worked together as one plan (see Fig. 5). They then "renovated" the initial CAD plan by adding walls and moving furniture around or completed an overlay plan and transferred furniture to it. From the early stages they were able to study rooms and spaces using 3-D visualizations. After criticism of the initial dwelling unit plans, the designs were renovated in order to insure accessibility for disabled people (see Fig. 6). The process again involved tracing paper overlays and revision of the computer model. The dwelling units were designed separately from the massing models of the initial buildings.

The building design began with urban design proposals. Most students started with hand drawn axonometric sketches from one vantage point to generate an initial scheme. They did a site plan in the same manner. Once they had developed a basic concept they entered the design as a site plan into the computer and extruded it to make a massing model that they then study using Worldview's perspective generating capabilities. Overlay sketches were used to revise the designs and students moved back and forth between the sketches and computer model.

The degree to which the students utilized paper and pencil as opposed to computer modeling varied depending on the individual's level of comfort with the computer and the nature of the design they were pursuing. As the designs progressed from massing studies to more detailed building designs, computer modeling became more useful. Dwelling unit plans were easily copied into the building plans. The adjustment of bay sizes, addition and deletion of bays and floors could be implemented rapidly.

As design projects advance to the level of floor layouts and structural concepts, there is a tendency for students to resist making major changes in their work. A major advantage of computer aided design is that, as long as the basic concept is not completely abandoned, changes can be made easily. In this case there was no established limit in terms of the number of units in the project. It was more an exploratory study to find the best match of urban design solution and context. Thus solid modeling was very helpful in exploring many different alternatives, visualizing the results and making further decisions about the character that the project should take.

Students made heavy use of perspective views (see Figs. 7), much more so than in a typical paper and pencil studio. They found that CAD was most useful for modeling repetitive elements. Developing variation to those elements could be more readily accomplished by drawing over the plot. There was a strong tendency for students to use the specific powerful features of the program neglecting manipulations of form that required more tedious operations. In the case of Worldview, these features were extrusion, rotation and translation. Transforming objects in ways that compared to carving clay was more difficult and thus tended to be left to the overlays of paper and pencil or simply neglected.
Fig. 3 Library of Spaces - Laundries

Fig. 4 A "Crude" Plan

Fig. 5 Overlay Sketch
Fig. 6  A "Renovated" Plan

Fig. 7  "Worked Over" Perspective
The lack of hidden line removal was a serious limitation of Worldview. If views were taken of the
massing model from a point that was low to the ground, all of the buildings in the surrounding CBD
This made it difficult to look at the building design from low station points because it was hard to
distinguish which lines were from the design and which were from the existing context. Thus
students tended to use views in which it was easier to distinguish the buildings from the context.
Sectional drawings were practically impossible to read and the students avoided them. Not enough
emphasis was placed on construction systems or on developing the 3-dimensional design potential
that sectional views help identify.

CONCLUSION

The experimental studio identified several pedagogical advantages of CAD modeling at an advanced
level in architectural education. The power of solid modeling for studying 3-dimensional issues is
far greater than either pencil and paper or scale model. Many more views can be generated in the
same time than with paper and pencil. This allows students to visualize the project more readily
and understand the implications of their decisions. With respect to physical models, the ability to
alter designs is much greater and the same model can be used to study the building from inside and
outside as well as at any level of detail or abstractness. Research information can be put into
graphic form and shared directly by all students. This access to a knowledge base allows a greater
depth of inquiry by each individual and increased utilization of precedent and empirical knowledge.
Design work can continue for a longer period of time because output in presentable form is easy to
obtain. Even at the very end of the semester students were able to revise final presentations within
hours by generating new views and different size drawings.

This particular experience with CAD also uncovered some serious problems that must be overcome to
make use of solid modeling most effective. Complex solid modeling requires extensive familiarity
with the program before its advantages can be fully realized. In this studio, the level of three
dimensional investigation achieved by the students during the major project was below what the
same students would have achieved with paper and pencil. This occurred because much time was
lost due to mistakes made in the use of the program, hardware breakdowns, software bugs and
limitations in the software.

Although sophistication in manipulating form was limited, the knowledge gained from visualization
and the utilization of the knowledge base on housing was probably far greater than what the
students would have obtained in a typical paper and pencil studio. Ideally, the benefits of computer
aided design should be reaped without sacrificing anything achieved in a conventional studio.

CAD is a medium that demands preciseness which means that much time can be wasted doing
accurate drawings at preliminary stages of design, unless students learn how to combine the use of
pencil and paper and computer modeling in an effective way. The students were all able to develop
a mode of operation that combined both media. Some achieved this more so than others. Two
students had access to an Autocad system; they found that Autocad was much faster for developing
2-dimensional representations than Worldview but was not useful for solid modeling. They utilized
both programs effectively. The Worldview system did not allow transferring Autocad files.

The software and hardware used in a CAD studio must be very robust. Although simple models are
easy to construct, analyze and modify, as projects become complex in detail, they become much
harder to manipulate. Fast screen refreshing, hidden line removal and powerful solid operators are
critical requirements. The staff of the Computer Aided Design Laboratory were confident that the
system would perform adequately for the project that was planned. However, several unanticipated
problems resulted in serious interruptions during the semester. Although the Worldview program had
been utilized for several years, it was in a constant state of development.
When new features were added bugs appeared, even after testing. The students used the program more intensively than anyone else had previously. They also were some of the most "naïve" users. Thus, they often did not understand what mistakes they had made nor the implications that certain actions would have on the performance of the hardware and software. It is clear that the environment of the CAD laboratory must be highly supportive for intensive studio work. Ideally, this support should be "invisible" so that the students encounter little problems of access and use.

The need to move back and forth from CAD to paper and pencil requires more space. Drafting boards and individual workstations should be available practically adjacent to the laboratory itself, if not right in it.

The need for ten or twelve students to plot drawings all for the same deadline can put extensive demands on hardware and laboratory support staff. Both the hardware and software must be carefully managed or students can easily become frustrated and lose morale.

This first experience at SUNY/Buffalo with an upper level studio has provided direction for improvement of the solid modeling program. It also has generated a knowledge base, the Library of Spaces, that can be used for many interesting learning exercises in both design studios and other classes. Finally, it provided direction to the instructor for refinement of studio teaching methods using CAD.

Previous to the implementation of the studio, two advantages of CAD had been identified: developing new ways of visualizing and manipulating geometric form, and knowledge based design through access to interactive libraries. Through the experience of this experimental studio, a third advantage became evident. Computers are a very powerful means of sharing information. The group development and use of the Library of Spaces and the site model during the course of the semester were two of the most impressive results of the experimental studio. Future applications of CAD in design education should seek to capitalize on all three advantages.

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REFERENCE


POSTSCRIPT

Three of the students in the class swept all three awards in the competition. Perhaps this is some indication of how CAD helped them develop better designs.