CAD TOOLS FOR SYSTEMS THEORY AND BOTTOM UP DESIGN

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ABSTRACT

The use of CAD is investigated in the teaching of *systems theory* to a fourth year group of design students. A comparison is made between the CAD group using MacArchitrion and a non-CAD group using traditional design methods. The paper includes a discussion of the meaning of systems design theories, relates the CAD and non-CAD student design methods and illustrates the results. It also includes recommendations for improvements so the computer can become more effective in this type of design teaching. Finally, it concludes with recommendations from the students at the end of the semester project. The basic premise for the CAD design group is that computers should encourage students to understand and use systems design theory.

1. INTRODUCTION

Christopher Alexander in the late 60's wrote a discerning essay about *Systems Theory* with visual descriptions of *systems as wholes* and *generating systems*. This design theory can be a useful tool for understanding and designing large complex projects such as hospitals and airports. Using this theory, a designer divides a building into its component systems and sub-systems. Then, using combinational rules, the designer begins combining groups and subsets of systems until all the building systems are included. Major building systems include; structural, enclosure, mechanical, and interior systems [Rush 1968]. Other systems and sub-systems such as; site, circulation, and climate are also combined to create a *system as a whole*, or whole project. *Bottom up design* can be thought of as designing the pieces and assembling them to create the whole.

In theory it would seem, computers were created for *Systems Theory* and *Bottom up Design*. They are able to couple three-dimensional data manipulation with color graphics, thus greatly assisting the designer. In actual practice with the computer, however, the accomplishment of simple tasks often takes great effort. Much of the micro-computer software and hardware available in the market today can make the design process even more confusing. If designers use this generic software to interact with the computer, they must often develop whole new strategies and unfamiliar design methodologies.

1.1. Theoretical background: systems theory.

Systems theory can be understood as a two part idea, one being, a holistic view and the other, a method of generating this view. The theory is an abstraction, a way of perceiving the relationship of parts and objects - but not a view of the parts or objects themselves.

> There are two ideas hidden in the word system: The idea of a system as a whole and the idea of a generating system.
>
> These two views, though superficially similar, are logically quite different. In the first case the word *system* refers to a particular holistic view of a single thing. In the second case, the word *system* does not refer to a single thing at all, but to a *kit of parts* and *combinatory rules* capable of generating many things. [Alexander 1967]

A building system can be considered a generating system. It has a kit of parts: columns, beams, wall panels, windows, doors, etc. These are assembled according to certain rules to form a system as a whole.

Bottom-up design methods can be considered the active part of systems theory - putting together a kit of parts with a set of rules to make a system as a whole. The design process moves from detail to general. It is similar to designing a tree from leaves to branches to trunk.

The opposite of bottom-up design is the top-down design method. It requires the designer to have a guide vision of the design and then move from general to specific. The tree is roughly visualized (the trunk, limbs, and leaves) and designed in steps with each pass making further design refinements at finer detail. Experienced expert graphic artists and designers usually work in a top-down fashion - beginning with a very schematic sketch of the whole object, then refining this, in step-by-step fashion, till the requisite level of precision and completeness is reached [Mitchell 1988]. In most design projects both *bottom up* and *top down* methods are used concurrently.

1.2. Teaching systems theory.

One way to test the capabilities of the computer and CAD software is to undertake a design studio using only these tools. A section of fourth year design students volunteered to do their fall semester design project using the Macintosh computers with Architrion software while the rest of the class did the project by hand.

The fourth year design studio at the college is known as the *Systems Design Semester* and seemed the most appropriate for utilizing a CAD package. Fourth year students have two prior years of design experience and have developed a certain confidence in their own design skills. It was expected that they would be able to spend the additional time required to move into the alien environment of the computer and learn a new set of software commands. Typically, the design problems in the fourth year are tightly constrained and are selected to facilitate the exploitation of systems theory. In other words, the building type are large in scope and demonstrate a repetitive and systematic nature.

In reality the faculty soon became aware that some fourth year students had a great deal of apprehension and prejudice against the idea of *systems theory*. Their initial reaction was, ***it is not human***. They had been taught to come at a design with a holistic view - to design a building as an object in space. This had worked well in the past with the design of simple building types. The faculty was now giving them a large building complex and asking them to design it in a new way. Their design views were being challenged and they were being asked to design using *systems theory* which they did not entirely understand. Instead of thinking of a small building as ***self expression*** they were being asked to think of a large building complex as ***problem solving***. They didn't understand why they were expected to use this new *systems theory* in order to handle larger pieces of information.

The students were given the option of choosing their design section. The students who chose the CAD option felt that computers would be important in their future and that they needed to be conversant with them. Some also, had the mistaken idea that the computer would save them time or that the CAD option would be less time consuming. A few ***loved computing*** and preferred to do everything they could on their computer at home or at school.

2. THE DESIGN PROCESS

The design project chosen was a 350 unit, 10 acre, retirement community with support facilities. Two similar sized sites were proposed, one urban and one suburban. Even though the problem was large in size, it was tightly constrained with definable spatial, climatic, and code requirements. A major restraint was to provide comprehensive handicapped accessibility due to the client's elderly age group. This criteria, when fully understood later, became a humane attitude that the students felt should be incorporated in buildings for all ages.

For the CAD group, the problem solving started with the design of single one and two bedroom units. There were several reasons for this approach. Since this project was to reinforce the bottom up design methodology - the design solution in large part would become the sum of the individual units. The students were being asked to learn a CAD program as a new set of skills and would be allowed, at present, to work off the non systematic design skills they had previously developed. The switch to bottom up design would happen later as the units were assembled into buildings. A one and two bedroom unit is a familiar and easily understood building type. It requires a minimum of type study, so the students can concentrate on learning how to use the new computer software. And finally, designing a single unit will reduce the hardware burden on the computer - restricting the number of three-dimensional objects that need to be entered.

The non-CAD group began the design process by adopting a standard one and two bedroom unit and made modular wooden blocks to be assembled into a *site systems model.* This color coded model showed the units arranged in building clusters with connections to pedestrian and vehicular site circulation systems. It demonstrated the *kits of parts* and *sets of rules* in a symbolic way. This type of approach had been used for the past several years to acquaint the students with the scale and scope of such projects in a systems format. The choice of beginning with the site systems models instead of the design of the individual units turned out to make more of a difference between the two groups than the use of the computer.

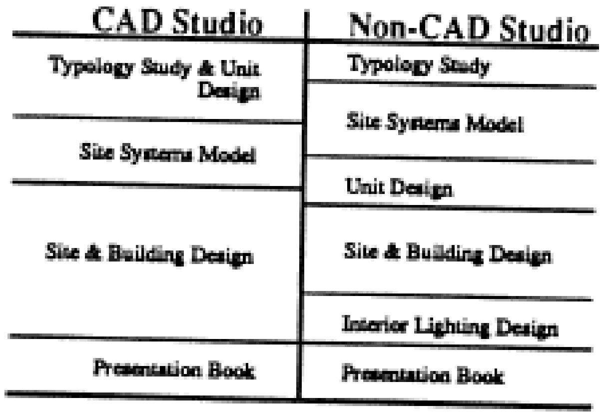

Figure 1. Systems studio time line.

Each group now had a central design focus. The CAD group was learning the software, researching, and designing the individual apartment unit at the micro scale. The non-CAD group was researching and developing the symbolic site systems model at a macro scale. Each was starting at the opposite end of the project's spectrum.

2.1. Using the Architrion software.

MacArchitrion basic creation element is a three-dimensional rectangle block.

> "The 3D building is assembled by placing blocks in space just as if you were building the building with clay or cardboard, or out of actual building material... The rules are that each. surface has to be a flat plane, and each block always has to have six sides (although one side can be as small as one pixel wide)." [Gimeor 1988]

A complex solid must be constructed from multiple blocks. The solids that can be assembled in this manner are nearly limitless in shape. A plane is a three-dimensional block one pixel thick and a line is a block one pixel thick, one pixel deep, and of any length. A limiting factor with this version of the software, is the block can only be created and replicated in plan view.

The 3-D block seemed limitless and the obvious element to model the apartment units. However, when the students began to build the units from these blocks, the process became mannered and calculated. It was time consuming to try different block arrangements and configurations. Students did little experimenting and, in fact, found it more productive to have the design firmly in mind before committing it to the computer. They were reluctant to make changes and resisted designing the required alternative unit because they were unsure how to *spin* one design off the other.

A reluctance to use solid shapes as the building block was also discovered in the non-CAD group. They had some difficulty manipulating the wooden blocks in a systematic way to build their system models. One logical explanation is that fourth year students have had three semesters or nine units of drawing. The three graphics courses to this point in the students careers have all stressed the use of line techniques in representing three-dimensional spaces. Study models are seldom use because model are primarily used as finished presentation tools in design.

History is laced with different types of design tools and the resultant buildings that came from these different design theories. It may, therefore, be reasoned that a familiar type of graphic communication, in this case the line rather than the solid, would be a better choice for these neophyte designers to use on the computer.

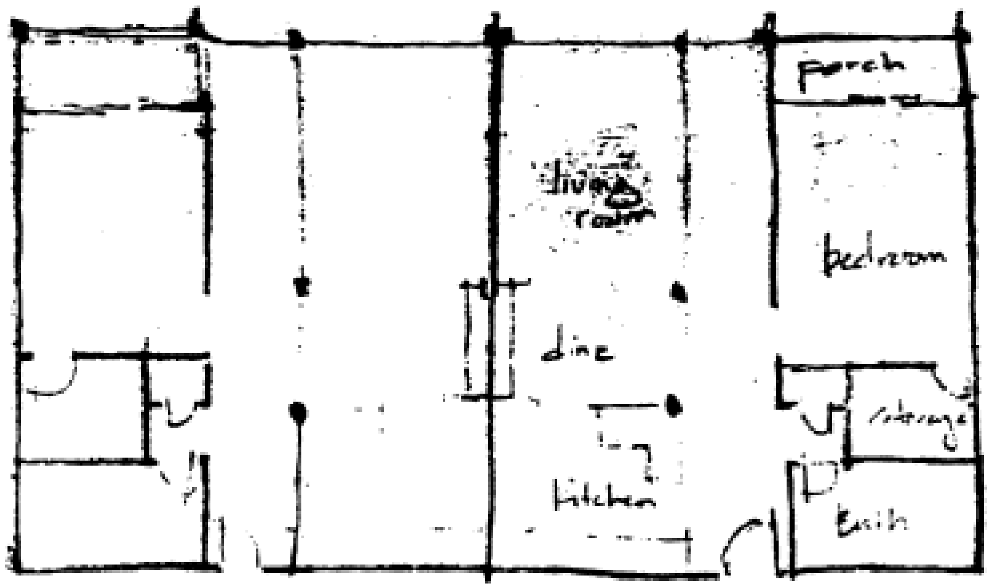

Figure 2. Non-CAD unit sketch.

2.2. Conflicts with the Architectural Program

An unexpected, but highly desirable interaction began to take place - the two different groups began to compare design notes. This was due to the fact that some members of the two groups shared tables and storage lockers and also because the CAD studio was immediately adjacent to the large studio space. The CAD students determined that the assumed areas for the individual one and two bedroom units was not adequate to incorporate the handicapped dimensions and requirements. The non-CAD group found, through local visits and case studies, the total number of units required for the site was excessive, given the retirement emphasis and regional attitudes.

Presentations of units and site systems were made with students in both groups taking notes. The students from both groups expressed concern whether the units from the CAD group would fit into the system models of the non-CAD group. This concern did not seem to be alleviate even when it was explained that the system models were ***symbolic*** and only represented relationships and not actual physical form.

The one and two bedroom apartment units were designed using blocks for walls, floors and furniture. Openings were made in walls. Doors and windows were retrieved from a three-dimensional library and placed in the opening. A nice feature of the software is that a door or window can be stretched and placed in any rectilinear opening. The MacArchitrion software was used to generate perspectives of the existing design. The two-dimensional images were rendered in Superpaint and moved to Hypercard for display.

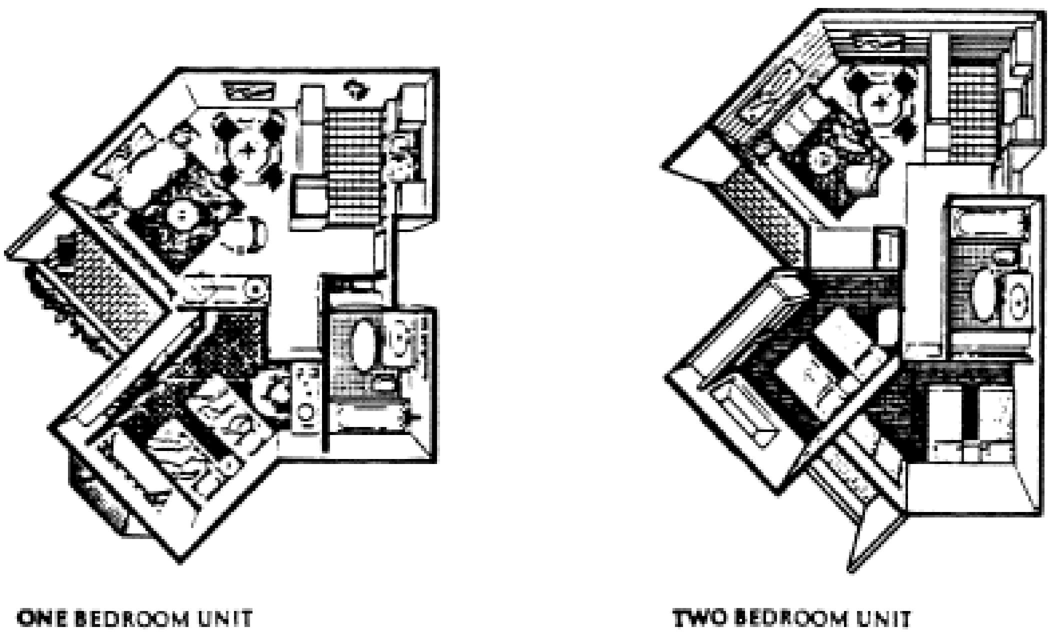

Figure 3. CAD designed individual unit.

At this point in the design process the program was altered and the students were allowed to reduce the number of units to a minimum of 250 units. The CAD group began work on a site systems model on the computer while the non-CAD group worked on a building systems model (group of units) with suggested unit plans.

2.3. Designing using site systems models.

The CAD group labored to construct the computer site systems model but it became very difficult to manipulate the pieces and the software commands lacked the quick experimentation possible with simple three-dimensional blocks and connecting sticks. The computer task was soon abandoned in favor of building a wood and cardboard model similar to the non-CAD group. Working with a model became a nice break from clicking a mouse and pressing keys and the CAD group could now have the site system model experience with the advantage of seeing the finished product of the non-CAD group.

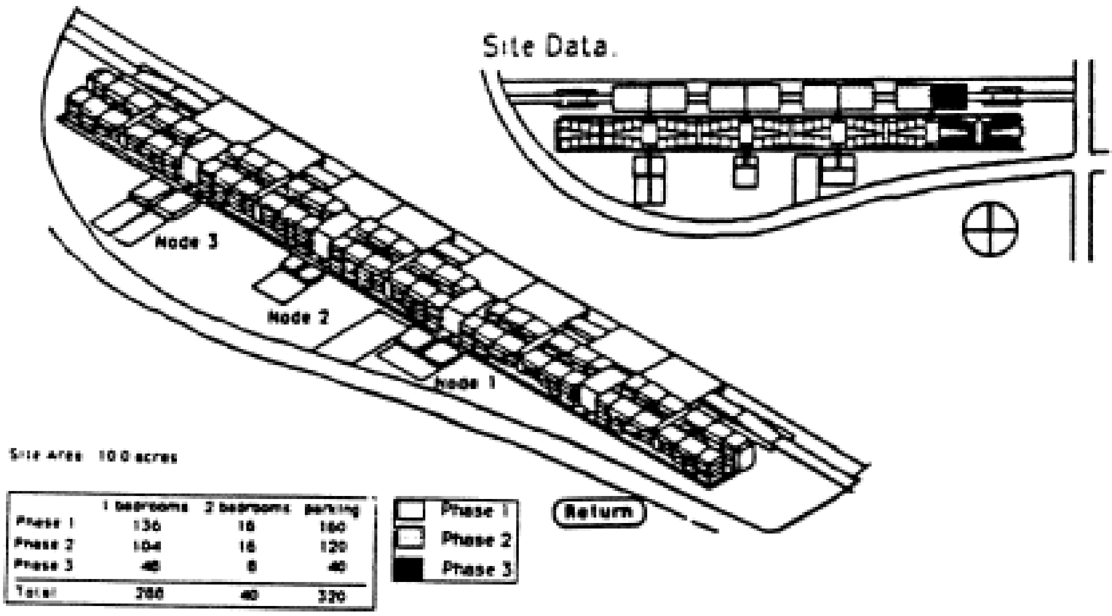

Figure 4. - CAD transferred site system.

After the CAD group built their study models in wood and cardboard and had a favorable critique they transferred the mass images into the computer to add text and shading.

The site systems were created using individual blocks as units. They were stacked, offset, and staggered depending on the environmental and site system rules. The clusters that were formed were linked to major circulation systems of other project facilities. All the systems were integrated with the three-dimensional building clusters to form the basic project site system. The following illustrations also demonstrate the tight site constraints imposed on the problem.

2.4. Introducing architectural form.

The design focus now began to alternate back and forth from macro to micro scale. The designers need to consider: external site pressures that influence the shape and form of the project, the scale and massing characteristics of the project on the site down to the structure, fenestration and materials of the individual units. This extensive experimentation period is expected to help designers discover and try large organizational ideas that will turn the systems model into an architectural form model. The ancillary facilities must also be considered and will provide the design with the much needed hierarchy of focal points.

The nature of the software and the building type encouraged students to thoroughly design the individual apartment unit and then duplicate it both horizontally and vertically along a circulation spine. This, however, became a problem because too much data was quickly generated for the system to handle. Each basic apartment

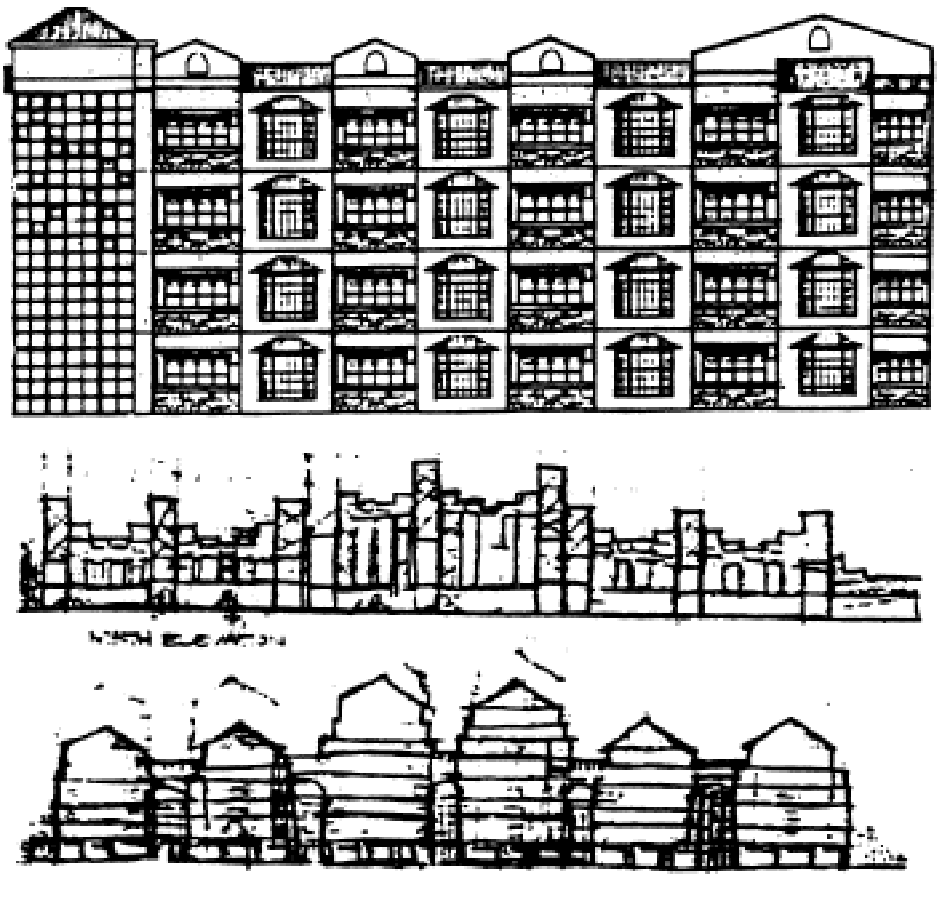

Figure 5. CAD & non-CAD cluster facade study.

unit consisted of approximately 100 three-dimensional objects. When students tried to replicate 350 units from the single unit, the total number of objects created was over 35,000. The maximum number of objects this version of the software can handle is approximately 3,500.

A complex perspective view, with hidden line removal, can take an extremely long time to calculate. A simple perspective of 1,500 objects takes over one hour to remove all hidden lines and display the results on the screen. As a result it was necessary to keep the files as small as possible.

Because of the relatively large size of the project some new strategies had to be developed in order to use this software. The students were able to speed up the perspective generation time by subdividing the building complex into three different files. The separation was made according to project scale:

1. Unit - 1 and 2 bedroom units with openings and furniture.
2. Building - 30 to 40 units as a single building.
3. Site - site massing, topo, and circulation.

As the students developed their projects in more detail other types of files were created to store this information

4. Presentation - buildings and units in detail.

2.5. Presentation

The presentation files are used to reduce the amount of data held in memory so that perspective generating time can be minimized. Files can be generated from various significant locations within the project. Another way to reduce the amount of building data considered in perspective calculations is to hide the images that can not be seen. Each item can be selected and hidden thus removing it from the three-dimensional data base. Still another method of reducing perspective generating time is to place different objects on different layers and turning the *unseen* objects off. The user must think through the perspective process and match building objects with views. One way is to save the file, erase the non-visible objects from memory, generate the perspective, then throw the incomplete file away by exiting without saving. Unfortunately, some of these processes begin to fragment the designers holistic view of the project.

Figure 6. Perspective of CAD design project.

Presentations on the computer is an interesting problem. Rather than plot or print the images some students used Hypercard to present their design drawings. Hypercard can be programmed to click forward or back or go to perspectives or other reference material with buttons. The critiques could then take place with groups of faculty huddled around the computer screen. If the crowd became larger some students used an overhead projector with a liquid crystal display device to project the computer images on the wall.

The Superpaint program was used to render the perspectives in black and white and make concept and explanatory drawings. References to the original program were shown opposite the appropriate formal solution.

The presentation concepts are different than typical large architectural board presentations. The screen resolution on the Macintosh is not high enough to produce highly rendered detailed drawings. Therefore, a larger number of lower resolution drawings are required. The typical viewing time for each screen is reduced to information that can be understood in 15 seconds.

3. CONCLUSIONS

This paper discussed using Macintosh computers to assist fourteen design students with the fourth year systems design process and compared their results with twenty-three design students doing the same project in the traditional paper drawing and wood model method. It became evident at the end of the semester that even though the design project was identical for both groups, the different design approaches and methods introduced many variables.

One factor which frustrated the CAD group was that fourteen design students had five work stations. These also had to be shared with fifteen other students. This limitation became critical as the completion date for the final project approached. The course requirements for the CAD group was judged to be excessive; a design studio and a CAD course. All students made comments that they needed a background course before taking the CAD studio in order to be able to fully concentrate on the design project.

A comparison of the two groups showed some significant differences. The nonCAD group felt that their approach to design had significantly changed. This is expected and has been documented for the past two years. The introduction to *systems theory* should fundamentally affect a student's design approach especially in the design of larger complexes. However, the CAD group felt that their design approach had not changed. This is attributed to several factors. The students were overloaded with too many new ***thing***s to learn and fell back into their old tried and true design methods. The Architrion software did not stimulate and encourage systems approach and thinking.

When asked if a design course which heavily relies on the Macintosh computer and a CAD package should be offered again next year, the students were ambivalent. The students who did well with their design projects agreed while the ones who did moderately well disagreed. All but two of the CAD students found it very difficult to design and present using the Architrion software.

There are a number of inherent problems with the CAD software that was used and the number of work stations provided. The basic premise at the beginning of the semester was: Computers should encourage designers to understand and use systems theory. From this semester's experience the conclusion is that it is more productive to teach the systems design semester without the computer.

3.1. Unit plans.

Since the two design groups began at opposite ends of the spectrum - the CAD group with the design of the apartment unit and the non-CAD group with the site systems model it is understandable that some differences would result from these opposite approaches. One characteristic that was noted by the faculty was that the unit plans of the CAD group were more involved and intricate compared to the non-CAD group, which only assumed an 800 square foot cube in the beginning. On the other hand, the CAD group had to do a certain amount of ordering to bring their unit configurations into an efficient structural system while the non-CAD group fought to add bumps and angles to make their plans less orthographic and in the students' opinion more interesting and less boring.

The building foot prints of the CAD group were more complex because of the more intricate unit plans. In some cases the facades became so ***busy*** that they would have been difficult to understand if they had not been modeled on the computer. Generating perspectives on the computer was relatively easy and could be counted on to keep control of any irregular shape.

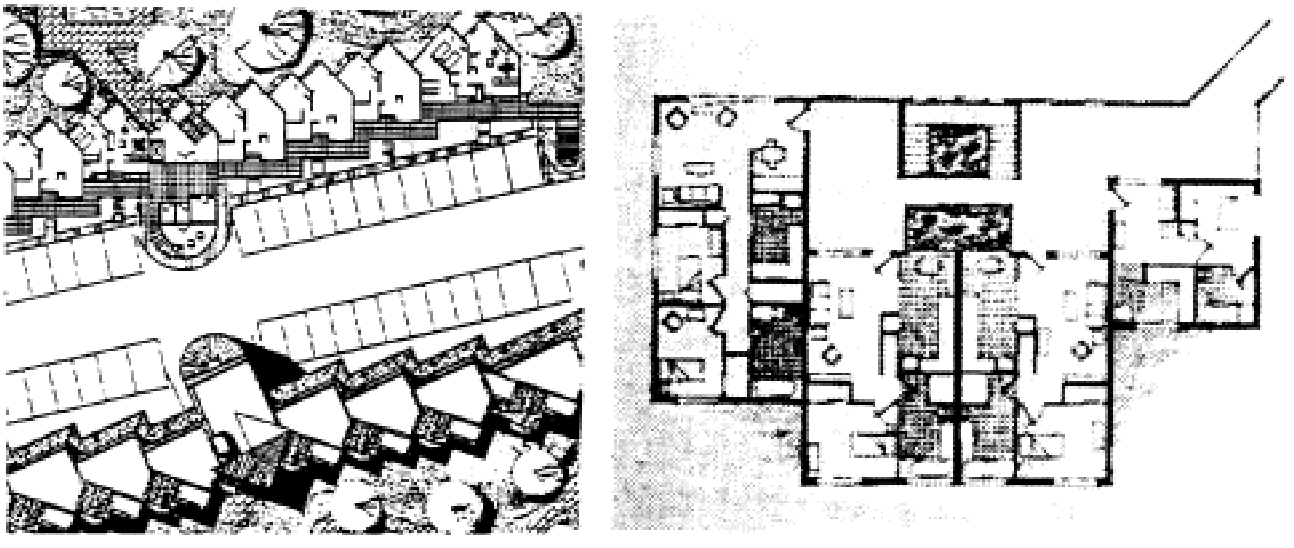

Figure 7. CAD & non-CAD cluster plans.

With this freedom, unfortunately, came an almost total lack of awareness of a structural system. The non-CAD group had used a structural grid to help them organize their units while the CAD group had copied simple units with an offset. Architrion requires the creation of buildings with 3-D blocks. It is not a simple matter to lay out a structural grid in plan and store it as an underlay with the three-dimensional model. Even in the preliminary stages (see Figure 2.) the non-CAD students could quickly sketch in a structural grid. This type of overlay sketching was difficult for the CAD group.

3.2. Building structure.

The CAD group did not need to considering building materials to build their three-dimensional model. This may have influenced their lack of structural thinking. The 3-D blocks are the building blocks of everything created, from walls to chairs. They are simply made of opaque ***stuff***. This is much like making a building out of marshmallows - everything is the same. This might be appropriate when form is the only architectural issue. However, creating a building in the computer did not develop the students awareness of structure and materials as a real physical study model would.

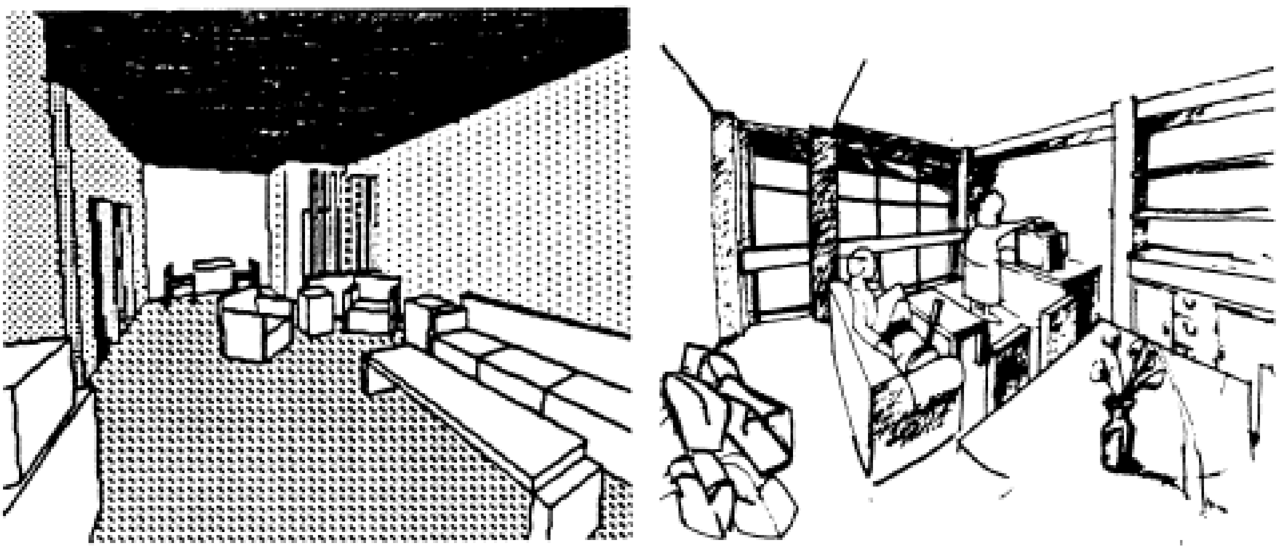

Figure 8. CAD & non-CAD interiors.

3.3. Holistic vs detailed focus.

The non-CAD group had a more holistic, top down view of their design from the beginning. They seemed to have a better understanding of how their building complex worked and the appropriate number of parking spots and ancillary facilities. The CAD group had a better bottom up view which focused more on the individual unit. The power of perspective generation had given them a better understanding of the intimate spaces that were actually created sometimes to their horror. The accuracy of the computer in its representation ran counter to the idea of image sketches. Even though images may not be accurate they may lead to other related solutions. It may, at time, be necessary to have free hand inaccuracies to see the final solution. This type of approach is more difficult when the building is modeled and perspectives are generated on the computer.

Figure 9. Non-CAD site plan.

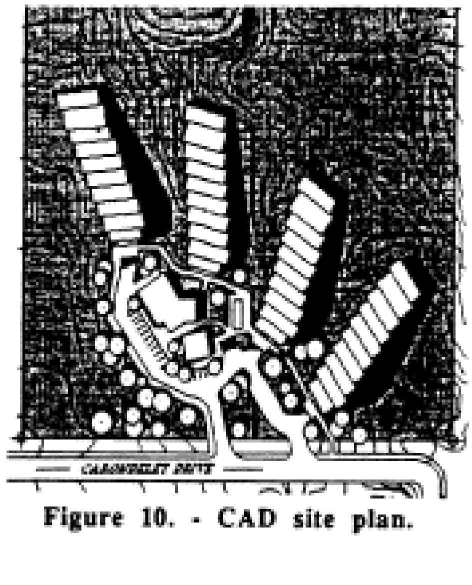

Figure 10. - CAD site plan.

3.4. The MacArchitrion in the design studio.

MacArchitrion is not an easy to learn intuitive program. However, it does have an excellent tutorial that, if used, will acquaint the user with many of the commands and strategies for creating a three-dimensional building model. Students who did not finish the tutorial had so much difficulty using the program that they had to go back and complete the tutorial before proceeding with their design. The program takes significant effort for a person to become accomplished with its numerous tools. The instructor spent four days in a MacArchitrion workshop sponsored by Gimeor to learn the basics.

As three-dimensional images are created they are relatively easy to view as wire-frame axonometrics. The Macintosh software concept facilitates moving images from one application to another. A three-dimensional building can be saved as a series of two-dimensional views, moved to a paint program and rendered, and then moved to hypercard for viewing and presentation.

A project that would take advantage of MacArchitrion's strengths would be a building that:

1. is ***one of a kind*** like a residence, small office, or gallery.
2. is small, less than 10,000 sq.ft .
3. requires study of spatial imagery and is volume orientated.
4. includes the design of its interior details and furnishings.

3.5. Recommended improvements to MacArchitrion.

The designer should be able to create and modify the objects in other views beside the plan. This is one of the biggest limitations to the program. For instance, it is essential that a designer be able to work in elevation to create openings and fenestration. Another deficiency is that it is extremely difficult to select an object if a number of them are stacked on top of each. The selection can only be done in plan view and it can become disastrous in the move or copy mode if the wrong level has been picked.

Many commands demand multiple selections or key presses. The program does not give any feed back as to what it is expecting next. For example, when generating a perspective, a user must locate the eye point and view point. A first time user sometimes selects the wrong location because there is no indication from the program which is to be selected first.

Most objects are drawn, modified, and manipulated by *eye*. The users of MacArchitrion need to have keen eyesight and carefully concentrate on exactly what points are being selected. It would be useful if the program had some type of snapping aids that are common on other CAD software. For example, if points are selected which are close to a objects corner, intersection, or end point the computer would automatically select that exact point.

More layers are needed that can be individually named. The software should allow for naming the various layers because different applications demand different types of layering structures. Even flat drawer files, the concept after which the program layers were modeled, allow for names to be inserted on the front of the drawers.

Everything is created on a work sheet and then transferred to a particular layer. Objects may be modified on layers but only created on the single work sheet. Much transferring needs to be done from layer to work sheet and back again. The use of the work sheet and the necessary transfers seem to put an unnecessary barrier between designer and object.

All the general drawing and project defaults should be saved with the drawings The building scale, measuring units, layer on and off switches, etc must be reset each time a three-dimensional model is loaded into the program. The design project that was undertaken in this class had three different scales so the default parameters were continually changing. Designers must continually check to make sure the scale is set correctly or the image will be represented incorrectly on the screen.

Other procedures that are difficult to do in Architrion:

1. Setting drawing scales.
2. Zooming to desired views.
3. Selecting axon views.
4. Saving perspective views without seeing them .
5. Creating a sloping irregular site.
6. Creating circular architectural forms.
7. Displaying intersections of penetrating forms.

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