THE USE OF THREE-DIMENSIONAL COMPUTER MODELLING IN THE DESIGN OF CUT AND FILL PLATFORMS FOR BUILDING SITES.

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ABSTRACT.

Computers have infiltrated all areas of human endeavour, from computer-controlled buildings to computerised toasters. Many design professionals have embraced computer tools, and reaped tremendous benefits as a result. Architects, planners, and urban designers have tended to resist their implementation, ostensibly on the grounds that most currently available computer tools are inapplicable to design tasks. This surmise can be investigated by reviewing recent design methods and computer capabilities. A more interesting challenge is to test it in practice by means of a computer application written to aid a particular area of design, that of cut and fill platform creation. Pilot studies of the use of this program have been encouraging, indicating that computers offer capabilities not available with any other design tool. Computer modelling is relatively new, and as with all tools there is a period of acceptance and maturing, but there is little doubt that three-dimensional design visualisation without computers will soon be as unthinkable as a return to report writing on manual typewriters.

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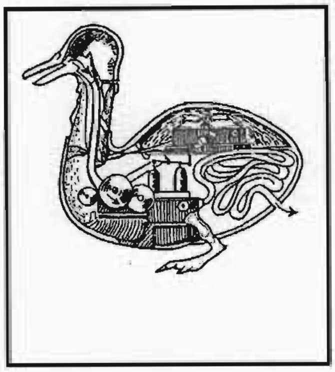
LIST OF ILLUSTRATIONS.

CHAPTER ONE - INTRODUCTION.



Vaucanson's Mechanical Duck.

The lure of the computer as a design tool is to be able to demonstrate any facet of a design to someone else. 'Intelligent' drawings or models can extend the audience of architectural documents, - they can embody more than builders' instructions for the construction of a project. The goal is a database of the designed object in its entirety comprising an accurate description of each part, with the information that is appropriate to different classes of viewers being made available as required.

The question of whether computers are of benefit to architects is adequately answered by examining the numbers of computers in use in architectural practices world-wide, (and the yearly increase in these figures) and has been well handled by Reynolds (1987) and others. What is still unclear is the value of the computer as a design tool as opposed to a drafting one.

There are two hurdles to cross if computers are to be of use in design. The first concerns the subjective nature of design work, which requires a myriad design criteria to be balanced against one another. Whereas many individual designers have a solid grasp of this process in practice, it is poorly explained in theory. Until designers are able to enunciate the process clearly, computer assistance will be of little use.

It is interesting that this problem of subjectivity and the use of computers is not an issue in other areas of design. Page layout and graphic design is a field dominated by computer tools, where the issue of stifled creativity is seldom raised. This has a lot to do with the information content of the graphical output. The information contained in an advertisement is almost always very near the surface - by intention it is easily accessible to as many people as possible. In contrast architectural design drawings contain a great deal of deep structure information. Accessing this information is possible only if the viewer has 'learnt the language', a process which can take several years. Many professions adopt an esoteric language with the express purpose of hindering access by people outside the profession.

The democratisation process evident in recent years and the call for community participation in design decisions, particularly in this country at present, is placing new demands on presentation drawings. There is an increasing demand for three-dimensional representation of proposals, an area in which the computer is particularly strong. The style of both presentation and construction drawings has changed markedly in the last 40 years. Various factors have influenced this; the pace and scale of building construction, trans-national architectural practices, and not least information technology advances - the development of computers, wide area networking, and fax machines. Not many years ago, there would always be at least one principal in any firm who would rage if the lettering and dimensioning of a working drawing was not fit to be considered a work of art. Nowadays, with hefty penalties for late completion being common, such artistic considerations fall by the wayside. What is of more importance is that the drawing is unambiguous and compatible with current technology. *"Will it fax clearly?"* or *"Will it transfer by modem quickly?"* are more pertinent questions.

There is some controversy over whether computers can ever be used in architectural design. Many of those that don't think so, treat any discussion on the subject with some disdain. They maintain the answer is obvious - any competent architect should be able to design far better than a machine, and therefore anyone interested in using computers is by implication not capable of good design. This line of reasoning is analogous to the reservations people had about drawing machines or technical pens - such new-fangled tools were inappropriate. Most of those who maintain this standpoint have not had much practical exposure to computers, and their reaction is understandable in the light of the complexity of the tool. The most obvious objection to this argument is that it lumps all possible architectural use of a computer into one category - that of *design generation*. There are many other areas where the benefit of using computers is undisputed. The calculation of solar penetration or heat loading are good examples.

While such essentially calculational uses of computers are time-saving, the emphasis of this dissertation focuses on tools that are geared towards visual design evaluation. Certain competent practising architects, after sufficient investigation, feel that computer use should be restricted to two-dimensional construction drawing production. Those that disagree, take this position largely on trust, as there have not yet been any truly convincing commercial software packages that break this mould. It is an interesting line to pursue, but to do so in a meaningful way involves using a rational approach to what is a very emotional issue. Since the time of Mr Ludd people have reacted strongly to machines threatening their livelihoods. This fear is not unfounded for many people regarding machines in general and computers in particular. There is a further element of apprehension, usually stemming from not being able to understand the inner workings of computers. Computers, though occupying less and less space, are getting more and more complex. The central processing unit, or *'brain'* of even a so-called micro-computer can contain over a million components on a sliver of silicon the size of a fingernail. Drawings every bit as complex as those for a building are produced, detailing the millions of connections between these parts. A perceptional problem many people have with a computer is that the parts are invisible, and nothing moves as it performs a calculation, in other words, it is more like a human brain than a machine A further problem older people face in this regard, is that young children seem so competent with computers. In a mixed class of newly qualified architects and mid-career architects being trained in CAD, older people often give up long before the full extent of their abilities has been reached.

The process of introducing computers into architectural practices is often handled so badly that it is not surprising architects are wary. The consumerisation of computers has produced marketing scenarios unimagined for any previous product. Very often expectations of performance are created long before a product is capable of performing those tasks. Computer technology is advancing very quickly. In the mid-1980s a computer generation was measured as 24 months. That period is now reduced to 10 months. The field of three-dimensional graphics is also undergoing great change. The information in this dissertation will soon be out of date.

Apart from the emotions associated with mechanisation in general, design methodologies, as a way of externalising the design process, have traditionally not been well received by the architectural profession as a whole. Paterson (1980) says:

> "At the present time, methodologies are extremely unpopular with architects, many of whom have returned to "seat of the pants" management systems and 2B pencils for their salvation, somehow

believing that art is despoiled if it comes into contact with science or modern management tools."

There is concern about the current poor state of architecture and the built environment, and many look to CAD as the cause, without acknowledging that there has been a shift in management of construction projects. Many site boards no longer list an architect; at best they mention a design consultant. The problem is not so much that CAD is ruining architectural design, but rather that the people involved in designing and using CAD packages are not designers.

Computers can perform repetitive tasks rapidly and with a maintained degree of accuracy. They are ideally suited to tasks that have a large degree of repeatability. Low-cost housing presents a great challenge in most parts of the world, but particularly in South Africa at this time. One aspect of the challenge is the vastness of the task. Because of the numbers of housing units needed, optimisation is vitally important, as any inefficiency is multiplied a thousandfold.

CHAPTER TWO - OUTLINE AND METHODOLOGY.

The general goal of this dissertation is to investigate the implementation of three-dimensional computer aided design in architecture and planning. The scale of design is aimed at the interface between the two disciplines, specifically at the level of layout and sub-division on steeply sloping land for purposes of low-cost housing requiring small sites. There are four sub-sections to achieving this goal.

1. It is necessary to come to an understanding of the design process in the light of current theories of design, design generation, and of design methodologies.
2. Existing computer tools need to be examined to determine their usefulness in design.
3. The reverse perspective needs to be investigated; what are the practical steps a designer takes to arrive at a solution.
4. A program written as a tool to investigate the process of design which will provide an accurate assessment of how useful computers can be in a particular design resolution typology.
5. Proposals or recommendations may arise out of the preceding parts suggesting how computers might be put to better design use in future.

There is a vast store of literature dealing with types of designers, the design process, and design methodology. Design tools, apart from forming a part of most recent design methodologies, have a documented history stretching back thousands of years. Of the many authorities on design methods and tools, Broadbent (1973), Broadbent and Ward (1969), Heath (1984), Jones (1981), Moore (1970), and Evans (1982) provide a fairly broad perspective from a theoretical point of view. A study of this material can provide a conceptual framework on which to base design tool proposals. A review of recent periodicals provides a fairly detailed account of current computer usage. Information is available on current tools, as well as an indication of the extent and success of computer implementation among designers.

There is a practical component to the title contained in the word 'implementation' - how does all of this affect the way a designer works?. Sub-section Two should certainly contain a component on the current failings of computers in design, and any proposed computer tools needs to be tested empirically. The practical section of the dissertation takes the form of a series of interviews and a computer program written by the author as a design tool.

The generation of such a program entails five tasks:

1. Identifying a real-life design problem type that is encountered on a regular basis.
2. Investigating how this problem is currently handled.
3. Designing and implementing a computer program to aid in this task.
4. Performing pilot studies of the program in use.
5. Evaluating its successes and failures.

The specific area to be addressed by the program is the problem of layout planning on steeply sloping land. Stated objectives are:

1. To calculate Cut and Fill platforms for a variety of soil conditions, for site topography ranging from good to difficult.

2. To suggest sizes of sites for specified or required platform or building sizes.

3. To optimise the position and orientation of platforms and top structure on the sites thus designed.

4. To evaluate these proposals at a micro scale of the individual site environment created.

5. To evaluate the urban fabric created by multiple sites, roads, and infill panels at a meso- and macro-scale, in other words, the total effect of the design.

6. To test and evaluate climatic influences on the built environment, specifically whether areas of a development receive sun during winter, and whether a particular built form overshadows another.

The dissertation document is divided into three parts.

1. Design Theory.

The design process does not sit easily within any one definition. There are various types of designers, and they engage in a variety of activities during design. Personal forces are brought to bear on the problem by each individual designer; problem solving capabilities, idea generation, and private rules for decision making. External forces also play a part and are embodied in various design concepts. These issues are covered in Chapters Three to Five, and provide a theoretical framework for the strategies and tools employed in the computer model outlined in Chapter Twelve.

2. Design Tools.

The language of design presentation - models, scale drawings, and design strategies - are discussed within a framework of levels of design activity which define the appropriate tool for a particular action.

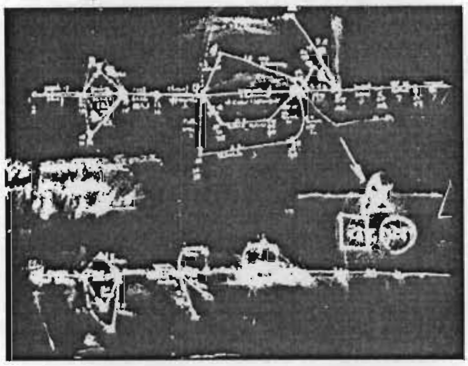
Computer tools are handled in four sub-sections. A brief history of computer usage in design is examined in Chapter Seven, while Chapter Eight deals with problems associated with computer implementation in general. The topic of existing computer aids has been split into two sections, viz. Chapter Nine deals with categories of computer aids - generation, simulation, analysis, and optimisation, while Chapter Ten covers three dimensional computer tools.

3. The Proposed Computer Model.

The last section comprises three parts. Chapter Eleven investigates the design process from the viewpoint of practising designers. The methodology employed was to arrive at a composite picture of the process based on one-to-one interviews conducted with several planners and urban designers. The second part involved drawing together the theory described in Section One, the strategies outlined in Section Two, and the practice investigated in the first part of this section, to arrive at a working model - inSITE, a computer program written by the author to investigate a practical implementation of computers in the design process. The last part of this section deals with feed-back and evaluation of inSITE by designers; their comments, criticisms, and recommendations.

As an addendum to the written document, a series of computer-based demonstrations have been prepared. These comprise audio-visual tours of the main features of inSITE.

CHAPTER THREE - THE DESIGN PROCESS.



Blackboard sketches of a mathematical Model. What is clear to the designer is often unintelligible to the onlooker.

The process of design is central to the activity of architects and planners, yet it is often veiled in mystery. In order to understand the role computers might play in this process, it is necessary to establish some frame of reference. How do designers tackle problems? There is no universally accepted method, although a number of theories have emerged. This chapter investigates both general problem solving methods, and specific design methods applied to spatial design problems. Spatial problems are more complex than most. They exist not only in 2 or even 3 spatial dimensions, but involve many, often conflicting additional dimensions involving social, economic, and political issues.

Jones (1981, pp3-4) cites 11 definitions of design.

- Decision making, in the face of uncertainty, with high penalties for error. (Asimow, 1962)

- Finding the right physical components of a physical structure. (Alexander, 1963)

- Engineering design is the use of scientific principles, technical information and imagination in the definition of mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency. (Fielden, 1963)

- Simulating what we want to make (or do) before we make (or do) it as many times as may be necessary to feel confident in the final result. (Booker, 1964)

- A goal-directed problem-solving activity. (Archer, 1965)

- A creative activity - it involves bringing into being something new and useful that has not existed previously. (Reswick, 1965)

- The conditioning factor for those parts of the product which come into contact with people. (Farr, 1966)

- Relating product with situation to give satisfaction. (Gregory, 1966)

- The performing of a very complicated act of faith. (Jones, 1966)

- The imaginative jump from present facts to future possibilities. (Page, 1966)

- The optimum solution to the sum of the true needs of a particular set of circumstances. (Matchett, 1968)

Each definition is different from the others, which suggests that there is no holistic definition of the process. The traditional objective of a designer has been to produce drawings for the approval of the client which serve as instructions to the manufacturer or builder. A distillation of the preceding might yield a general definition of design as that which defines and initiates change in man-made things. With the inclusion of the concept of initiating change, other objectives become apparent. If the object being designed is to bring about the prescribed changes, the designer needs to be able to predict future effects that the object might have on its environment, and the steps required to achieve this changed state. The emphasis of design shifts from the designed object, to the design process - the changes required of manufacturers, distributors, and even users and society in general in order that the designed object may come into being.

The design process is complex in that designers are required to use current information to predict a future state, which may not come about if their predictions are inaccurate. An ultimate state has to be imagined before the means for achieving it can be investigated. This investigation will often reveal that particular solutions are too expensive to achieve, or suggest more attractive ultimate states; either of which may require a modification to the prediction. It is this instability of the process which supplies both a richness, and a complexity to design.

As a framework for discussion, and based on categories suggested by Best (ed Broadbent and Ward, 1969) and Broadbent (Broadbent, 1973), design activity may be broken up into 5 broad stages:

1. Recognition of the problem (or need) and a definition of the design constraints. There are also tacit design influences in the intentions of the designer and the client.

2. Formulation of a strategy for approaching the solution.

3. Creation of an interim realisation of the solution, possibly with alternatives.

4. Evaluation of the interim solution or solutions in terms of criteria that the designer feels are important, such as aesthetics, organisation, circulation, structural feasibility, energy, or cost.

5. Presentation of the design.

The fourth stage usually results in a process of iterative looping through any or all of the previous stages; usually the third and fourth. This looping ends when no significant improvements are made to the proposal, or when time runs out for completion of the project.

Architectural and planning design problems are so variable and idiosyncratic in practice that it is difficult to explain them definitively, yet a designer must interpret a problem in order to deal with it. Interpretations can never be definitive; in most cases they are simplifications which can introduce distortions in the perception of existing difficulties. Theoretical models are expressed in terms of a descriptive language which reduces real-life experiences into forms that can be expressed in that language. (Parry, cited in Evans, 1982) Difficulties arise in that these forms, by definition simplifications, usually describe dynamic objects, which, in order to retain meaning for the period of evaluation, need to be viewed statically. It seems there is no way to escape the dilemma: action requires interpretation, but inherent in most interpretations is distortion; the distortions are likely because of the very variety that necessitates interpretation.

The process of inputting information involves a transition from an unstructured problem space as the designer perceives it when starting a design, to a state in which the information gathered becomes personally meaningful. This may be achieved with sketches, diagrams, or graphs, the aim being to expose underlying structure in the problem. Best (ed. Broadbent and Ward, 1969, p157) states that we cannot understand without interpreting. Interpretation involves reducing initial information to an understandable description or representation. Within this process, a designer may elaborate what is seen as essential in the light of individual experience of analogous situations. (de Bono, 1969) This may increase the information content of the interpretation, as opposed to a straight simplification which would usually reduce information, but information is added in terms of familiar concepts. Information to be encompassed is managed by a process of homomorphic reduction. (See figure 3.1) This process associates information in the problem space with concepts contained in the designer's interpretation of reality in a many-to-one mapping, so that a number of elements in the first set may be represented by just one in the second. (Broadbent, 1973, p377, Best, ed. Broadbent and Ward, 1969, p157)

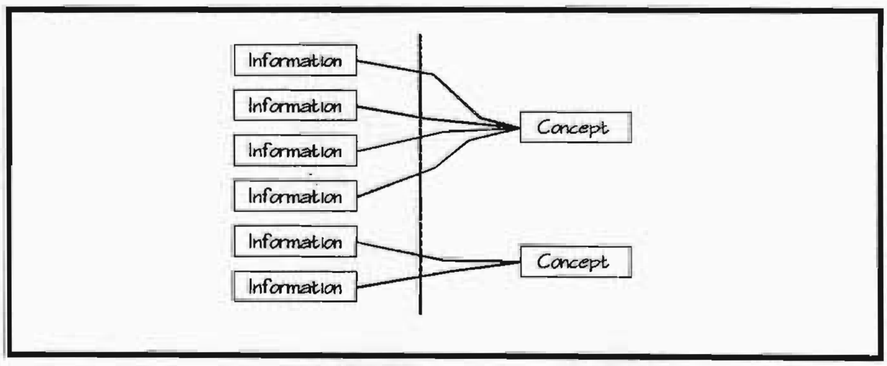


Figure 3.1 Homomorphic reduction - the filtering of masses of information.

In this way a designer attempts to make sense of a mass of information that may have no apparent structure. The homomorphic reduction serves as a filter through which all other information passes in the process of dealing with the problem. The appropriateness of filters selected for this process differentiate good designers from bad ones. Poorly chosen filters necessitate greater manipulation of data for it to conform to the moulding of interpretation. Well chosen filters seem only to clarify or orientate information, in the same way polarising filters appear to orientate light in a photograph, revealing previously obscured details. Best's theory identifies two stages in the processing of design information.

1. Search for an analogy or model of the problem that is appropriate for the individual designer which encompasses as much of the information available as possible.

2. Interpret the remaining information in the light of this model. This is a dynamic process, which may follow cycles of iteration.

The interpretation and reduction process is a personal one and varies depending on the particular designer's experience and skill. In reducing the problem space in this way, a designer is attempting to manage the variety inherent in a real-world design situation. For any given situation, each designer will arrive at a different personal filter or model, suggesting that variety is not implicit in the information that makes up the problem definition, but rather in the interpretation we place on that information. Best (ed. Broadbent and Ward, 1969) gives the example of the design of the main street in a small town. Initial analysis would suggest a fairly straightforward problem, but if it is considered from the viewpoint of various consultants who may be involved, the variety becomes apparent.

- A transport engineer sees the street primarily as a vehicle path, with certain minimum requirements and conditions ensuring that these vehicles reach their destinations as quickly as possible.

- An estate agent views the street in terms of economic zones, each with different investment potentials and sale criteria.

- To a sociologist, the street may be the stage for important social activities.

- A building scientist regards the street as a potential source of noise and pollution.

- A shopowner sees the street layout in terms of potential passing trade.

If each of the above designers considered only 20 possible options for their interpretation, the combination of options would be over 3 million.

The preparation of a model or a drawing of a design proposal is a formalisation of a particular designer's interpretation of the design situation and its solution. Other people, particularly those not involved in the design process, may build up their understanding of the problem based on this model. If their interpretations do not coincide with those of the designer, and if their views are important, (such as in the case of the client) it may be necessary to modify the form of the proposal until there is consensus. It is the mark of consummate skill on the part of the designer if the structuring of the problem interpretation captures the important aspects of the problem situation. The interpretation is then rich in meaning, and other interpretations are either implicit, or can readily be incorporated without loss of consistency. An inelegant proposal, on the other hand, may require significant modification when considered in the light of other issues, and instead of refinement may require dissolution and restructuring.

DESIGNER TYPES.

Jones (1981) has identified three analogies of the designer which have gained popularity in design methodological circles.

1. Designers as Black Boxes. Theorists such as Broadbent, (1973) and Rapoport (ed. Broadbent and Ward, 1969) argue that the action of the unconscious mind is an important element of the design process. Humans (they say) are capable of arriving at solutions to problems in which they have confidence, without being able to explain the process. It is fairly easy to describe the act of riding a bicycle, but teaching someone to ride with written instructions is rather more difficult. Higher human actions such as writing or playing a musical instrument can be explained only if one accepts the unconscious action of a skilled nervous system. Newman (cited in Jones, 1981) suggests that the brain can be thought of as a network of patterns that are re-arranged according to information received from the physical world. The so-called leap of insight occurs when this network arrives at a pattern that accommodates the information received. Bartlet (cited in Jones, 1981) theorises that past experiences are re-patterned each time they are recalled from memory. The combination of these theories suggests that the brain functions semi-automatically, solving problems by modifying patterns of received information, and matching these to stored patterns of experience. (de Bono, 1969) Experimenting and unravelling the workings of the human mind is a laborious process. At this stage there is little hard evidence to support theories of thought processes. One view of designers is the analogy of a black box; feed in information at one end, an invisible process occurs inside, and a solution pops out at the other side. In observing designers at work, the following points support this analogy.

- Solutions that a designer proposes to a problem are based on information received about the problem as well as information recalled about previous problems and experiences.

- Designers can speed up the generation of possible solutions by agreeing to relax social inhibitions for a time. These solutions may not necessarily be of high quality, but they can be used to seed the imagination.

- The capacity to produce relevant solutions depends on the designer being able to assimilate information and organise it internally into patterns representing the underlying structure of the problem that make personal sense. In this process, inexplicable to the rational mind, a pattern that fits most of the relevant information, may suddenly present itself in a leap of insight.

- If information is fed into the brain of the designer in a suitable form, a richer offering of solutions is likely.

2. Designers as Glass Boxes. The majority of design methods attempt to explain design actions by rational means in order to externalise the process. A common analogy likens a designer to a computer that receives information, analyses it, and synthesises a solution, which is evaluated in terms of the original problem definition. The process is repeated until the optimum solution is reached. During this process:

- Strategies are laid out in advance.

- Objectives, variables, and criteria are determined in advance.

- Analysis is generally completed before solutions are attempted.

Solutions using GLASS BOX techniques have been neither uniformly good nor uniformly bad, (Jones, 1981) but the methods are certainly more appropriate for certain classes of problems. Those that admit splitting into discreet sub-units respond best to GLASS BOX methods, allowing assemblies to be farmed out to separate designers for parallel solution. This scenario has a built-in advantage in that evaluation of multiple possible solutions is largely an objective process; the methods employed to arrive at solutions are known, and it is purely a matter of comparing output with input.

The problem of both GLASS BOX and BLACK BOX design processes is that neither provides a theoretical mechanism for dealing with the thousands of possible solutions that may be generated. *"The quality of a design is limited* *by the number of alternatives explored.* " Davis, AR, June 1984. There are too many combinations of options to evaluate all of them by rational thought, in a GLASS BOX fashion. To make an intuitive, or BLACK BOX, choice between options would be merely to reverse the previous process. In other words, it is no good to use intuition to generate as many options as possible, and then use intuition to pick one option.

3. The self organising system, Jones' third designer; (Jones, 1981) divides design effort into two parts:

1. that which carries out the search for the best alternative.

2. that which directs and evaluates the pattern of search to provide strategy control

Blind searching is replaced by an intelligent strategy that makes use of external criteria and the results of partial previous searches to locate short cuts through alien surroundings. Strategy control must encompass a model of the design situation and problem space, and of the search strategy itself. The combined model of situation and self allows the designer to monitor the balance between the design, its situation, and the cost of the current design process. This is achieved primarily through the use of a design meta-language which allows the description of relationships between a strategy and a design situation. The meta-language allows the modelling of alternative strategies, and to predict the most promising for the current design. A specific example of such a meta-language is Matchett's Fundamental Design Method. A more general form of design progress monitoring is provided by critical path analysis. The network models design time in relation to various ways of arriving at a solution. Even though Jones refers to the *"self-organising system"* as a designer, it appears to be more a design strategy than a type. It is an attempt to meld a systematic or structured approach onto a BLACK BOX approach.

It is unclear as to the exact operation of the mind and how its processing takes place, and as de Bono (1969) comments, even if we were to know, how would this help us? There is some debate as to whether it is possible to encompass and fully understand the human mind with the human mind. Two polar theories propose a design process that is either unconscious and unknowable, or rational and describable. There are highly respected professionals in both camps, and it is clearly an issue that isn't easily resolved with reasoned argument. What seems most probable is that different designers use one or the other broad approach, depending on their temperament. Obviously the rational, GLASS BOX approach lends itself willingly to computer aid at all stages of the process, whereas the BLACK BOX designer might only find a use sorting mechanism. Patterns stored in the brain tend to make an impression, and this impression affects the way the brain receives information about future patterns. The same pattern or even a pattern slightly different from the original will tend to be recognised as the same pattern. The brain is not returning exactly the same information that was fed into it; it is returning something more useful: an identified pattern. The strength of the brain can also be its weakness; a pattern may be incorrectly identified and matched, but on the whole the strengths outweigh the weaknesses. Pattern matching is something that current computers do not do very well, but by building on de Bono's explanation of the human process, it is possible that a computer equivalent could be designed.

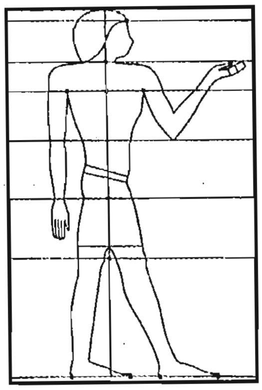
Modelling design information (point 6) has traditionally been done with both conceptual and representational or scale drawings. This design action will be examined in more detail in Chapter Six - design tools.

Linking of dissimilar data (point 7) has been the focus of a great deal of research from the late 1960s. It is recognised as an inherent weakness of current computer technology that whereas linking, ordering, indexing, and sorting similar data types is a relatively simple operation, being able to tie together different types of information is a complex operation that requires conceptual changes to information technology. Various concepts have been suggested, but the one that is receiving a great deal of attention at present is hypertext, the basis for disseminating information on the Internet. The system allows linking text, graphics, video footage, and sound information in a unified format that can be interpreted by many different computer hardware platforms. It also supports the concept of information threads, an analogy being the path in time and space a person might follow in researching a particular topic in a library. One reference might list a second, which might suggest an offshoot line of enquiry into a related topic. Hypertext allows a similar linking of related topics with multiple threads.

In terms of a theoretical framework for a computer tool, the GLASS BOX designer type is virtually a definition of a computer process. The BLACK BOX type, is conversely a workable definition of a human designer, given that the eleven definitions at the beginning of the chapter have not particularly clarified the function of design. Interestingly, the self-organising unit type nicely describes a human designer using a computer tool. The computer performs searches through vast amounts of data, while the human directs and evaluates resultant patterns. The next section examines the personal forces a designer brings to bear on the design problem.

CHAPTER FOUR - CREATIVITY AND RULES

Personal or internal forces acting on the design process.



Egyptian
Proportional Figure.

> "... the search for those highly universal ... laws from which a picture of the world can be obtained by pure deduction. There is no logical path leading to these ... laws. They can only be reached by intuition, based upon something like an intellectual love of the objects of experience." Einstein, 1934, cited in Popper, 1959.

As outlined in Chapter Three, problem solving, idea proposal, and decision making are important actions of the design process. They involve a great deal of personal contribution from the designer, with scope for originality. No matter which of Jones' (1981) three designers are retained to submit a proposal, each will make use of some strategy to decide which is the best course to follow. The process of thinking is often characterised by polar opposites; convergent and divergent problems, cognitive and rational thinking, or objective and subjective analyses. No doubt reality is a subtle mix of all of these, but simplifications are useful in understanding complex subjects.

Much has been written about the functions of the left and right sides of the brain, often with the subdivision into cognitive and rational abilities. Designers need to draw on both faculties in solving planning problems which involve, among others, spatial and numerical issues. Cognitive modelling, often described as seeing with the mind's eye, is externalised through the action of spatial physical representation, usually drawings. This mode of thought makes use of analogy and involves recognition and manipulation of patterns to achieve an integration of concepts. Rational thinking is seen more in terms of linguistic or semantic definition of a problem, a form of internal debate. It is externalised through symbolic language, often in mathematical or scientific notation. Its form can be categorised as digital, sequential, and analytical - concepts with strong ties to computer science. The process involves categorisation and logical deductions or inferences. Because of its analytical nature, rational thinking is itself far easier to analyse and understand. For this reason design methods often have a stronger theoretical basis in rational thinking.

Decision making is explicable only in terms of some frame of reference, which in design terms is usually a personal conviction. Einstein believed that access to universal laws or truths is via intuition, or personal insight. This chapter explores the formulation of rules that allow designers to make decisions, and tools that aid creativity in their application.

PROBLEM SOLVING.

Many problem solving methods have their roots in the thinking of Rene Descartes (1596-1650). He proposed that a problem should be broken down into the smallest parts that still have meaning. Each of these sub-problems should be solved, and the results synthesised into an overall solution. Descartes believed that if sub-problems could be reduced to a point where axiomatic truths applied, the overall solution was rationally tenable. This theory is evident in most methodologies and forms the basis of computer programming. Many designers feel this results in a simplistic analysis of a problem, as the inter-relationships between parts and part assemblies tend to be ignored. A further difficulty arises if axiomatic truths do *not* present themselves.

A problem may be defined by imagining a person in one situation who wants to move to another situation, and who does not immediately know what steps to take to achieve this. A method may be defined as a list of actions that must be performed to get from the problem to the solution. There are various categories of problems.

Convergent Problems such as crossword puzzles, noughts and crosses, and chess, all have a solution by definition, which is usually a complete and satisfying resolution to the problem. There may be more than one solution to a convergent problem, but the steps to reach it are finite, and objective tests may be employed to determine whether a solution has been achieved. Each step in the solving process attempts to reduce the number of possible steps needed to achieve the solution. These problems may be categorised as puzzles - they may initially stump us, but with enough effort we can always arrive at a solution.

Divergent problems are open ended. Each step in the solving process tends to suggest more possible steps, and a myriad solutions can stem from any given problem. It is possible to apply tests to evaluate if a solution is valid, but this in no way implies that the search has ended; there is always the chance that a better solution exists. There can be no definitive answer to a divergent problem.

Problem solving involves re-ordering complex information regarding the problem situation into patterns; either mental images or physical sketches, or a combination of both. Within these patterns a designer attempts to resolve unstructured information into a more easily perceived form, and in doing so, emphasises personally important aspects of the situation. (de Bono, 1969) This is a dynamic process in which a series of patterns may be generated, each being an attempt to resolve conflicts highlighted in the preceding pattern. There are two influences on the evaluation and generation of new patterns.

- Internal relationships between design components within the problem space respond to changes in the overall design concept.

- External influences arise out of the degree of freedom the individual designer has in relation to personal or social constraints on acceptable or unacceptable thoughts or actions. This is manifest in the sensibilities of the designer concerning issues such as what is morally acceptable and what is aesthetically pleasing.

IDEA GENERATION.

What sequence of events precedes a design solution? There is usually a period of incubation, (encoding) during which a designer gathers vast quantities of information, and may concentrate on apparently trivial aspects of the problem with little result. The way forward from this directionless phase may be marked by a leap of insight; a dramatic change in the way the designer views the problem which translates a complex problem into a simple one. What is the source of design ideas? Da Vinci's advice to a student to *"Draw, Antonio, draw."* has been the designer's catch phrase for hundreds of years. The student's grand sketching tour is the concentration of an occupation that should ideally last a lifetime, the accumulation of a repository of images to serve as analogies for later designs. Many designers have acknowledged the influences on their proposals relating back to sketches made decades before. The design will usually be an interpretation of a stored image, an analogy.

Murdoch (1956, cited in Heath, 1985) lists four types of idea generation designers may use during synthesis stages, all of which can draw on this image repository.

Variation is the modification of a type caused by a change in the application or use of the artefact, or as a result of incremental changes motivated by feedback from specific instances of the object over the period of its use; a *"successful mutation."* Called unselfconscious design by Alexander, it is generally a slow process, and is similar to Jones' craft design. It can be regarded as an extrapolation; maintaining an existing design idea, while modifying some dimension of it. Development of architectural styles generally follows a process of variation. Variation is easy to understand, and can be understood as a GLASS BOX process.

Cultural borrowing describes the design action of appropriating and applying ideas or styles from other parts of the world or other historic periods to analogous problems. The spread of the Modern Movement is a good example of this process, and highlights a drawback to cultural borrowing. Designs often incorporate details or constructional techniques that are regionally specific, and do not travel well. The current information-rich period has made such catholic borrowing an attractive design generator. This process often accompanies the phenomenon of cultural emulation, which is evident in the present explosion of American food, clothes, music, values, and culture. This can also be seen as a GLASS BOX process.

Invention involves *"the transfer of elements of habitual behaviour from one situational context to another."* (Murdoch, 1956, cited in Heath, 1986, p46) A problem in one field of endeavour is recognised as being analogous to one in another field for which a solution is known. A leap of intuition is required to bridge the differing frames of reference in the differing fields, and as such this is a BLACK BOX process. This process is seen in the development of the jet engine as a result of observation of animals with similar propulsion systems, such as the squid.

Tentation, or trial and error describes the random behaviour that a designer may resort to if a number of variations of existing habitual responses do not produce an acceptable result. During the course of tentation, a novel accidental response may provide a problem solution. Crises often trigger tentation. Complex, ill-defined problems, such as those found in architectural and planning situations, do not respond well to tentation, an inefficient idea generator. By definition, tentation is not intuitive, and as such can be classed as a GLASS BOX process.

Broadbent (1973) has four of what he defines as design types, but which may equally be viewed as idea sources, and have some parallels to Murdoch's.

Pragmatic design is concerned with getting the job done. Whatever materials and tools are available to produce the object in the most direct fashion are used. Trial and error may be used in refining a design, but once established, such a design may remain unchanged for hundreds of years. The igloo is an example of such design.

Iconic design is established in the fixed mental image a member of a group may have about the form and construction of an artefact. If children are asked to draw a house, the results at similar ages below eight or nine will generally conform to a standard image.

Analogic design is similar to Murdoch's invention, and relies on the same process of identifying analogy across different frames of reference.

Canonic design draws on some ordering system to supply a structural concept. Grids, or proportion or modular systems provide the designer with a framework on which to base decisions concerning shapes and sizes of components of a design, what Broadbent calls the *"authority of a geometric system."* This is an idea source that is readily applied to computer aided design.

RULES FOR DECISION MAKING.

Design may be viewed as a series of problem transformations, which are governed by codes or rules which link the design solution to the abstract requirements of the problem. A rule may be any transformation that achieves a reduction in the number of variables in the solution domain. This is achieved by mapping a problem expressed in terms of the brief, to a solution or class of solutions that will satisfy the problem requirements. (See Chapter Three for a discussion of homomorphic reduction mapping.)

These rules are expressions of pre-existing cognitive ability on the part of the designer and embody a personal design philosophy and ideology, and social values. Rule systems are dynamic, and by definition particular to a designer's abilities, and sense of taste and style. These are subject to change, not only from designer to designer, but may vary for each designer as social contexts and styles change. Research has tended to concentrate on the more abstract and general rules, as these tend to be easy to analyse, they apply across a broader spectrum of designs and disciplines, and are more stable. As the level of detail increases, rules become more unstable, and are applicable only in specific cases. It is in the formulation of rules that design methodologies often fall short.

The application of a rule at any stage in the design process acts as the generator of a set of solution links that need to be evaluated specifically in terms of the conditions of the rule, and generally in terms of the overall problem definition. This process takes place from within the context of the rule, and involves relative achievement of the stated criteria. Failure to achieve these criteria results either in a modification of the problem constraints to allow the existing rule system to arrive at a workable solution, or an analysis of the problem structure leading to the inference of a new rule which can be incorporated into the general rule structure. This process is described as analysis through synthesis.

Originality may be stifled by mental rigidity which occurs when a designer operates in a way more regular than the situation demands. At the other extreme, a designer may ignore or be incapable of perceiving external realities that render a solution unworkable. This wishful thinking may restrict good design. The design process can be seen as one of recursive conjecture and analysis. At a broader scale considering a series of projects, design progresses in a series of paradigm shifts marked by successive modification and refinement of the rule system.

Spatial design or built form problems are regarded (by architects and planners) as more complex to solve than problems such as those of mechanical engineering. A designer applies solution techniques to an existing problem situation to arrive at a design goal. The final design situations or states that will accommodate candidate solutions need to be generated before these solutions can be evaluated in terms of the desired goal, and the heuristic that guides the change of state relies not only on information internal to the particular problem (the design brief) but also on information that is external to it. (such as traffic circulation, regional economy, and employment opportunities) The complexity of the problem is compounded in that information necessary to the design is always incomplete, and often inaccurate. There are usually several acceptable, but very different solutions to any given problem.

In summary, two personal forces can be brought to bear in the design process:

- The function of personal creativity during the stages of synthesis in design.

- Building up a set of design rules - a personal task for each designer - to assist in decision making.

The proponents of computer aided design see the implementation of a set of computer-based design rules lying at the heart of a successful implementation of this tool. A computer expert system that could implement the refinement and elegance of a truly great designer would surely be useful. At present no great designer has produced a written account of these rules, without which there is little chance of programming such a system. Currently available expert system shells are incapable of handling the complexities of spatial design. There is also the question of whether this is what the majority of designers want. The answer is almost definitely in the negative.

- Most designers list generative design as their most enjoyable activity.

- Such an expert system would be available not only to existing designers, but to any untrained person unskilled in design who could operate a computer.

- The process of codifying such a system would be colossal.

On the whole, it appears that these functions of creativity and decision-making are best left in the province of the designer. A number of issues affect further understanding of decision making in the design process.

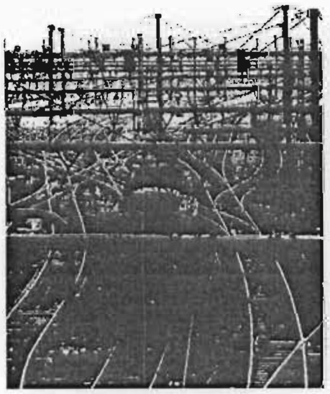
It is necessary to determine if a complete and accurate set of parameters to describe a state in the design process is attainable. This is a function not only of time, but of practicability. It is likely that it will never be possible to capture all relevant information, and it becomes a question of determining what constitutes sufficient relevant information, and capturing this. Computers, with their abilities to store vast quantities of information, and to perform rapid searches to weed out unwanted data, are well-suited tools for this task. At present a CD-ROM disk can hold 800MB of information. Technology will soon be available to increase this capacity by a factor of ten.

There is no explicit process available to generate candidate solution states based on existing problem spaces. Traditionally this is a BLACK BOX function. It is a common design methodology failure point, and as such represents the area least suited to computer implementation.

There is little understanding of the process involved in making trade-offs between differing qualities when evaluating design proposals, which certainly appears to be a BLACK BOX function. Notwithstanding this, there is a variety of proposed methodologies which attempt to codify this design phase.

CHAPTER FIVE - DESIGN METHODS.

External forces acting on the Design Process.



Railway Networks.
Complex structures to
achieve a simple end.

"It must of necessity be that even works of Genius, like every other effects, as they must have their cause, must likewise have their rules." (sic) Reynolds, cited in Heath, 1984

The search for a framework for accumulating knowledge, or epistemology, can be traced at least as far back as the time of the Greek philosophers. Plato maintained that all knowledge could be stated in general terms that anyone might apply. (Mike Cooley, ed. Thakara, 1988) Any set of procedures that could not be framed in such terms was merely belief, and as such did not involve understanding and therefore could not be understood, a neat, frustrating syllogism.

> "... what cannot be stated explicitly in precise instructions - all areas of human thought that require skill, intuition or sense of tradition - are relegated to some kind of arbitrary fumbling." Mike Cooley, ed. Thakara, 1988.

The criticism levelled against many design methods is of having too rational a basis with no mechanism analogous to the leap of insight. This argument gains specious validity in that authors of these theories are often self-professed realists or rationalists, whose designs might lack creative spark anyway. The counter-argument might be that a rational mind is required to attempt to codify the process of design. It is not unreasonable to hope that some, if not all of the steps in the process can be understood, and that unclear areas may be regarded as isolated knots in an otherwise untangled cord.

Since the time of Violet-le-duc, designers have striven to place design theory on a sounder intellectual and practical footing. The fields of structural theory, and building, psychophysical and social science have all attempted to describe the design process within the framework of a working model of the task. Design schools still emphasise two dimensional drawings as the vehicle for understanding and presenting designs. In consequence there is a dichotomy between the so-called realists who understand the technology, but are often unable to produce fine designs, and the conceptual artists, who may be unable to modify their designs to the requirements of the construction industry. This is no doubt in part due to personality differences between individual designers, but it underlines the fact that as yet no model exists that embraces both facets. There are designs that are beautiful and impractical, as well as those that are practical and ugly. The fact that those exist that are both practical and works of art, suggests that some designers or partnerships have synthesised these two goals. As Heath puts it, these designers have a method, but it is not an explicit method.

Levy (cited in ed. Pipes, 1986) has proposed five paradigm shifts in design thinking during the 20th century.

< 1920 - Craftsmanship concerns.

1920s - Industrial Arts.

1930s - Professional Designers.

1950s - Design methods debate.

1970s - Design Research.

1980s - Holistic design approach or design ideology.

These shifts have usually been due to radical social or political reforms such as the Great depression, World War II, concerns about public participation in design, and the information technology revolution. Until the early 1950s, the definition of design might have been simply *"what designers did."* (Evans, 1982) This process involved transforming a conceptual idea into a desirable artefact. Prior to the mid-1950s there had been little research into the mechanism of this process. Traditionally young designers acquired skills through years of working under an acknowledged master. It was held that either a person could design or they couldn't. With the increased industrialisation of the late 1950s greater pressure was brought to bear on the designer to perform, and the concerns of professional liability became an issue. (Evans, 1982) It was during this period that the search for an explicit method began in earnest.

DESIGN METHODS.

Systematic design methods gained currency in Britain and the United States of America in the 1950s. Various conditions fostered their development and implementation. Towards the end of the second world war, a number of military and para-military bodies expended a great deal of effort in analysing problems posed by the changing nature of warfare. One example is network analysis which was originally developed as an aid to the torpedoing and bombing of Axis submarines. The study of ergonomics also grew out of this rich period of development. At no time in the past had so many objects to be made for such a massive group of people. Millions of guns needed to be efficient in the hands of millions of soldiers, no matter what their physique.

The development of Information Technology was accelerated by the war in two areas. Vast efforts were expended in developing sufficiently secure encryption methods for allied intelligence. Coupled with the development of machines for cracking Axis codes, this led to great strides in the development of abstract logical problem solving and computer programming techniques. Electronic components evolved rapidly, from the thermionic valve current during the war, to the transistor which was first demonstrated in 1948, which paved the way for computers of greater and greater power. This was a time of technocratic optimism, the age of the scientist. After the climacteric events of the culmination of war against Japan, few people envisaged anything but a rosy future for the human race, who had control even over the atom. In the United Kingdom, the labour government under Harold Wilson saw the future "forged in the white heat of technological revolution." (Evans, 1982, p247)

Critics of these design methods claim that technical problems of a systems engineering nature were specifically chosen as application areas for emerging methods. There was an ever-present undertone of automation as the ultimate goal of design methods which can be seen as a preparatory step in the computerisation of the design process. (Foque, ed. Evans, 1982)

One of the most significant models of the 1960's, formally propounded at the Imperial College Design Conference in 1962, views the design process in terms of an iterative process of analysis, synthesis, and evaluation. The analytical stage consists of investigating the problem, identifying and articulating the requirements, and assembling the relevant information. This information is then synthesised into a design proposal, which is tested against the requirements. Suggested improvements arising out of this evaluation result in further iterations of the loop, until a 'best-fit' proposal emerges. The main drawback of this model is that it offers no help in arriving at actual design proposals. It has also been criticised on the grounds that it provides no theoretical basis for evaluation. As this model is one of the most widely used, it will be covered in some detail. Jones (1981) prefers the labels divergence-transformation-convergence for the analysis-synthesis-evaluation cycle.

Divergence. refers to the process of enlarging the boundaries of a design situation so as to have a rich enough search space in which to find a solution. Divergent search has the following characteristics: (Jones, 1981, p64)

- The general goal of this stage of the process is to increase uncertainty, while ignoring preconceived solutions. As much relevant information as is possible should be amassed, hence the label divergence.

- Objectives are tentative and unstable.

- The problem boundary is unstable and undefined.

- All information, no matter how much it may conflict with other information, is important; filtering of information is deferred.

- The clients' brief may be regarded as a starting point for investigation, but it is likely that it will be modified during the course of design.

- Research carried out at this stage should attempt to gauge the sensitivity of various elements of the design to consequences of changes in design objectives and problem boundaries. Results should be geared towards establishing ranges of acceptable values of such changes. Important factors are users, clients, markets, suppliers, and manufacturers.

Divergent searching may be seen as testing for stability or instability in all aspects of a problem. Stability and instability may be spread evenly across the scale of the design situation; from the smallest component part to a system implementing multiple designed objects. Designers should avoid latching onto patterns already experienced in previous projects, deferring all decisions until the next stage. While it is necessary to gather as much information as is possible, it is also important not to waste time and effort gathering information that has little value. Jones' catch phrase here is that *"the cost of not knowing must outweigh the cost of finding out."*

Transformation. This is the stage of analysing patterns, of creativity, and of flashes of inspiration.

- The concern is with finding a pattern that will transform a difficult problem into a simple one. This pattern will link the various practical aspects of the brief in such a way as to direct further effort towards a specific, tangible solution, complete in all details.

- The brief, design objectives, and problem boundaries are solidified, and important variables identified.

- The problem is split up into sub-units which may be farmed out to individual designers.

- Successful transformation relies on the freedom to change sub-goals in order to avoid major compromises, and the speed with which the consequences of these changes may be evaluated. This is where the skill and experience of the chief designer in the team comes into play in traditional product level design.

- *"In general, the stronger a person's mental grasp of the world, existing and potential, the more intolerant will he be of any transformation but the one he perceives as being correct."* (Jones, 1981, p67)

Convergence. The designer's aim is to reduce uncertainties until only one of a range of possibilities remains as the chosen design solution.

- A regimented approach is required in eliminating as many variables as quickly as possible. As a designer approaches the point of convergence, the effort and detail required to evaluate candidate solutions increases dramatically.

- The problem most often encountered during convergence is that unforeseen sub-problems can prove to be insurmountable unless prior decisions are revised. Ideally the pattern selected during the transformation phase consciously or unconsciously addresses or anticipates all such sub-problems.

- Two opposing strategies may be employed for detail design during convergence; out-in, (or top-down) where the problem is tackled by solving broad issues before details are considered, or in-out, where detail design informs the broader issues.

- The language used to model solutions should become less and less abstract, finally resulting in scale drawings, prototype scale models, or computer models of the design proposal.

Most design research focuses on the process as a problem solving activity. From a systems approach it is necessary to assume that the form of a complex system may be analysed as stable so as to be able to uncover the structural laws shaping a design problem. The design solution emerges from a linear series of reshaping exercises carried out on this revealed structure. The creativity of the process is manifested in selecting the optimum or most cost-effective path through a series of activities to arrive at the solution. In this sense, creativity is reduced to finding the perfect sequence of steps through a complete analysis of a problem. (Foque, ed. Evans, 1982) This view of design as a rationally explicable and transparent process typifies Jones' GLASS BOX designer.

During the mid 1960s designers moved away from a systems orientated concern with the most efficient means of structural intervention in the design situation. Emphasis shifted towards the designer's personal contribution to the problem statement and involvement in the design process. Motivation for this move can be found in the perceived failure of technological management in areas of pollution, traffic management, and welfare-related ills. Foque describes this as a shift in emphasis from means of *intervention* to means of *insight*. Design research techniques such as brainstorming and synectics, while having the effect of defining the design situation, also emphasise the thinking processes of the designer and allow the design to be charted. The use of interviews, questionnaires, and participatory observation, now regarded as standard design analysis tools, became current during this period; another indication of the shift from technical to social concerns.

Research in the early 1970s focused more on communication of information to the so-called naive user, the stated goal being increased user participation in the design process. Designers were faced with the added burden of explaining what was still largely a dark art. The inclusion of the user raised questions as to the primacy of the designer in the process and the relevance of the profession as a whole. Cross (cited in Evans, 1982) goes to the extent of stating that this inclusion, (of the user) once completed could reduce to nothing the traditional distinction between designer and user. Methods of this period aimed to:

- Expedite the gleaning of information aimed at fitting the design to the users' requirements.
- Facilitate user understanding by striving for a transparent design process.
- Include the user in decision-making.
- Include the user in the realisation of the project.

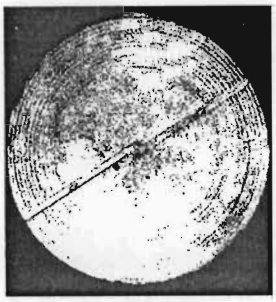
These outlined design methodologies have been employed in architecture and planning with mixed success. The analysis-synthesis-evaluation cycle has been of more far-reaching effect in all spheres of design. As Foque (ed. Evans, 1982) points out, the use of methods that are in essence optimising algorithms equates creativity with optimisation, as the system that is most rigorous in its optimisation would be regarded as the best. This is clearly not the case.

Technology is advancing at such a rate that Cooley (ed. J Thakara, 1988) notes *"It has been said that if you could divide knowledge into quartiles of out-datedness, all those over forty would be in the same quartile as Pythagoras and Archimedes."* This complexity stretches the ability of designers to cope with entire problem spaces in their heads. The use of design methods encourages the transparency of process necessary for more than one designer to contribute in the critical conceptual design stage. Foque (ed. Evans, 1982) gives three motivations for the implementation of design methods:

1. As a means of managing increasing complexity. If the designer's efficiency as an information processor can be enhanced, a better end product will result.
2. As a means of gaining clearer insight into the problem; a tool to provide a better understanding not only of the design problem, but of the designer's mind as well.
3. By externalising design, other designers and end users can participate in the process.

These reasons are equally compelling when applied to the implementation of computer design tools. Not only is complexity increasing, but so is available data. This is generally in digital form, and needs to be converted to useful information as expeditiously as possible. The accessibility of information to members of the design team and end users and the facility computers offer in this process is explored in the pilot studies.

Chapter Six - Design Tools.



William Oughtred's
Circles of Proportion -
an analogue computer.

The word *"design"*, indicating the process of design, appeared in European languages during the Renaissance. The original Italian word *'disegno'* carried a double meaning, both of *'drawing'* and of *'intention'*. That is not to say that the process had not already taken place, but rather that it became necessary to acknowledge an emerging discreet activity. Previously the processes of conceptualising and building were intimately bound together; a great structure such as a church would be 'built' by a master builder. What became apparent was that the design drawings could be built by any number of suitably competent builders. The definition of these words indicated a formalisation of the separation of the design from its built form. One of the requirements of this separation is the need for a language to describe the design.

Of various tools used by designers, three stand out as important; models in general, scale drawings in particular as the most used models in design, and specific design strategies, which involve directed use of models.

> "... an historical overview of design reveals a progressive, if slow, development in the power and scope of modelling, though the oldest methods, literal physical models and drawings, continue in extensive use." Heath, 1986, p7.

Jones (1981) identifies a hierarchy of four levels of design activity - community, systems, products, and components. (See figure 6.1) Each level has an appropriate scale, unit, and required resolution of detail. The design tools and models suitable to each level vary considerably. Models of components and products tend to be representational. Tools such as scale drawings or scale models emphasise physical properties. Concepts of systems and communities tend to be more complex and require a greater degree of interpretation, so models tend to be symbolic, often taking the form of mathematical relationships or abstract computer simulations.

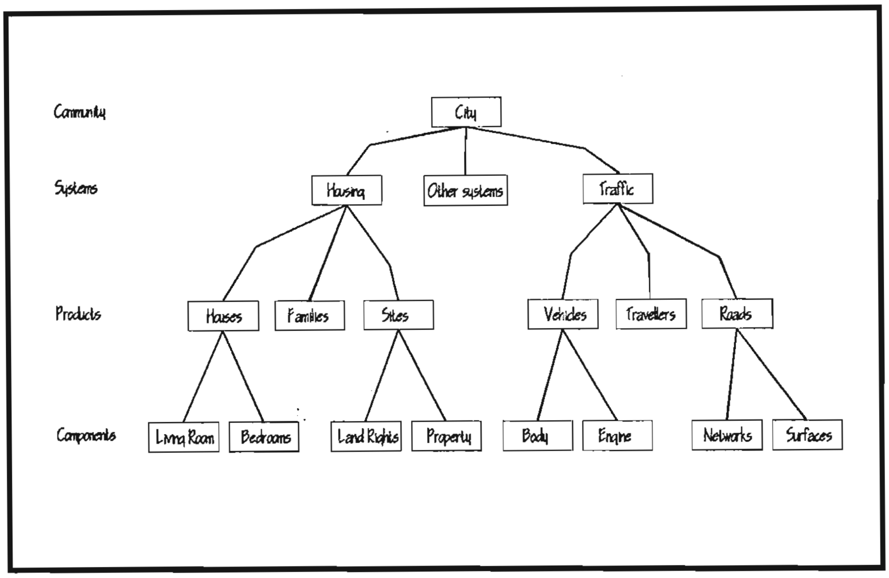


Figure 6.1 Levels of Design Activity. (Jones, 1981, p31)

Models can be seen as complex analogies specifically selected by designers to describe the structure of a design situation, and serve the purpose of representing ideas that might otherwise be difficult or impossible to comprehend. Certain problem spaces, such as society, are impossible to see, and can only be visualised in comparison to other things we can see and understand.

The earliest discovered use of architectural drawings, being diagrams with some form of scale and measurement as instructions for the construction of a designed object, occurs in approximately 2800 BC in Egypt. One of the best preserved examples consists of an ink drawing on a limestone chip representing an arc with measurements below for its setting out. (See figure 6.2) The implications of this drawing are important. Instead of working with building materials and positioning them on site, a designer set down an intention to build before beginning construction. It is possible that several curves were proposed before the final one was chosen, drawn, and dimensioned. This off-site preparation has consequences to the process of artefact production. The designer becomes interested in the drawing as something apart from the object itself. The restrictions of the medium imply certain conceptual changes in the mind of the designer. In order to fit large objects onto limited sized vellum or stone, designs must be scaled. Drawing aids were soon employed to help in this process of estimating the media requirements of a design; grids and axes.

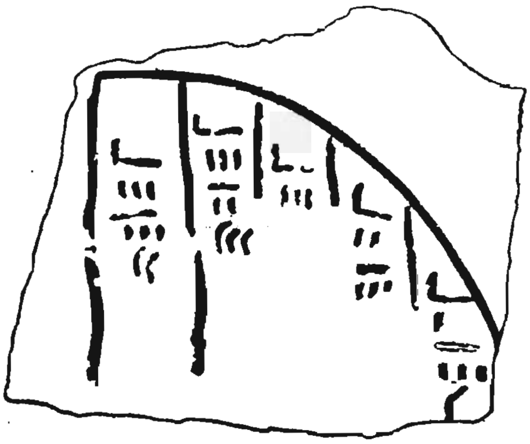


Figure 6.2 Diagram of arc on stone chip

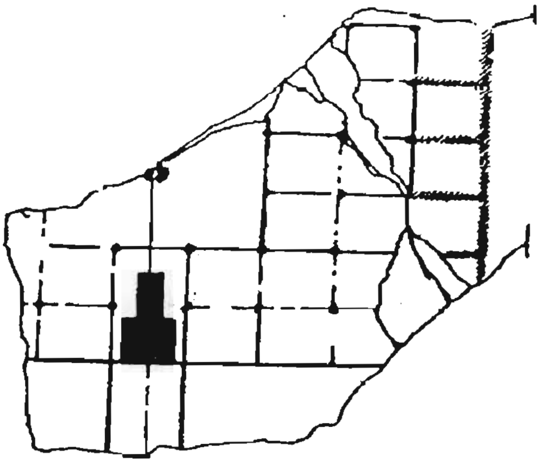


Figure 6.3 Landscape plan of temple at El-Deir al-Bahari. (Broadbent, 1973, p34)

In another example of a limestone drawing of a landscape plan for a temple at El-Deir al-Bahari, c 2100 BC, the symmetry and repetition of the layout grid seems to have captivated the planner to the extent that it is continued into the adjacent plot. (See figure 6.3) The offending grid lines have been scratched out on the drawing, and excavations of the site reveal that this encroachment was never built.

Egyptian sculptors used geometric grids to lay out work on stone surfaces. In classical times, architects such as Vitruvius employed the characteristic modular principles of Greek and Roman design. The adoption of the Indo-Arabic numeral system made scale drawing a far easier exercise; in particular the inclusion of the symbol for zero, which reached Europe some time in the twelfth century. (de Bono, 1971, p206) In medieval times tracing floors and stones were used as geometric design models. There are also some surviving physical scale models from this period. The invention of perspective drawing at the start of the Renaissance allowed relatively quick and accurate three-dimensional visualisation of designs to be constructed, something which had previously required a scale model.

Any drawing, model, or analogue will contain distortions of the object or idea that is represented. This is inherent in the concept of a model being a simplification of the object. A model by definition can never present a one-to-one mapping of every detail of what it represents. Models tend to focus on specific aspects of an object, those parts the designer wants to explain or emphasise. Three types of models may be identified:

Iconic models look like the objects they represent - photographs, paintings, and sculptures may be iconic models of people, places, or things. Scale models such as model steam engines, or model buildings also fall into this category. An iconic model exhibits a specific relationship to what it represents, usually scaled up or down, but can not share all of its characteristics.

Analogue models are used for objects, processes, or systems for which it would be undesirable or impossible to construct an iconic model. Properties of the object are represented by properties of different kinds in the model. Maps may be thought of as analogue models with intangible entities such as country or property boundaries being represented by lines, and topography being simulated by contour lines. Additional information such as population densities may be enumerated by means of hatched or coloured areas.

Symbolic models express relationships between entities by means of mathematical equations.

Models of any type may be descriptive or normative. As the name implies, descriptive models provide information about reality from a particular point of view, which may be static or fixed in time, or dynamic and varying over a period of time. Normative models attempt to predict future conditions, describing unknown situations in terms of known ones.

SCALE DRAWINGS.

What turns an ordinary object into a designed object? Conversely, what turns a person into a designer? No one person is credited with the design of the farm waggon, the rowing boat, or the violin, yet each exemplifies exceptional design. That objects of such complex form and fitness of purpose should have been produced without the help of research, a design team, and a marketing department is quite remarkable. In looking at this craftsmanship, valuable insight into the function of scaled drawing is revealed. Jones (9181) suggests an evolutionary progression from craft work to design by scale drawing, motivated by a need to increase the *"perceptual span"* of designers.

The designer achieves increased perceptual span by concentrating the geometric aspects of a design in a drawing. The drawing functions as an interpreting tool, allowing far more complex objects to be conceptualised than could be managed if the designer's head were the only store of information. With drawings as markers, design can progress through a series of development cycles. Geometric consequences may be tested; spatial combinations of component parts, physical effects on the design, or contextual massing impact. Limitations of the craftsman's partial understanding of reasons for particular forms, and the high cost of testing by construction are reduced. Designers differ from most other industrial specialists in that they are required to maintain a broad view encompassing many aspects of the design of an object. Drawings are particularly versatile in this respect, as they allow diverse and tenuously linked pieces of information to be stored.

The scale drawing can be seen as a model of an artefact that can be rapidly manipulated to test relationships between components of the whole. The ease and speed of these manipulations, and the possibility of storing tentative solutions to sub-problems while other issues are addressed, reduces the vast amounts of information to be processed to manageable chunks. This is achieved by helping the designer to identify geometrically promising component combinations. If a design problem consisted of ten component assemblies, each having ten possible combinations of parts, a designer would have to investigate ten billion alternatives to exhaust all possibilities. If the scope were reduced to ten geometrically compatible components, the number of combinations to be explored is 100. Even if a further nine compatible sets are investigated, the number to be explored is still only 1000. In this way the drawing tool allows a designer to home in on promising layouts, thereby reducing the majority of unfruitful combinations.

The drawing process is directed towards solving issues of internal compatibility between components, which can generally be modelled geometrically. One of the weaknesses of traditional design by drawing is the difficulty of gauging the fitness of an artefact in respect of its manufacturing process, and intended use. For the craftsman, the construction process is central to his involvement in producing an artefact. Designers draw largely on memory and imagination in judging what can be built easily, and what is comfortable to make use of. Certain objective tests can be performed to aid in this evaluation. Scale models and prototypes allow viewing and visual testing in three dimensions. Critical parts can be tested for conformity to established standards. These tests may be performed by the designer directly or by specialists such as civil or structural engineers. The same concerns arise in dealing with relationships external to the proposal, such as traffic flow around a building, or business trends in a sub-region.

Architectural design has tended to be concentrated in the component and product levels with the emphasis on scale drawings as the preferred form of communication. Even though planning places more emphasis on community and systems levels, scale drawings are still the preferred model choice. In both instances, an improvement over scale drawings as the main vehicle for communication needs to be made for various reasons.

1. There is a perceived failure on the part of architects and planners to deal with problems occurring at a community and system level. (e.g. traffic congestion, crime, pollution) Any innovation at the systems level might require sweeping changes not only in components of a product, but in the products that make up the systems, and possibly in the organisation of the community in which the systems are employed. It is difficult, if not impossible to model these inter-relationships with scale drawings.

2. Given the complexity of design problems at a product and systems level, participation of designers in a team is required. There is also a move to community and user participation which requires clear externalisation of information, methods, decisions, and proposals. The language of design and medium of communication must be easily accessible if this is to occur.

3. Externalised design thinking makes design automation and the use of computers to speed up design generation feasible. One of the most common features of design methods is the use of block diagrams, matrices, and networks. This mapping of relationships can be seen as an attempt to increase the designer's perceptual span at a systems and community level of design.

DESIGN STRATEGIES.

A strategy may be defined as a series of design actions that transform the initial outline of a problem into a final design. These actions may be traditional - sketching or scale drawing - or they may be of the newer methodologies such as synectics, brainstorming, or network analysis. A single design method may be sufficient to solve a problem, in which case it may also be defined as a strategy, but in most cases, a strategy will comprise a list of methods or actions to be implemented in the solution of a problem. Strategies may be thought of as collections of design tools, or toolboxes. There are various categories of strategy. (Jones, 1981)

Linear strategies comprise a sequence of actions. Each action is dependent on the output of the preceding stage, while being independent of the output of any other stage.

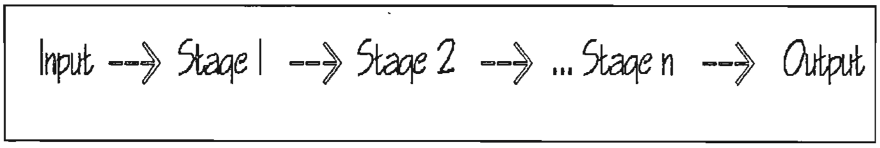


Figure 6.4 Linear design strategy. (Adapted from Jones, 1981, p76)

A **cyclic strategy** is similar to a linear one, except that certain stages are affected by the outputs of more than one other stage. This allows cycling or looping to occur over certain critical parts of the problem. There may be loops within loops and the structure of a cyclic strategy may become complex.

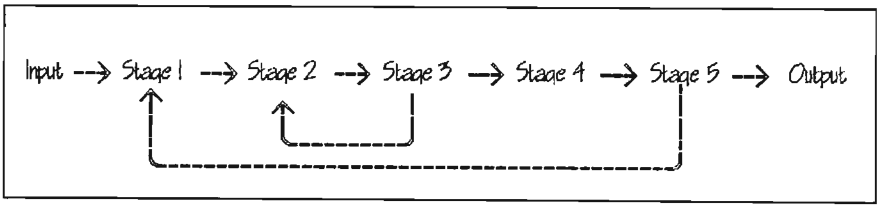


Figure 6.5 Cyclic design strategy. (Adapted from Jones, 1981, p76)

The designer must strive to avoid an endless loop or vicious circle which is an ever-present danger in a cyclic strategy. In this case resolution is not possible unless the pattern of the problem definition is altered.

A **branching strategy** is appropriate where particular design actions are independent of each other. The independent stages may be parallel, in which case there is the advantage that several designers may work simultaneously on them, or alternate, in which case the path ahead is dependent on a deciding action.

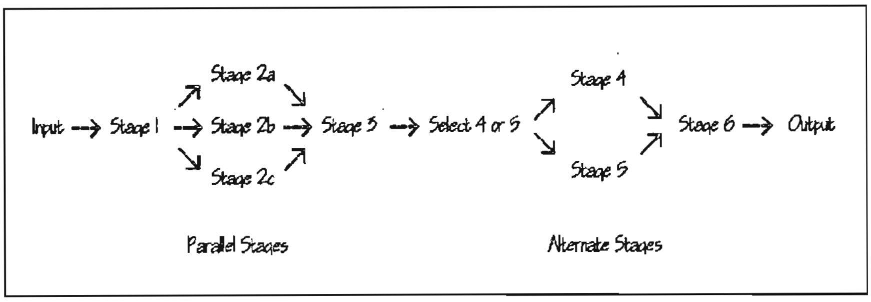


Figure 6.6 Branching design strategy.(Adapted from Jones, 1981, p77)

Adaptive strategies only prescribe the first action. Each stage is decided by the outcome of the previous. This strategy allows a designer to act on impulse but also employs the most intelligence, because each step is taken on the basis of all information available at the time. It is also the most expensive, as design resources and time cannot be controlled or predicted.

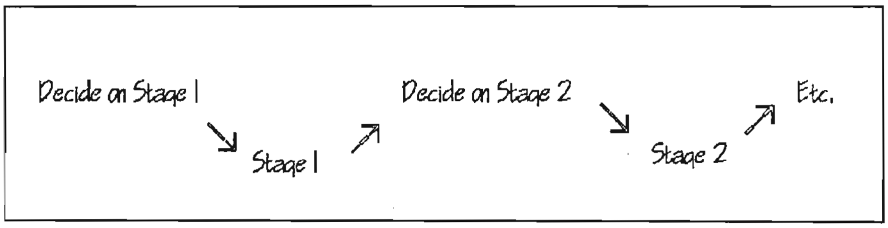


Figure 6.7 Adaptive design strategy. (Adapted from Jones, 1981, p77)

An **Incremental Strategy** is a modified and somewhat more conservative version of an adaptive strategy. One variable at a time is modified, and the effects on the outcome examined. Problems associated with this method are that if the increment is too big, a promising solution may be missed, and if too small, design time is enormous. This method is the basis of traditional craft-orientated design.

Random search is useful when many starting points are required for input into one of the other strategies. A point is selected at random in the problem space, and any possible solution at that location is identified. The last starting point and any results from it are ignored in the selection of the next point. This method is the basis of brainstorming.

The move from on-site and craft design to scale drawings involved major conceptual changes in the concept and process of design. Similarly, the change to computer modelling will require no less of a shake-up in thinking.

> "The nature and power of the conceptual tools available to the designer determine in no small measure what he can conceive and accomplish." Heath, 1986, p12.

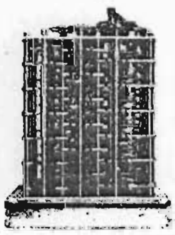
The converse is true; any limitations in the methods of conceptualisation will be apparent as limitations in the design.

> "The student or young architect who cannot draw freely or confidently will design within the limits of his powers of representation. He is a victim of 'analogue take-over': his tools and models constrain his thinking." Heath, 1986, p12.

The fact that a computer can produce output identical to traditional two-dimensional construction drawings tends to obscure the fact that as a tool it is vastly different from the drawing board. A conceptual change is required on the part of the designer. The emphasis of the computer as a tool is on an accurate representation of many facets of the designed object, rather than a stylisation of parts of it. In this respect it is so radically different from scale drawing it may be considered a new design language Computer modelling combines the ease of visual analysis of the scale model with some of the flexibility of sketching. In terms of the four levels of design activity, computer models can be employed on all levels.

- Scale and resolution of detail may be adjusted at will.
- Representational content is high, and physical properties other than visual ones may be modelled. (Iconic modelling)
- mathematical and parametric relationships may be modelled. (Symbolic modelling)
- Perceptual span is increased over scale drawings, as there is virtually no limit to the quantity of data that may be modelled.
- Geographical information systems allow modelling of non-graphical information. (analogous modelling)

CHAPTER SEVEN - A BRIEF HISTORY OF COMPUTERS IN DESIGN.



Charles Babbage's Difference Engine.

> "The machine can be nowhere creator except as it maybe a good tool in the creative artist's toolbox. It is only when you try to make a living thing of the machine itself that you begin to betray your human birthright. The machine can do great work - yes - but only when in the hand of one who does not overestimate its resources, one who knows how to put it to suitable work for the human being."
> Frank Lloyd Wright, cited in AR, January 1990, p171.

Wright might have been speaking on the very subject of this dissertation. The history of electronic computers is a relatively short span of approximately fifty years. Mechanical calculating machines are much older; drawings of an unbuilt adding machine were discovered in notebooks of Leonardo da Vinci. Gabriel Pascal built a calculating machine in 1642 to assist his father, a tax-collector. The machine, though bringing him fame, was not a commercial success. Businessmen thought it too expensive, and clerks feared it would put them out of work, (Trask, 1971, p67) indicating that human fear of replacement by machines is not a recent phenomenon.

Computers were first used in business in the 1950's, mainly for scientific calculations and accounting tasks. In 1963, Ivan Sutherland of the Massachusetts Institute of Technology released his SKETCHPAD computer drawing system. This program could produce drawings consisting of lines, circles, and arcs with the aid of a special pen and associated computer hardware. Three years later a system specifically aimed at building construction was released by the Imperial College in London. This system included predefined building elements such as floor and wall sections, that could be assembled into a design. The program could also extract bills of materials, quantities, areas, and calculate heat loss and lighting levels automatically. During this period theoreticians were formulating systematic design methods, which often required computers to process the vast amounts of data that resulted from activity interaction modelling. It was not surprising that many architects and planners saw this development as heralding a new age of design automation. A number of British government bodies such as the West Sussex County council went as far as to convert their entire drawing offices to computer operation, discarding all manual draughting facilities.

Designers in private practice had very different experiences. The systems outlined above were very advanced for their time, but were generally available only on main-frame computers which tended to be located on university campuses or in government organisations. Systems available to practitioners were expensive and had very slow processors and crude graphics sub-systems. A typical single user installation cost more per month than the salaries of a number of drafters. It was discovered that running a computer system was a full-time job which required data-processing skills. Software on offer tended to focus on tasks that exploited the current computers' strengths, those involving many calculations, such as beam design, heat-loss calculations, and daylight factor analysis. Designs produced by computer were found to be very naive, tending to concentrate on optimising a single factor; usually circulation, at the expense of all other considerations. Designers who espoused computer systems found they spent more time on computer administration and technical issues than on design. The building recession of the 1970's, and particularly the oil crisis of 1974 set the seal on their disillusionment with computer systems of this period.

CAD systems were first formally marketed in South Africa in 1978, (Brief, June/July 1983) and at that time the majority of purchasers were mechanical engineers. A typical installation of the time cost in the region of R250 000. Even by 1980, 80% of South African graphics installation were batch processors, meaning that data was prepared at a location separate from the computer, and then fed into the system for processing, with results only being available at a later time.

In 1981 IBM released the first IBM PC. Whereas microcomputers had been available prior to this, most notably the Apple II series, the PC, or personal computer was to herald a flood that has not yet abated. Current estimates number PCs as over 100 million world wide. A 1986 survey in Britain (Reynolds, 1987) found that 67% of architectural practices owned at least one computer. This percentage has risen in the last four years; currently only the smallest businesses operate without a computer.

As with most technical fields, there appears to be a desire on the part of computer users to indulge in deliberate use of abstruse terms and acronyms to confuse the uninitiated. CAD as the most common acronym refers to computer aided design to some people and computer aided drafting to others, while CADD refers to computer aided design and drafting. Part of the confusion arises out of the differing interpretations placed on the concept of design in the various professions that use CAD. To an engineer, the design process has more to do with drawing an object to predetermined dimensions based on calculation, than with the iterative development process associated with design. In offering three-dimensional modelling, current CAD packages go a long way to aiding this process. To a designer, current programs offer little in terms of design tools; with their main use being seen in construction drawing production.

The design process has been examined in Part One. In it, some of the complexities of the design process have been outlined. A process that yields readily to thorough analysis is relatively easy to automate with computer tools. This is not the case with architectural design and planning, which is a subtle mix of explicit, rational actions, and intuitive, BLACK BOX processes. The designer may use various levels of prototype or iconic design solutions gained by experience. This distillation process of experience and time defines prototype as unique, and therefore not able to be regularised or computerised. Often the first computer implementation of a tool is a crude or direct interpretation of manual techniques or existing non-computerised tools. There is usually a period of several years in which computer tools mature. In this time, programmers come to terms with the finer aspects of the process, and, together with information fed back from professional users of the computer tools, they are able to produce more elegant and original solutions to the initial brief, often adding capabilities that were originally impossible or unimagined.

This progression is clearly demonstrated in the transition from manual typewriter to computerised word processor. A typewriter is a character-orientated device - the user has a choice as to what character to select, but once it is typed there is no going back. Early text handling facilities by computers were little better than this. Words were typed in, with destructive back spacing being the only editing tool. If a mistake was made near the beginning of a line and only noticed near the end of the line, all intervening text had to be erased and retyped to correct the error. The next generation of computer text editors were line-orientated; it was possible to edit any part of the line of text before storing it in the computer's memory. Word-processors offered document- or page-orientated editing, in which the whole document could be edited before printing, or stored for later use. Development up to this stage reflected duplication of the facility of a typewriter. The next stage of refinement was to offer image-orientated editing facilities; the word processor had now crossed the boundary into the realm of typesetting and page layout, and far surpassed the original model of the typewriter. Instead of being able to handle text only, word processors now offer the facilities of including "objects" in a document; graphs, diagrams, images, drawings, and even sound or video segments.

CHAPTER EIGHT - FEAR OF COMPUTERS.

Mummified heads and oracular figures which 'speak', referred to in the Bible as Theraphim.

> "It will be a sinister day when computers start to laugh, because that will mean they are capable of a lot of other things as well." de Bono, 1969, p22.

There are a number of valid concerns regarding the use of computers in design, such as user-related health issues, mediocre design results, and the fear of loss of jobs. The architectural and planning professions are quite well positioned in terms of computerisation. In other fields, the introduction of computers has been at a fundamental level, with a corresponding fundamental change in the role of people in the post-computer era. A good example is in telephone exchanges. Whereas most telephone line switching used to be done manually, it is now done almost exclusively by computer. This has resulted in increased efficiency of telephone services, and increased flexibility, but has virtually eradicated the job of a telephonist within telephone service companies. A further change has occurred in the position of the switchboard technician in the hierarchy of the telephone companies. Digital switches are more reliable than their mechanical counterparts, and have the ability to signal their failure to a controlling computer. This means that human interaction is reduced to swapping faulty components at the instruction of a computer. Skill is greatly reduced, as is the number of technicians needed to service any particular zone. A rather bitter joke circulates among telephone technicians - new exchanges need only a man and a dog to staff them - the dog to guard the building and the man to feed the dog.

Based on the interviews in Chapter Eleven with designers, there appear to be four areas in which computers are being used in architecture and planning.

1. General office tasks, preparing reports, and managing finance.

2. As a tool to speed up boring or repetitive tasks such as extracting quantities, creating drainage sections, or preparing window schedules.

3. To extend the range of skills of a competent designer, such as to generate a three-dimensional model of a design, and thereby providing an evaluation tool.

4. For the generation or optimisation of design. This is the realm of Artificial Intelligence - the brain of a competent designer has been rifled, and the contents codified, so that decisions made along the path of a design can be measured against a "correct" response. The appeal here is not so much to the designer, but to the property developer. Such a system could produce a passable design quickly and easily that would comply with building regulations and wouldn't incur large professional fees.

It can be argued that this last situation has existed for some time in the form of the drafter. Designers have always felt the pressure of losing work to less qualified people with lower fees, but a reasonable counter-argument to this is that the designer needs to provide a better service to the developer or client, so that they will appreciate the value of investing more in the design component of a project. It is not difficult to demonstrate how such an investment can show a good medium- to long-term return. Sound and durable construction results in lower maintenance, and design with climate control affords a far more pleasant internal environment. Unfortunately there is a global trend, seemingly in all spheres of commerce, to consider only short term costs and gains.

What is the relevance of this to design? Most people have a fear of being controlled by computers. The fact that a poor designer will be able to turn out poor designs faster by using a computer will not in any way enhance the quality or value of that poor design. What sets spatial design apart from mere draughting is the idiosyncratic approach each designer brings to each differing situation. Computer art has never caught the public imagination in the way human art has. The very qualities of impartiality and rationality that are aimed for in accounting programs work against computer art. No-one has yet discovered a computer that has true empathy for the human condition, or that has been able to imbue its work with anguish. A recurring human urge is for individuality. This is in conflict with what is an underlying principle of computing - each time the same information is fed into a computer and the same operation is performed on it, the result should always be the same.

Many designers are concerned that computers tend to mould the design process. This is a problem inherent in the use of a tool for any task; its strengths and weaknesses indicate an easy path for it's use. The so-called "60-30" architectural designs of the 1960's arose out of the ease of using a set-square to generate these angles. The use of computers can lead to more repetition and standardisation than is healthy for a design, as there is the temptation to use elements that have already been resolved in past projects, rather than design from scratch. There are three counter-arguments to this.

- Designers have always had the facility to trace over past projects manually, and it is in the province of their design integrity to arbitrate when this is detrimental to the current design.

- It is a necessary step in the process of developing a recognisable personal style to build up a vocabulary of design elements, and it is the repeated, intelligent use of these elements that identifies a designer's work.

- There is increasing pressure from the construction industry to standardise and rationalise building components and make use of modular dimensioning in the interests of industrialised manufacturing processes.

Current CAD computer hardware and software tends to impose a sequence of operation on a user. This is problematic in that design is a process of drawing out concrete proposals from inchoate data. A designer working with a 6B pencil is concerned with broad issues, whereas most CAD packages insist upon knowing the endpoint co-ordinates, width, and colour of each line. A designer will often spend time on different parts of the design; possibly moving from initial design proposals to expected rentals of the finished product within a moment. Current procedural-based computer programs don't cope well with this sort of rapid context-changing. Limitations of this kind are typical of immature software applications, and are usually eliminated within a period of years.

Computer use of any kind can cause chronic health problems. Most common complaints are eye-strain, neck and back pain, and general headaches. Swedish research indicates that there is a risk from X-radiation emanating from computer screens. CAD usage is often more rigourous than other computer tasks, in that sessions are generally longer, and concentration is maintained at a high level for the whole session. Health problems are consequently more severe. Supporters of CAD argue that the design profession has suffered these ailments anyway (with the exception of radiation) as a result of manual drafting.

Just as the machines and factories of Russia of the 1920s were going to free people from boring manual labour and allow 3 day working weeks, computers have been touted as modern-day drudges, removing from designers the tedium of repetitive tasks. A field worker (cited in Reynolds, 1986, p12) comments *"It has frequently been argued that computerised equipment could free man from the soul-destroying, routine, back-breaking tasks to engage in more creative work. Anybody who looks at a highly automated factory must simply question whether this is, in fact, so."* A computer's strength lies in its ability to process vast amounts of data quickly and accurately. It is the "vast amounts of data" that cause the problem; a person needs to enter this information into the computer, and this is a boring, error-prone task. To be fair, this information can generally be re-used for future projects, and in this way a library can be established which will tend to reduce the data requirements for subsequent projects. It is also possible to buy information already entered in the correct format. Nevertheless, the task of managing this information is not trivial and requires a skilled person for its accomplishment.

As it is unlikely that computer technology will disappear in the near future, it is important to identify problem areas associated with its implementation in design situations.

1. The fear of computers taking over jobs goes back at least to 1642 and Pascal's adding machine. This in no way lessens the importance of the issue, but certainly questions the urgency of an issue that is far from acute. In the same way as clerks now co-exist with adding machines, designers will likely come to terms with computers. It is a question of accepting the challenge of new technology.

   "If the architect does not grasp the technology fast, there's going to be a machine down at the building supply store to do all this. Architecture has to lead, to set standards." J Pace, cited in AR Jan 1990, p171, S.S. Ross.

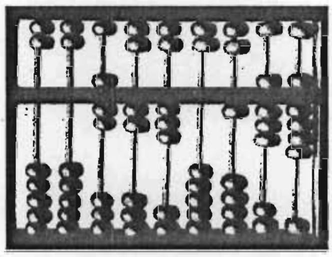
2. The primacy of the designer in the design process isn't challenged by the use of computer tools. It is unlikely that computers will duplicate the originality (and possible perversity) that human designers can inject into their work. If they do gain this facility, the results will no longer be original, as anyone with a similar computer will be able to duplicate them. What is an issue is the possible subverting of the design process by the

implementation of a tool with a strong identity in a particular kind of procedural problem solving. This is an issue more for CAD software programmers, as it is at the level of software design that the tendency to handle a problem in a particular way may be usefully channelled or entrenched. CAD has been in use for the last thirty years, and though the mechanical functions of the drawing board have been duplicated and improved upon, the conceptual facilities of drawing as an aid to the design process have not been touched. (Jones' increased perceptual span) What is needed is the involvement of design professionals at a software programming level. CAD software is not yet a mature product.

3. Health problems relating to computer use need to be addressed. As long as users demand lower prices, and raise no objections to the use of dangerous equipment, computer manufacturers will not change their current manufacturing policies.

4. The implementation of computers in any business requires the support of management, and is not accomplished without a reorientation of business practices. This is of particular concern in architectural and planning practices, where it is common to find differences of opinion regarding the need for computerisation. Computer aided design, and in particular three-dimensional modelling, presents such a marked departure from existing manual techniques, that the transition from old to new practices requires realistic strategic planning for successful implementation.

CHAPTER NINE - COMPUTER DESIGN AIDS.



Chinese Abacus.

Computers are used in almost all businesses, and many homes boast one or two computers. The SOHO (small office home office) segment of the computer market currently has the highest growth rate. The use of computers for tasks such as accounting or word processing is not specific to architecture and planning. This chapter concentrates on those applications directed towards design.

Because the cost of hardware and software during the 1960s was much greater than the cost of labour, the emphasis in computer use in architecture and planning was on design aids. The lure of better end product was too attractive a prize for a designer to pass up even at a high cost. The added expense could always be justified if a superior design were to result. In fact, the last thirty years of research has indicated that useful computer-aided design is an elusive goal. Reynolds, (1986) in his analysis, feels that design-aid programs offer the architect and planner relatively little.

Most computer aided design models fall into one of three categories; generation, simulation, or analysis and optimisation. (Radford and Gero, 1980)

GENERATION.

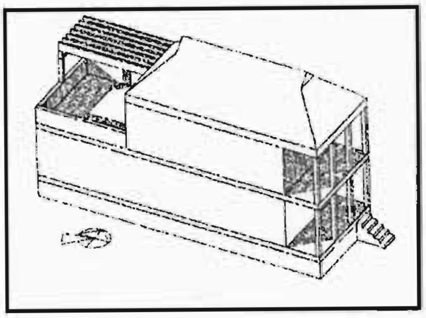
As a generative tool the computer produces solutions based on information concerning the design situation. The generative approach received much attention particularly in the 60s and early 70s, but has been almost completely abandoned by designers, as the results were considered unacceptably naive. Generative systems that have been marketed on a commercial basis have been unable to incorporate the vast number of criteria required if the full complexity of a typical design situation is to be addressed. Sometimes this has been due to lack of computer processing facilities, but more often because of the intangibility of many of the most important of these criteria.

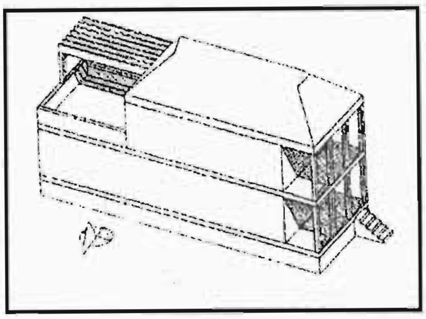
Plan generation programs usually require the user to define all of the rooms that will make up the design, together with a value representing the desired proximity of each room to every other room. Various techniques are used to arrange the rooms in a plan that represents the lowest cost in terms of some measurable design criterion, often circulation. Some packages allow for planning in three dimensions and take into account the increased complexity of vertical circulation. More sophisticated programs attempt to minimise construction costs by reducing external wall lengths and avoiding awkward angles and shapes in plan. The main reason that plan generating programs have failed is that they rely on optimising one or two variables at the expense of all others. Such programs work only with design considerations that have measurable values and that can be evaluated against a standard. Circulation is not the primary consideration in the majority of designs; aesthetic concerns are rated far higher by most architects. No-one has yet developed a computerised style evaluator. In a few recent designs of office buildings, circulation has in fact been extended so as to provide sedentary office workers with some much-needed exercise.

SIMULATION.

As a simulation tool, the computer manipulates a mathematical model of the design proposal to predict the consequences of a particular set of design choices. Decision making is independent of manipulation of the model. Thermal, acoustic, and daylight simulations are examples of situations which can be modelled either manually or by computer. Behavioural simulation - predicting the cumulative effect of many people acting independently - was not possible before the advent of relatively cheap and fast computers. The number

Shadow Analysis and sun penetration is important not only insofar as it affects thermal performance, but also in terms of aesthetic effect and user comfort. A courtyard that is in shadow for most of the day is not pleasant, and a classroom with sun shining into pupils' eyes is virtually unusable. Visual tests such as these are easily performed by computer analysis, and are invaluable to the design process.





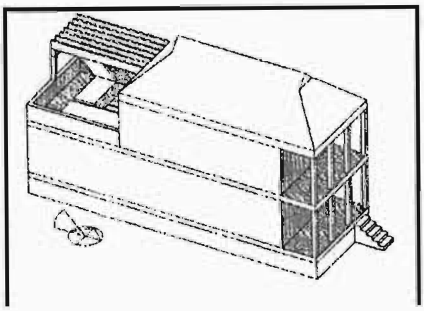


Figure 9.1 Sun shadow analysis - January 21, 3:00 PM, July 21, 11:30 AM, July 21, 3:00 PM. (Jacobs, 1991)

Acoustic analysis is important in two ways. It is essential that certain work areas do not exceed maximum levels of noise, for example the noise in open plan offices must not be so loud as to preclude telephone conversations. In certain rooms such as auditoria and concert halls, acoustics and sound are of primary concern and more sophisticated tests are employed not only to gauge maximum ambient noise levels, but to determine optimum reverberation times, echo characteristics, and sound path analyses as well. Computer programs can predict all of these criteria, and suggest remedies for problems that may emerge.

Intelligent, computer-controlled buildings, touch a chord in the paranoia of many people, as indicated by the popularity of films featuring renegade buildings. A great deal of research has gone into centres such as the Xerox facility in Europe, which are drawing attention for reasons of energy and security efficiency. The concept of the intelligent building is control of all

CHAPTER TEN - THREE-DIMENSIONAL COMPUTER TOOLS.

Duchamp's Nude descending a staircase. Three dimensional form and time expressed in a two dimensional medium.

Computer modelling is concerned with producing a representation or analogue of a real-world object, which may not yet exist in the real world. As the vast majority of real-world objects are 3-dimensional, it is necessary to define such models in 3 dimensions, and to be able to present them, often in a 2-dimensional medium, so that they have the appearance of true 3-dimensional objects.

The change from two to three-dimensional computer graphics is not merely a matter of including three rather than two co-ordinates for each point. Apart from the procedural problems of coping with far more data, there is a fundamental difference in the expectations people have of three-dimensional graphics. Two-dimensional drafting is a highly developed, quite artificial means of representation that involves a great degree of interpretation on the part of the viewer. It is a skill that has to be developed, and is in fact one that was in the past jealously guarded.

> "... therefore, no worker, no master, no "wage earner" or no journeyman will divulge to anyone who is not of our Guild and who has never worked as a Mason, how to make the elevation from the plan." quoted by Mike Cooley, Design after Modernism, ed. J Thakara, 1988.

Most designers realise how much they take this skill for granted when explaining a design to a client by means of drawings. Moving from drawings to a scale model often elicits the response "*Now* I know what you mean." The line of reasoning is not meant as an insult to those uninitiated in the art of interpreting two-dimensional drawings, but rather to highlight the large amount of work done in the brain of someone viewing a two-dimensional drawing. This means that a corresponding large amount of work doesn't have to be done by a two-dimensional computer program and the task of the programmer is equally a lot easier. On the other hand, three-dimensional images only make sense in as much as they resemble real-world objects. In fact the *raison d'être* of three-dimensional computer graphics is that little or no interpretation is required of the viewer. The ultimate goal is to reduce interpretation to nil, in which case a model could theoretically be fully understood or interpreted by any other person or computer. The aim of computer modelling is to approach the original as closely as possible.

A scaled physical model, which was previously the most easily interpreted presentation object, has several disadvantages over a computer model:

- It is more expensive to construct.
- It is difficult to modify to accommodate design changes.
- Physical lighting conditions are difficult to simulate.
- Colour and texture are difficult and expensive to simulate accurately.
- A physical model is not transmittable or easily transportable, whereas a computer model may be emailed to the other side of the world.

- A physical model represents a static scale and context, and cannot become a set of construction drawings, as a computer model can.

The benefits of computer modelling are clearly appreciable - designs can be tested far more accurately than any other presentation technique currently available.

- Most areas of visual testing are easily performed. Any view of the object can be obtained quickly and easily, in orthogonal or perspective projection.

- Texture and colour can be applied easily to the model to simulate materials. Even though colours don't scale correctly, a fair representation may be obtained.

- Shadows can be projected to simulate climatic conditions and geographic location.

- Three-dimensional consistency (clearances, junctions, etc.) of all parts of the object can be examined.

- Perspective presentations, particularly those containing video footage of the actual site of a design, can offer by far the most realistic and accessible method of conveying a design solution to clients.

- Working with three-dimensional models impels the designer towards a greater degree of accuracy. A higher resolution of the design is required at an earlier stage in the process.

- A three-dimensional model allows evaluation of the overall proposal, not just the parts the designer knows look good.

In the last twenty years developers of computer aided design and drafting have concentrated on duplicating the functionality of the drawing board. In many cases the concepts and procedures are direct translations from manual drawing office techniques. The concept of layers, for example, sprang directly from the technique of manual overlay drafting. The influence of two-dimensional modelling techniques has been more fundamental than this, and its effects more damaging to the progress of CAD. Early two-dimensional CAD packages perpetuated the manual drafting concept that the three-dimensional model lived in the designer's head, and the paper drawings were representations of this. A consequence of the medium, (paper, film, etc.) was that these representations were static views that had no logical link to each other or, in fact, to the model itself. Each represented a snap-shot of the object at a particular point in space, a particular scale, and at a particular time.

Current CAD packages use a different paradigm. The model is the central object. It is as detailed as the design requires, and embodies all aspects of the design. There is no longer any need for separate plans, sections, elevations, and details. All that is required for construction drawings are different views of the same model. These views:

- can display different aspects of the same object.
- may be at different scales.
- can have different sets of information visible or invisible, such as builders work, dimensions, or electrical work.
- are dynamic; as the model changes, they automatically change to reflect this change.

Jacobs (1991) says: *"Given its potential for contributing to design quality and competence, CAD modelling will necessarily become a fundamental instrument of the design process."* In focusing on the designed object as a whole, design issues come to the fore, in that the end result in computer terms is no longer a two dimensional representation of the design, but rather an accurate model. Representation systems prior to CAD provided fragmented, abstract interpretations of a mental model. CAD redefines and merges these multiple interpretations or views into a single entity, a detailed mathematical model of the design object. In this way CAD becomes an instrument for the generation and evaluation of form. Because there is only one instance of the model, there is less chance of error. Modifications made to a window, for example, are automatically reflected in plan, section, and elevation views. It is a relatively simple task to generate perspective views of any aspect of the model at any distance from it. Interior perspectives are just as easy, with tools to cut through walls, slabs, or any other intervening objects to reveal any part of the design. In fact, two dimensional orthogonal views - plans, sections, and elevations - are incidental to the process of producing the model. They do not need to be constructed by the user, but are a by-product of model creation.

The expectation of reality requires that the surfaces of a three-dimensional object need realistic representations of physical properties in order to be visually interpreted correctly. Whereas two-dimensional drafting tends to use points and lines to define edges of objects, three-dimensional objects are often modelled with surfaces. Describing the surface variations of an object is a very complex task and can increase the amount of data required to represent an object by a power of two. In three dimensions topology becomes far more important. Curves drawn on a page can be connected arbitrarily, because the intervening space can be imagined, i.e. interpreted by the viewer, but resolving all surface junctions in three dimensions can be a laborious process if erroneous discontinuities are to be avoided. (Upstill, 1990) It is necessary to address all conflicts if a three-dimensional model is to be useful. An interesting example of this concept is found in the deliberate ambiguous drawings of M.C. Escher, which rely on just such disquieting unresolved three-dimensional to two-dimensional transformations. (See figure 10.1)

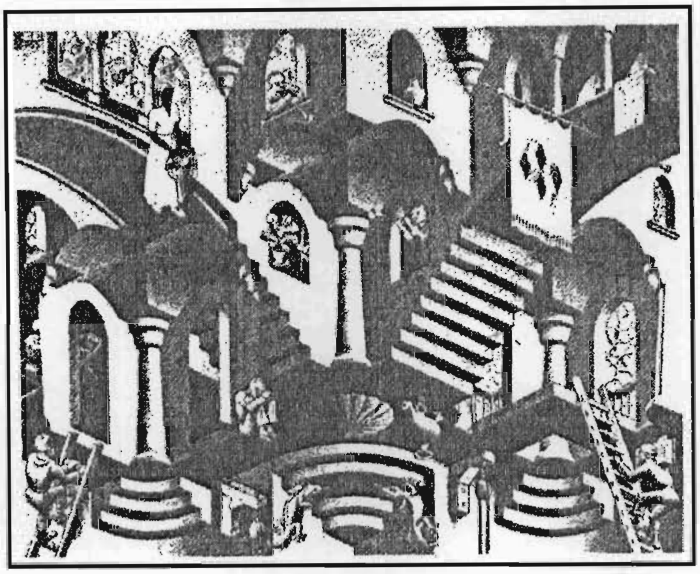


Figure 10.1 Three-dimensional ambiguity in M.C. Escher.

Many problems arise out of the limitations of using a two-dimensional screen or piece of paper to render a three-dimensional object. The complexity of manipulating three-dimensional images on a two-dimensional screen is not just 50% more difficult than similar manipulations of a two-dimensional image. The conflict of representation and medium, which requires a translation of three-dimensional images onto a two-dimensional medium, places much greater demands on the computer running the program. A great deal of processing has to happen behind the scenes to give the illusion of smooth, fast flowing, realistic objects being created with ease.

Upstill (1990) compares a three-dimensional modeller to a handler of radioactive materials. The handler uses a robotic arm to manipulate cups in a lead-lined chamber, and views the actions through a small window. The task is somewhat easier than that of the modeller, in that the handler's eyes provide depth of field to aid in placement of objects, and the handler's head can easily be moved to provide different perspectives. The cup to be manipulated is real; not a wire-frame image, and the manipulating device, the robotic arm, is a more versatile tool than the computer's pointing device; usually a computer mouse. The handler isn't trying to create anything; the most difficult operation performed is to remove a lid from a container. The frustration of being separated by the shielding and viewing window and having to work with a mechanical arm is similar to that felt by computer operators who may harbour the desire to dash the computer away, grab a pencil, and get back to the drawing board.

Three-dimensional software programs allow users to create and manipulate images described geometrically in terms of co-ordinates in three-dimensional space. This is usually a two-part process:

1. **Modelling:** Creating three-dimensional objects, positioning them in a composition, defining a view point and lighting conditions, and determining how each object will look, and

2. **Rendering** - assigning attributes to these objects for further processing. The most common test is visual evaluation. In its simplest form this involves applying flat areas of colour to surface planes of an object, which allows parts of the model that would be physically obscured from the viewer to be hidden on screen. More complex programs allow colour, patterning, and texture maps to be applied to object surfaces. Light sources may be placed in relation to the model, allowing shading, reflection, and refraction simulations. The combined effect can produce a remarkably realistic model.

There are 3 techniques currently employed in computer modelling.

Wire frame models are the most abstract of currently used three-dimensional visualisation tools. Information content about the modelled object is low. Objects are represented by defining edges with line and arc primitives. Only information giving the location of end points of the primitives in (x,y,z) co-ordinates is stored. (See figure 10.2) No information is stored regarding the properties of material between these points. The viewer is required to link these points to imply surfaces and edges. As the computer has no knowledge of space between these points, it cannot hide background elements that would be obscured by foreground objects at the current viewpoint. These models are suitable for limited visual testing only.

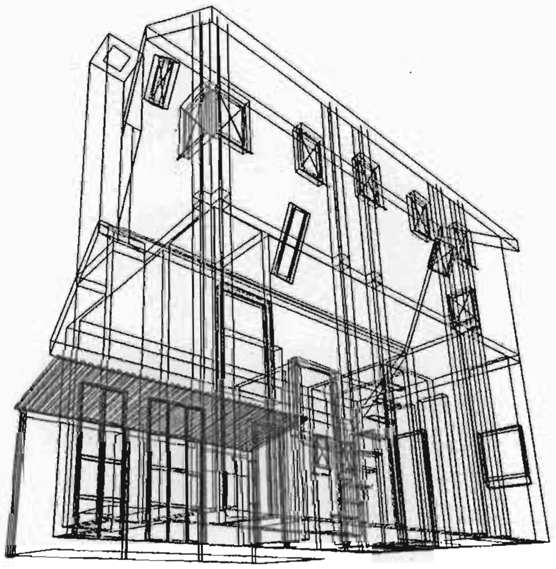


Figure 10.2 Wire frame model of a cottage.

The advantage of wire frame representations is that they are relatively easy and fast to generate. They are usually the first step in creating surface models, and are used by most solid modelling programs for fast displaying and editing of on-screen images. They are ideal for generating perspective views to be used as templates for hand-rendered images.

Surface Models. As with wire frame modelling, edges are defined by lines, but surfaces between these lines are also defined. This results in dramatically improved readability of models, with some loss of speed during model creation. Information content is greater than wire frame models, but is limited to visual data. (See figure 10.3) Even though surface-modelling can be seen as discreet from wire-frame or solid modelling, it is not practical for generating the description of an object. Invariably an object is described in terms of points (wire-frame) or volumes. (solid modelling) Surface modelling is best used for object presentation. Two methods are used in surface modelling; shading, and ray tracing.

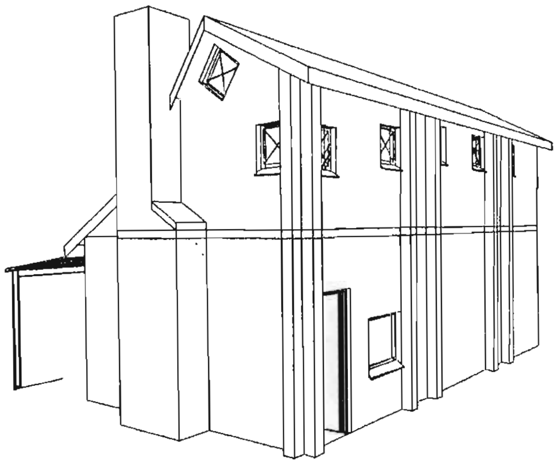


Figure 10.3 Surface model with hidden lines removed.

Shading is a reasonably simple process of simulating the form of an object by grading the shade of each surface. This enhances the three-dimensional quality of the two-dimensional representation. It helps to resolve ambiguities of form.

A more advanced technique of surface representation is **ray tracing**. The visible surfaces of a model are broken up into discreet zones, each of which has particular visual characteristics associated with it. The computer simulates groups of light rays striking the model from a particular source, and calculates the effect each zone has on the refraction and reflection of light from the affected surface. From this data, simulated shadows, textures, and reflections are generated. If the data available on the given surfaces is comprehensive, and the area of each zone is relatively small, very realistic images are obtained.

At present the complexity of the generation of such images reduces the usefulness of this technique as a design tool. Describing each surface in terms of refraction, reflection, texture, and colour takes a long time, and the time needed to compute the image can be several hours even on what is currently regarded as a fast machine. The state of this technology is constantly advancing. Several software packages are available with already-described materials, allowing designers to pick from a library of available options. As computers increase in power, the time required to perform the ray-trace will decrease dramatically. Ray tracing is a task particularly suited to the use of parallel processors, as the generation of the image can be divided into discreet sections. Whereas parallel processing computers generally house multiple central processing units in one system, a far more economical implementation of this concept utilises multiple workstations in a network to provide the functionality of a single computer with multiple processors.

Solid modelling involves the representation of all parts of a design by solid objects or three-dimensional primitives: cubes, spheres, cones, wedges, extruded solids, and revolved solids. Extruded solids are formed by projecting a two-dimensional bounded region along a path, while revolved solids are created by rotating a two-dimensional region about an axis. Complex forms can be constructed from these primitives by means of set arithmetic. The *union* operation combines forms, *subtract* gives the difference of two solids, and *intersection* yields the regions common to both solids. (see figure 10.4) For example, to construct a room, one would start with a cube representing the outside wall faces, and subtract from this a concentric cube representing the inside wall faces. This would leave a void inside the second cube representing the room volume, and a solid between the two cubes representing the wall matter. Creating openings is a further operation of removing cuboid volumes from the wall mass. As can be seen from this simple example, this technique is fairly complex, time consuming, and very computer-intensive.

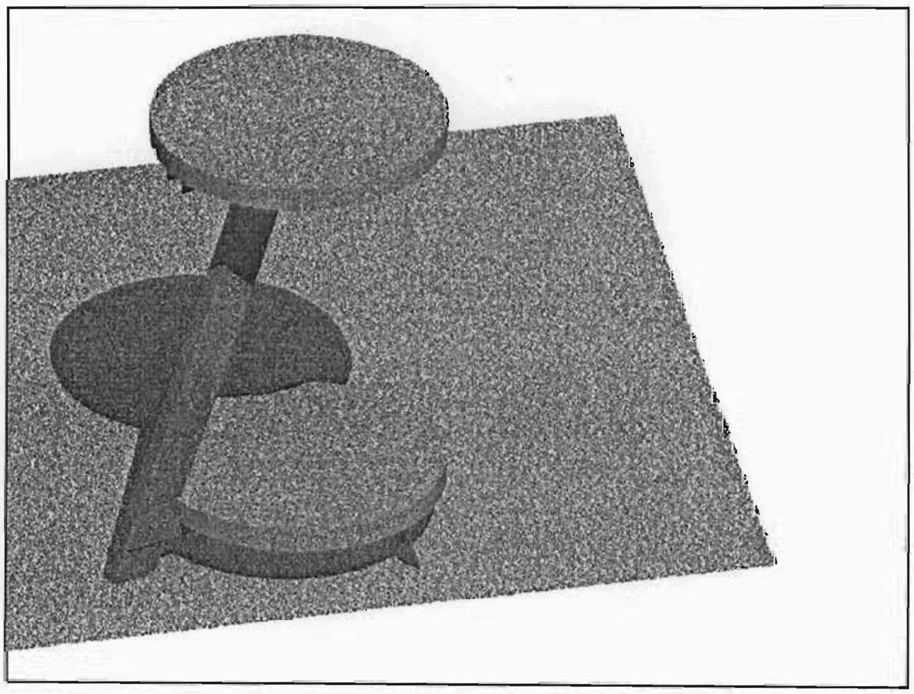


Figure 10.4 Solid model of a steel and glass table.

Solid modelling presents the most complete computer object model currently available. An almost limitless number of attributes can be associated with the primitives that comprise the model. With this information, the computer can perform many tests that have previously been possible only with physical scaled models. Because objects must be described unambiguously, it is easy to perform interference testing to determine whether moving parts will meet any obstructions in their cycle, or to check whether all ducting sections in a building have unobstructed paths.

As with most things in life, computer modelling involves a compromise between speed and facility. Wire frame models are fast to construct and manipulate, but allow limited testing. Solid models allow very accurate testing of most physical characteristics, but are slow to construct and work with. With the increase in complexity of the modelling technique there is an accompanying increase in information content of the drawing. In traditional 2 dimensional drawings, each line has a very low information content. Lines are symbolic, and not associated with the model in any way. Wire frame lines are directly associated with the model; as it changes, they change. Information content is low; the model knows only of boundary edges, not of what lies within these edges. Surface models have more information still; they represent what lies between the edges of an object. Only visual information is stored. Solid models contain the most information; the physical and formal aspects of the model are represented. It becomes possible to assign physical attributes to parts of the model such as thermal or acoustic properties, mass, and rigidity.

Various developments are helping to improve the facility of three-dimensional modelling programs. One is the decreasing cost and increasing power of micro-computers. For computer modelling to be accepted by the design community, the speed and ease of real-time manipulating images must be such that there is not a perceptible lag while the computer performs calculations. At present, three-dimensional modelling on the fastest commercially available micro-computer is too laborious for serious work. For example, to perform a reasonably simple Boolean volume calculation can take a minute. This is too long to maintain the appearance of an interactive design session. The bottleneck is the software; the hardware exists (albeit at a price) for seemingly instantaneous on-screen regenerations of drawings. It is usual for software programmers in good structured programming style to produce very generalised packages that can be tailored to almost any draughting task. Unfortunately, the tailoring often isn't done, and the designer is faced either with becoming an amateur programmer and devoting time rather spent on design to customising the software, or with accepting an application that is not integrated with the work at hand, and is consequently clumsy to use.

MODEL SIMPLIFICATION.

Because the complexities of three-dimensional modelling are so great, many programmers have taken the approach of simplifying the domain in which modelling occurs. Most common is some limiting of the primitives available to the designer. A second area of complexity and hence of potential simplification is in the multiplicity of possible locations and orientations of an object in space. Given that

- Most people live in a geocentric world.
- Horizontal and vertical planes are very important in Western construction.
- Many built surfaces are orthogonal - most floors, walls, ceilings, and working surfaces.

It can be seen as an advantage if an object created in a three-dimensional package defaults to a horizontal or vertical orientation. Many modelling packages provide conceptual tools that simplify construction tasks on these lines. They may be likened to a drawing machine on a board - movement in the x and y axes is kept orthogonal by the machine rails. The angle of the scales is set with the machine head.

Working with CAD is all very well when the model you are designing is orthogonal and parallel to the X and Y axes. It is easy to calculate distances, and tools that lock cursor movement to orthogonal axes and snap point placement onto grids help to speed up drawing creation. As models become more complex, with elements lying in planes at arbitrary angles to the normal, point specification by relative co-ordinates is almost impossible. Three dimensional CAD systems provide additional tools to reduce this complexity.

The default geometry mode for most CAD drawing editors is for the computer co-ordinate system to be aligned to the world co-ordinate system, (WCS) the one used to lay out most domestic maps. X is positive to the right of the screen, Y is positive towards the top of the screen, and Z comes straight out of the screen. It is possible to change these axes at any time to make it easier to work with difficult geometries. The x and y axes may be aligned with arbitrary entities, which may then be rotated to position them orthogonal to the screen. Such a changed state is called a User Co-ordinate System. (UCS) Many such UCSs may be established, named, and saved, and quickly recalled. It is typical practice to create a UCS for each elevation of an object, making it very easy to work on each in turn. User co-ordinate systems turn three-dimensional tasks into two-dimensional ones, by obviating the need to enter z co-ordinates. In effect, the ease of drawing any section or elevation on the drawing board as though it were a plan is brought to the computer.

A useful concept in three-dimensional work is the differentiation between model and paper space. Objects created in CAD are drawn in model space, which exists in three dimensions, and as a group these represent a model of the design; for example a house. The problem arises when it is necessary to plot out production drawings of this house. It is required that a 1:500 site plan, a 1:100 floor plan, and 1:20 details, be plotted all on the same sheet. Prior to three dimensional modelling packages it was necessary to create copies of the floor plan, rescale them, and lay out these duplicates to create a sheet layout. The disadvantages are obvious - more than one copy of the model exists, so making any alteration involves changing several instances of the object which is more difficult and is prone to error. The solution lies in the concept of paper space. Paper space only embodies 2 dimensions and literally represents a flat sheet of paper. Within this area one or many views of the object in model space may be constructed, like photographs pasted on a sheet of paper. These views may:

- Be at different scales.
- Be seen from different viewpoints.
- Have different layers turned on or off.
- Have hidden lines removed.
- Be set to different UCSs.

See figure 10.5. The disadvantage of the paper space/model space concept is that it is somewhat more difficult to grasp than model space only, but the extra effort of comprehension is more than compensated for by the added flexibility.

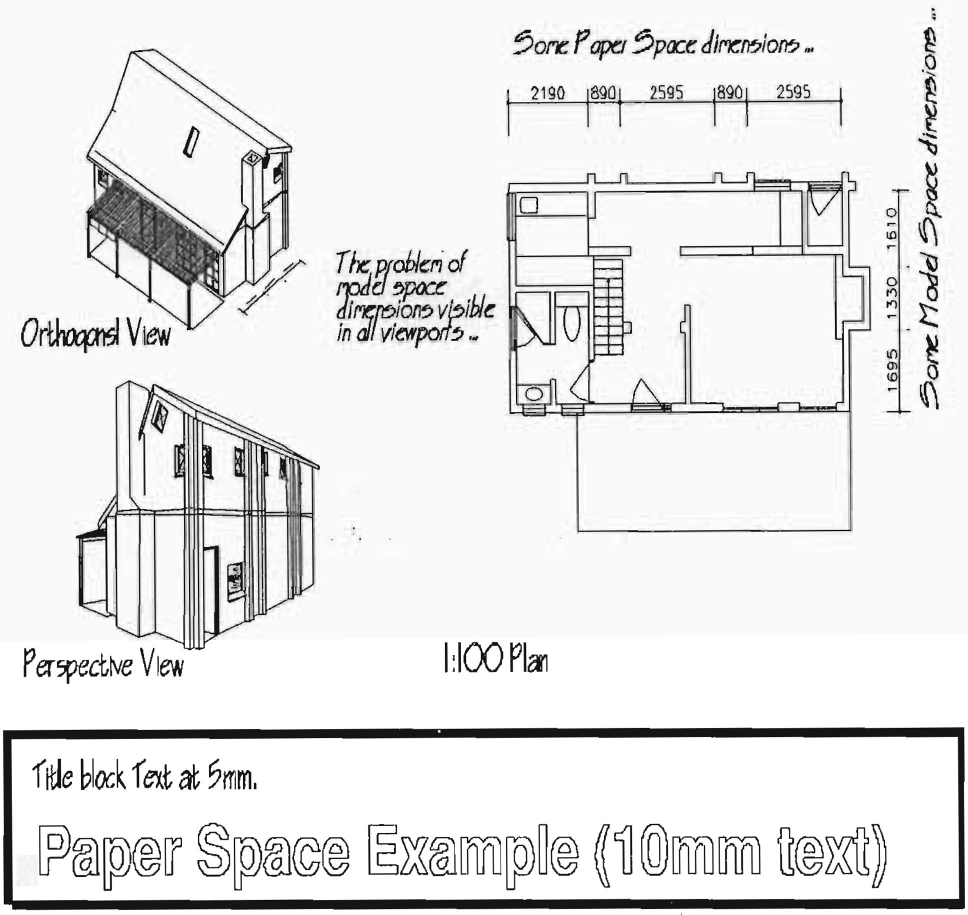


Figure 10.5 A three-dimensional cottage created in AutoCAD r13 for Windows. Paper space allows one to create a single model of an object, in this case a cottage, and present it at different scales on one page for plotting. This example contains a plan at 1:100, and 2 three dimensional views at different scales on the same page. Information from the upper storey (windows, rooflights, verandah sheeting) has been turned off in plan view to yield a more readable drawing.

DATA MANAGEMENT.

The amount of data required to model an object in 3 dimensions is a great deal more than might be expected. The addition of the z co-ordinate would suggest that 50% more information is required. In practise the figure is closer to 100%. It involves specifying information that was only implied in 2-D drawings. The increase in drawing size requires careful ordering of information to avoid slowing down the computer with additional processing.

There are additional considerations when standard 2-D production drawings are required to be extracted from the 3-D model. For example, if the model is of a multi-storey building, it is advisable to separate information by level, so that each storey may be separated. It is also advisable to group elements by type, as this facilitates working with different assemblies or trades easily. This allows easy separation of information for creating plans of particular levels. It becomes possible to select all layers that start with a 1, or all layers of windows for the whole project.

Three-dimensional modelling packages require greater effort to learn and, once mastered, to maintain fluency with than two-dimensional drafting packages. This remains the final hurdle for perhaps 90% of potential users who would otherwise use three-dimensional graphics.

> "Perhaps the most dramatic and simplifying realisation is that designing 3-D models from scratch is inherently difficult and much harder than designing in two dimensions." (Upstill, 1990)

Three dimensional modelling can require significantly more time than 2-D CAD drawing. Part of the reason for this is simply that the information content of the model is greater. Another reason is that ancillary operations such as hidden line removal, surface shading, or solid model geometry calculations are complex tasks, and consume much computer processor time. Until significantly faster processors are available, it is necessary to ensure that a designer's modelling technique is optimised.

- Wherever possible 3D tasks should be converted into 2D tasks by using UCSs. This will simplify and speed up model construction, as existing 2D skills may be employed.

- Any drawing task should be analysed to find all repetitive elements, mirrored objects, and duplicated assemblies.

- Wherever possible blocks should be used. A block, or symbol, is a complete component or assembly that is stored as a drawing in itself. It may be inserted any number of times into any number of drawings without the designer having to redraw it each time. The use of blocks ensures that even though the first time an object is constructed in three dimensions it may take longer, whenever it is used again, it will take no longer than using a 2D block in a drawing.

- Make use of layers to manage data. This can reduce time in selecting objects for manipulation. As models get larger, it is possible to switch off layers of information that are not currently required.

- Limit the number of complex operations such as hidden line removal, shading, and rendering that are performed.

The area of visualisation and visual testing is at the heart of three-dimensional modelling. These capabilities differentiate it from any other design tool currently available. With all its benefits, there are particular areas of CAD implementation that could be improved.

CAD lacks the suggestiveness and forgiving quality of hand sketching. Drawing a line with CAD requires the specification of the line type, weight, layer, and precise location. A hand-drawn line, in contrast, is from "here" to "here". An apparent aid to the design process is redrawing over existing lines. Important aspects of a design are emphasised in this way; pivotal parts of the object rise out from the page to suggest elements of the next iteration of the design cycle. Duplicated data of this sort is anathema in the traditional correct model of a computer database, and can wreak havoc at later stages of CAD construction drawing production, where redundant elements can cause costly mistakes.

Whereas with paper-based design, there is a paced transition from imprecise, suggestive diagrams to refined detailed drawings, CAD models always appear accurate and precise. Even though a CAD model may be modified easily, its vector-based specification gives it a definite form. Traditional design procedures are more visceral; they are more open to the inclusion of concepts - symbols, metaphors, and icons. CAD packages need some mechanism for incorporating this imprecise information into the model.

Stage One.

Four classes of design determinants emerged as forming the basis of Stage One investigation:

1. Physical constraints influence the design of a particular project such as:

- Soil conditions affect the slopes of Cut and Fill banks that may safely be utilised, as well as influencing building technology to be employed.
- Slope determines the viability of building type and the layout of vehicular access.
- Site topography influences patterns of major access and service routes.
- Position of flood lines.
- Features, both natural - rivers, high points, rocky outcrops, etc. and artificial - surrounding structures, historical buildings, religious sites, etc.
- Existing access and bulk service connection points may dictate links to new development.
- Climate affects not only the top structure, but also the viability of specific areas within the overall scheme. For example, sites that never receive sunlight in winter may be considered unsuitable for residential use.

In the incorporation of these constraints into possible design solutions, experience-based or Iconic Design strategies play an important part.

2. Planning issues include any regulations that pertain to the area of development, as well as any collateral development that might be required.

- Minimum plot and building sizes, which may be determined by existing Town Planning Schemes, or by end-user specification.
- Standards of services to be provided.
- The scale of development seen together with surrounding facilities would influence the need for support development - schools, commercial, and industrial development, etc.

3. Delivery Systems concerning the implementation of the development.

- Finance and phasing of implementation. Will finance come from government, the public sector, or from individual end users?
- The type of delivery system: "Site and Service", turnkey, "Core" housing, or informal settlement upgrading.
- The building technology to be employed is of great importance in "Site and Service" or "Core" housing projects in terms of available skills. It is also of fundamental importance in determining a design philosophy to deal with steeply sloping land. Will the approach be Cut and Fill platforms with deep foundations or beams and mini piles, cut only, stilts, or split levels?

4. Client/End user requirements and facilities have recently been taken far more seriously than has been the case in the past. This is no doubt largely due to a more democratic dispensation, but also as a result of the realisation that community participation is more likely to result in a project that develops and improves over time rather than one that deteriorates.

- The quality of the built environment plays a direct role in the commitment individuals have to maintaining and upgrading their neighbourhood.
- Communities may be created or fostered by engendering a sense of place.
- In the case of existing development, residents may have evolved 'mind maps' locating focal points that should be preserved or emphasised to ensure a legible plan.

Computer usage during this stage was limited to compiling information and creating progress reports. One designer was beginning to use the Internet as an information source, and it is likely that this will streamline the process or at least broaden the scope of gathering pertinent design information. The fact that designers were comfortable in codifying this stage suggest that it can be defined as a GLASS BOX process, and that computerisation is feasible.

Stage Two.

In formulating a design strategy, designers spoke of developing a design language to be employed in site layout. Components of the language include tangible elements such as sub-divisions, platforms, and roads, as well as less definable elements such as service arrangements, site dimensions, and site access. Development of this language comes from experience not only in working with components, but in understanding their inter-relationships. For example, site road frontage and service runs per site form a major portion of service costs. Evaluation of the issues outlined in the preceding stage together with cost and density objectives enables the designer to arrive at a set of design parameters within which to work.

This stage contains GLASS BOX and BLACK BOX actions. While design language components can be described explicitly, the process of arriving at suitable expressions of these components, and fluency in their use is not as transparent. There was no indication of computer usage among any of the designers during this phase.

Stage Three.

The issue of idea generation, outlined in Chapter Four, is a thorny one. How does the designer move from a blank sheet of paper to a concrete proposal? Of the four idea sources discussed in Chapter Four, both Iconic and Canonic design activities (Broadbent, 1973) fit those described by the designers.

Over a series of projects, a designer develops fluency with elements of the design language. These are peculiar to the designer's experience and may result in the emergence of an identifiable design style. In effect, the designer builds up a store of pro-forma patterns that fit the requirements of classes of design problems, and need only be fine-tuned for specific instances of the problem. This is clearly a simplified analysis, but it serves to clarify the process.

Canonic design draws on an ordering system to provide a structural concept. Two designers rated access patterns or grids as being important shapers of design solutions. According to Klug, it is common for sub-division layout plans to be based on a regularised grid structure.

A typical Stage Three process example might read as follows. Analysis of the site in terms of the design parameters defined in Stage Two will indicate a suitable major circulation pattern, overall site yield, and non-residential land use requirements. At this point, the planner and engineer in consultation will determine the layout of major services. Based on this overall framework, interstitial services and plot patterns can then be proposed. This consultation can cause problems in extending the length of the design cycle. It is also a problem in that the priorities of planner and engineer are very different. This can complicate the transfer of ideas, concepts, and design proposals between team members.

The use of computers at this stage for these designers in their current work was limited to production of two-dimensional layout plans. None of the designers made use of generative computer programs.

Stage Four.

The proposals of Stage Three are now subjected to testing and refining, resulting in the final proposal. Evaluation of rival solutions may be subjective and rather visceral, but the following points were identified as being important:

- **Physical evaluation.** Proposed site density yield is compared with the original design brief. Simplicity, length, and accessibility for maintenance of service runs are evaluated. A simple quantities analysis is performed on elements such as manholes and survey points.
- **User amenity.** What proportion of sites have vehicular access? How extensible are building platforms and built structures?
- **Visual and three dimensional evaluation.** Sight lines along access routes and between sites need to be checked.
- **Social amenity.** Does the proposal foster the creation of enclaves, hierarchies of built form, and privacy between public and private spaces and between adjacent private spaces? Is there an overall elegance and legibility to the scheme? Does it incorporate landmarks or focal points within the neighbourhood?

Stage Five.

Presentation most often takes the form of scale drawings; two-dimensional layout plans of design proposals, and written reports. Occasionally scale models are used in presentation, but the cost of such models is prohibitive. Colour is used extensively in layout plans to demarcate land usage. Such drawings may still be painted by hand in non-computerised offices, but the cost is tremendous; an A0 drawing can take two staff members a week to complete. All of the designers indicated that they used CAD for presentation drawing production and report writing during this stage.

There are problems associated with current presentation techniques. Most clients are not trained in the interpretation of orthogonal drawings and height inference from contour lines, and their expectations gained from drawings are not always met on-site. (Forbes interview, 1996) The problem is not limited to clients. A civil engineer, upon being shown a computer drawing during an interview, tried to calculate the horizontal distance between two buildings by counting the contour lines.

CURRENT METHODS.

Designers made most use of cyclic and branching search strategies (described in Chapter Six) during Stage Four. For example, the actions involved in determining suitable Cut and Fill platforms for a site might be as follows:

1. **Perform a slope analysis of the proposed site.** This is often performed manually by someone working from a contour plan to calculate the average slope conditions in pockets of land. This is a laborious task, and involves a degree of inaccuracy, depending on how small the pockets are. Within any one pocket there may well be areas that are markedly different from the average.

2. **Determine the most common slope and soil conditions.** This is done with reference to the slope analysis and geological survey.

3. **Determine an appropriate Cut and Fill platform** to accommodate a suitably sized building based on these conditions. This is once again a manual task, and must be performed for all categories of soil conditions and slopes. These categories treat entire pockets of land as having one slope, and there may well be particular areas that are very different from this average condition. Note that Steps Three and Four may be interchanged, depending on whether the brief calls for a certain number of units, or defines certain space standards.

4. **Determine a suitable subdivision size and shape.** This is based on a number of determinants, such as platform and Cut and Fill bank size, space standards outlined in the brief, and layout of major services. This is a manual task, and generally involves experience of previous design situations - Iconic design. Note, once again, that Steps Three and Four may be swapped.

5. **Apply the sub-division solution to the site.**

6. **Determine soil and slope conditions for land that falls outside those already calculated.** Loop back to Steps Three, Four, and Five, until all conditions have been tested. (See Figure 11.1)

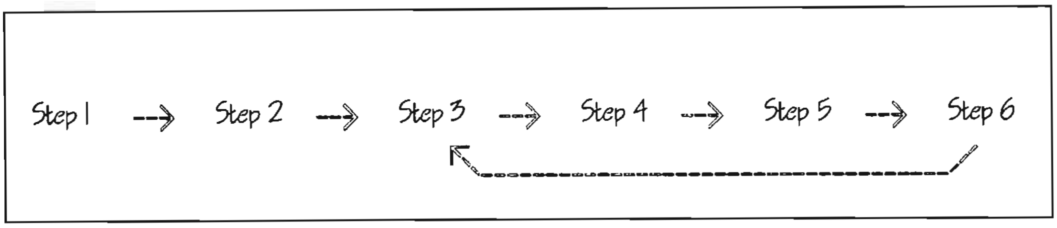


Figure 11.1 Cyclic Cut and Fill analysis strategy.

Design paths often follow complex combinations of cyclic and branching strategies. For example, a refinement to figure 11.1 would be to list step two as a stage comprising two parallel parts: slope analysis and soil type analysis. The result of the above strategy would be a series of Cut and Fill platforms and sub-division sizes, corresponding to the various conditions of the site. In practice, generation of appropriate sub-division/platform combinations is often limited to certain average soil and slope conditions that satisfy a large proportion of the site. Problematic or unusable sub-divisions may only be identified on-site during construction, when it is all but impossible to correct the situation. (Forbes interview, 1996)

The cyclic or iterative process outlined above is epitomised in the analysis-synthesis-evaluation method described in Chapter Five. The method may be used at all stages of design activity, but is most clearly seen when rival options are being evaluated. Once a particular proposal has been selected as the most suitable, there is a stage of fine tuning or optimising.

- **Macro-optimisation** at overall development scale investigates bulk earthworks, minimum wasted inter-site space, and economical major service runs. This stage could result in increased site densities, if this is still in line with initial desired densities.
- **Micro-optimisation** at an individual site scale is concerned with minimising soil movement on or off the site, maximising building area, and minimising service runs per site.

None of the designers made use of computer optimising tools of any sort. One architect spent over two months laboriously calculating Cut and Fill platforms for every sub-division on a large proposal, and discovered that over 25% were unusable.

IDENTIFIED PROBLEMS.

No obvious bottlenecks were identified during the first three stages of design. Problems were apparent during the evaluation stage of the design cycle, and were manifest in two ways:

1. In using manual methods designers spend valuable time evaluating options. The results merely indicates success or failure of an option, and do not suggest viable alternatives. The process takes too long for this feedback to be useful as part of an iterative design process. Actual evaluation of options may be by a person other than the designer, in which case the possibility of errors or mis-communication is increased. In short, the process follows a linear path, rather than allowing cyclic or alternate routes.

A specific problem was identified; that of generating and testing Cut and Fill platforms. A number of shortcomings can be identified in the current process as outlined in figure 11.1.

- It is very time consuming.
- It incorporates underdeveloped facilities for iterative testing of options.
- Each step of the process is discreet, allowing little chance for jumping backwards or forwards in the chain, i.e. alternate or cyclic evaluation of design options.
- Checking is either left undone, or left to the engineer, or fobbed off on someone other than the designer, usually at the end of a linear process.

This results in either an unacceptably high percentage of unusable sub-divisions, or an extended design cycle, with proposals needing to pass through the professional pipeline more than once. On a large project, manual checking of all sub-divisions can take several months.

2. Using current methods designers cannot afford to test too many rival solutions. In most cases it is not feasible for proposals to cycle through the

professional team several times, so that by the time sub-divisions are tested, the design proposals are at a fairly concrete stage. Any problems that are identified must be sorted out as expeditiously as possible, with as little impact on the rest of the design as possible. Masson defines the process as one of fine-tuning, rather than re-working. It is usually inappropriate to suggest evaluating a completely new layout at this point.

Problems apparent in the presentation stage relate to the language used. The most commonly used medium for conveying spatial information is two-dimensional orthogonal drawings. Three out of four of the designers listed misunderstanding of drawings as a serious problem. End-users, seeing a plan view of a proposal on a flat piece of paper, often expect the site to be flat, and are very disappointed at the on-site result. (Forbes interview, 1996) Other professionals on the design team may not appreciate the designer's intentions, or may misinterpret drawings, resulting in confusion and possible errors.

Based on these findings, five conclusions may be drawn.

1. Current CAD usage is limited almost exclusively to presentation drawing production.

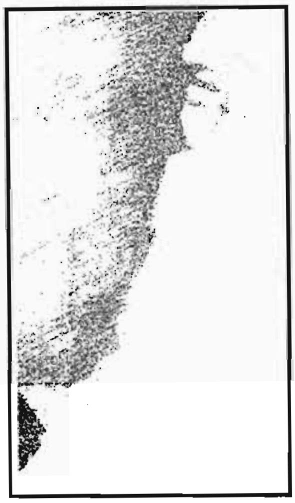
2. Current manual optimisation of design parameters is a clumsy, time-consuming process. A specific problem area is in the calculation and optimising of Cut and Fill platforms on steeply sloping land.

3. Designers need the flexibility to test out as many options as possible for a greater part of the design cycle.

4. Communication between members of the design team of concepts, ideas, and design proposals could be improved, particularly between those of different disciplines.

5. Communication of design proposals to end users is currently a serious problem.

CHAPTER TWELVE - INSITE URBAN MODELLING PROGRAM.



Reflections in a
computer screen.

Of the five tasks identified in Chapter Two as being necessary for the completion of the practical section of this dissertation, the previous chapter covered the first two - identifying real-life design problems that are encountered on a regular basis, and investigating how these problems are currently handled.

This chapter covers the third; designing and implementing a computer program to aid in solving one of these tasks. In selecting the area of focus for the investigation of computer implementation, various criteria were applied.

- The tool should address an area of design that is currently not handled well.
- The goal should be attainable; one that can be implemented and tested in a situation of professional use.
- It should address a meaningful part of the design cycle.

- If possible, the action or actions addressed should be of a non-contentious nature in relation to the GLASS BOX/BLACK BOX debate, so that arguments of design style need not be an issue.

Drawing on the conceptual and historical analysis beginning in Chapter Three, computer implementation in the five stages in the design path can be summarised as follows:

1. Problem Definition and gathering of information. This task can be readily expedited with computer tools. More and more information is becoming available on CD-ROM, a format in which it can be quickly extracted and sorted. Available tools are sophisticated and fairly easy to use. Graphical and textual information can readily be presented in a variety of formats. It is most useful to maintain resultant data in a digital format, so that it can be used as input for future stages. As mentioned in Chapter Eleven, the Internet is also becoming increasingly attractive as a source of information.

2. Strategy Formulation, the stage during which ideas are formulated, as outlined in Chapter Four, is a process that design theorists have had little success in describing. It is not surprising, therefore, that there has been little success in computerising this task.

3. Interim Realisation of a Solution. Most design methodologies concentrate on this phase during which the analysis-synthesis-evaluation cycle is most easily implemented. Prior to the advent of three-dimensional computer modelling, computerisation of functions in this activity enjoyed limited success because of clumsy implementations. Two-dimensional CAD systems of the late 1970s and early 1980s functioned as construction drawing production tools, and understandably performed rather poorly as design tools.

Various requirements of the designer need to be addressed during stage three:

- Rapid feedback and testing on visual and formal aspects of the proposal, and testing against stated design criteria. This facility is certainly available in current modelling packages, but is not readily useable, due to cumbersome input interfaces and speed limitations of existing processors.

- To provide an easily accessible repository for information in a variety of formats. This can be achieved with an integration of hypertext and CAD systems, although no system offering this function currently exists. Processor speed is once again a current limitation.

- A facility to deal with literal as well as symbolic objects. This is an issue that has not been properly addressed, either theoretically or practically. This is the realm of the 6B pencil, of being able to emphasise important aspects by repeatedly drawing over them, and the implementation of an explicit design language.

4. Evaluation of candidate solutions. This is the domain of the simulation and optimising tools of Chapter Nine. Most objective criteria can be evaluated by existing computer programs, and computers have been fairly successfully implemented in this stage. Subjective evaluation is by definition precluded from computer analysis, but three-dimensional computer models provide a far more accessible medium for visual evaluation by viewers than any other.

5. Presentation. CAD tools for drafting and more recently for rendering provide virtually complete computerisation of this stage.

It is in Stages Three and Four - interim realisation of solutions and evaluation of these solutions - that the application of computer facilities by designers to these problems is currently poor. These stages are most closely associated with design activity, and most jealously guarded by design purists. Three design requirements are listed for Stage Three. The facility to handle literal as well as symbolic concepts is currently beyond the reach of standardised computer software and hardware. The computer as a repository of diverse data is possible, and is implemented to a limited extent in certain available programs, typically GIS type packages. Visual feedback during the design cycle is available in a variety of packages, but not in a readily accessible form. These last two requirements have been selected as a suitable vehicle for evaluating the effects of implementing computer tools in the design process, in that:

- this particular action, visualisation of design proposals, does not impinge on the action of idea generation, so it avoids the debate of GLASS BOX/BLACK BOX design processes.

- It addresses an important part of the design cycle, that of accurate testing and feedback to the designer at a critical stage in the process.

- The chosen area of implementation, that of low cost housing township layout, (and in particular small sub-divisions on steep land) is of particular importance to this country at this time. The tool, if successful, will be able to perform a useful role in this part of the design process.

A specific practical design problem that conforms to all of these criteria, and identified at the conclusion of Chapter Eleven, is the calculation and optimising of Cut and Fill platforms on steeply sloping land. Drawbacks of current methods have been outlined in Chapter Eleven. In addition to the specific task, there are various allied functions that can be addressed. Design at this scale lies at the interface between planning and architecture, dealing specifically with built form and visual analysis of township layouts. Design issues that need to be addressed are:

- The design of the Cut and Fill platform.
- Right-sizing of the sub-division.
- Three-dimensional evaluation of the design in terms of interaction with other design elements.
- Climate control - shadow and sunlight analysis.
- Social interaction between people.

The interplay of design elements at this scale is often neglected, in that it falls between the briefs of all professionals. Planners often don't have the time or inclination to get involved in such issues. Architects are often involved only at a theoretical planning of top structure stage, that is in designing typical plans, not in actually laying these out on sub-divisions. A specific example of the results of this lack of planning may be seen in a development close to the E.B. Cloete interchange outside Durban. Adjacent house walls are within two metres of each other, and when roof and gutter overhangs are included, the aperture for sun penetration between houses is approximately a metre. In the dark alleys that result, windows also face directly onto each other, resulting in a lack of visual and aural privacy.

At present two-dimensional plans are created, either manually or on computer showing site layouts, contours, roads, and house block plans. These are checked by the engineer, but tests are usually based on slope analyses, which grade land pockets into categories of slope. This means that in most cases not all sites are checked; only a representative sample. This can result in a certain percentage of sites being found to be unusable when earthworks begin on-site. (Masson interview, 1996) Given the premium on developable land, such wastage is unacceptable. In cases where sites are allocated to beneficiaries before work begins, it is imperative to know that all sites are useable. This involves a fairly skilled person analysing every Cut and Fill platform for every site, which can take several months for a large development if done manually. The disadvantage of manual analysis is that it serves to test the proposal only, not to offer any correction of discovered problems. There are existing computer programs available to perform the task of platform creation, notably

ModelMaker, but the emphasis of their usage is on engineers, rather than on planners.

GOALS AND OBJECTIVES.

A tool is required that is easy to use, with an intuitive feel comfortable to both GLASS BOX and BLACK BOX designer types. The fact that it is implemented on computer should not be an issue, as the inner workings should be transparent to the user. The aim is to provide visual design information to the planner while layouts are being generated and tested, not several weeks later, when the earthworks drawings come back from the engineer. In this way, the computer will become an aid during the design process, not just a drafting tool once design work is finished.

Stated objectives are:

1. To calculate Cut and Fill platforms for a variety of soil conditions, for site topography ranging from good to difficult.

2. To suggest sizes of sites for specified or required platform or building sizes.

3. To optimise the position and orientation of platforms and top structure on the sites thus designed.

4. To evaluate these proposals at the micro-scale of the individual site environment created.

5. To evaluate the urban fabric created by multiple sites, roads, and infill panels at a macro-scale, in other words, the total effect of the design.

6. To test and evaluate climatic influences on the built environment:

   Sun Exposure.
   Shadowing.

Guidelines on the structure and use of the model are:

1. The program should be easy to use, even for designers who are not too comfortable with computers in general.

2. Data of various types should be able to be included in the model, and data transfer between this program and others should be quick and easy.

3. Placement of three-dimensional building models on sites must be an easy task, so that in a short space of time, a reasonably accurate visual model can be constructed, showing the relationship of built form to site layout and circulation systems.

4. Perspective views of the site model must be quick to produce, with sufficient realism to be easily readable by members of the community who will live in the houses.

5. The program must be able to model difficult cross-fall sites - ones that lie at an angle to the contours.

6. Minimum input of data should be required of the user, and the result should be a compact model.

7. Visual accuracy and ease of use is more important than complete physical accuracy - design issues are emphasised over the concerns of construction drawings.

CONCEPTUAL FRAMEWORK.

inSITE is based on the metaphor of building blocks. Respondents to the Design in Action interviews spoke of developing a design language, that consisted of various component parts or elements. (see Chapter Eleven) This idea formed the basis of a conceptual framework for the program. Construction of a three dimensional model is achieved by assembling building blocks to form a design. Currently available objects are:

- Sites or sub-divisions.

- Platforms with associated banks.

- Road segments.
- Infill panels.
- Buildings.
- Trees.
- Cars.
- People.

Each object stores information about itself in various categories depending on its type, relating to its position in space and form. The types of objects and the parameters stored for each result from an analysis of the first stage design determinant classes identified in Chapter Eleven.

This concept of a building block has various advantages. The designer need only be familiar with eight objects. Using this apparently limited toolbox, it is possible to clip together an assembly that models a complex design. No knowledge of the objects' three-dimensional attributes or inner workings is required, in the same way that a bricklayer need not know how a brick is manufactured. It is possible to modify objects rapidly, because each object contains all information about itself. This information is stored in parametric form, and is grouped in a consistent way for all object types. Graphical as well as non-graphical information may be stored in this group, fulfilling one of the design requirements - that of unifying diverse data types. Objects are self-aware, which means that if a designer modifies an object's shape or size with a standard CAD transformation function, such as stretch or move, the object can automatically update its own properties.

Apart from being stored within each object, information groups may also be stored as templates, which may be used from design to design. In this way a profile of common objects may be saved and reused, which obviates the tedium of respecification. The program in effect learns from past instances, and establishes a library of iconic design forms..

The parametric storage of information allows the designer to make use of linear, cyclic, and branching search strategies (see Chapter Six) in the evaluation of design proposals. By cycling through a range of values for an object, the effects on other elements can be observed, and at any point in the cycle it is possible to branch off onto another track and modify a different object's parameters.

inSITE has been written as a clip-on module for AutoCAD, that in effect teaches AutoCAD the language of planning design. It runs from within

AutoCAD, and draws on all of the graphical tools AutoCAD has to offer. An additional add-on package supplied by AutoDesk has been used for certain of the presentations in this dissertation; AutoVision. This allows the creation of accurately rendered images, such as Figure 12.2.

Building Blocks.

Each object is automatically given a tag for identification and selection. This takes the form of a disk located in the centre of the highest object boundary. (see Figure 12.1) This tag serves various purposes. It stores all information about the object. (Like an ID tag) It is a handle for selecting an object to be modified. For site objects the tag serves as a 'traffic light' indicator of bank conditions - green indicating that everything is okay, and red indicating that banks encroach over site boundaries.

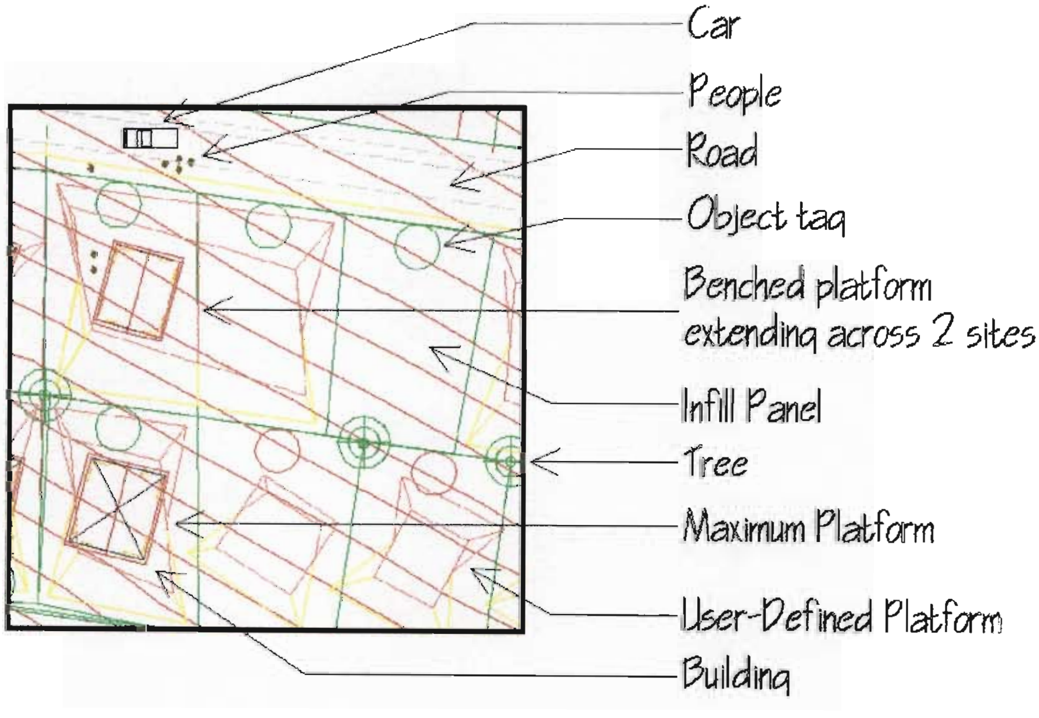


Figure 12.1 inSITE object types.

All objects are automatically given three-dimensional form and colour when they are created. This greatly simplifies the process of creating perspectives and rendered views.

Sites.

Each site has various properties assigned to it that determine its structure.

- The position of each corner point, locating the site in space.
- The platform type it contains.
- A description and location of any built form on the site.
- A safety margin, measured in from the site boundary within which no banking is to be constructed. This may be set to a planning recommendation, or be set to a value representing the propensity of the soil to erode and cause problems on adjoining sites.
- A label, which could be a site number or owner's name.

Sites may currently have only four sides. See Figure 12.1.

Platforms.

There are two types of platform; maximum and user-specified. For a maximum platform the program calculates the largest platform that can be accommodated on a particular site given the existing soil conditions. For user-specified platforms, the program considers soil conditions and platform rotation in its calculations. The default position of the platform is in the middle of the site, at the average angle of the back and front boundaries. This is usually the best option on small sites, and in any event, provides a starting point for investigation.

Various parameters are stored concerning platforms.

- Banking soil conditions - angles of repose - for both cut and fill.
- Banking may be enabled or disabled on each side of the platform to accommodate benching of platforms across multiple sites.

- A platform rotation angle. This allows platforms to be orientated to run with the contours rather than following site boundaries, to accommodate cross-fall sites.

Platforms may be previewed before being inserted into the model. This is of particular benefit as the design increases in size, for with each additional site, the calculation of new objects takes more time. Previewing allows rapid option testing. (See Figure 12.1)

Roads

Road objects are intended primarily to give an indication of the form of services in relation to sites, and are not accurate enough to be used as a basis for engineering calculations. Curved roads need to be broken up into a series of straight segments for modelling purposes. (See Figure 12.2) They are treated as special cases of sites, which have platforms that stretch from left to right boundary with no edge banks so as to link to the next road segment. The depth of the platform specifies the width of the road. A common problem with steeply sloping sites is achieving off-street site access. Road objects give a good idea of height differences between platforms and roads, as well as indicating required road reserves. (See Figure 12.1)

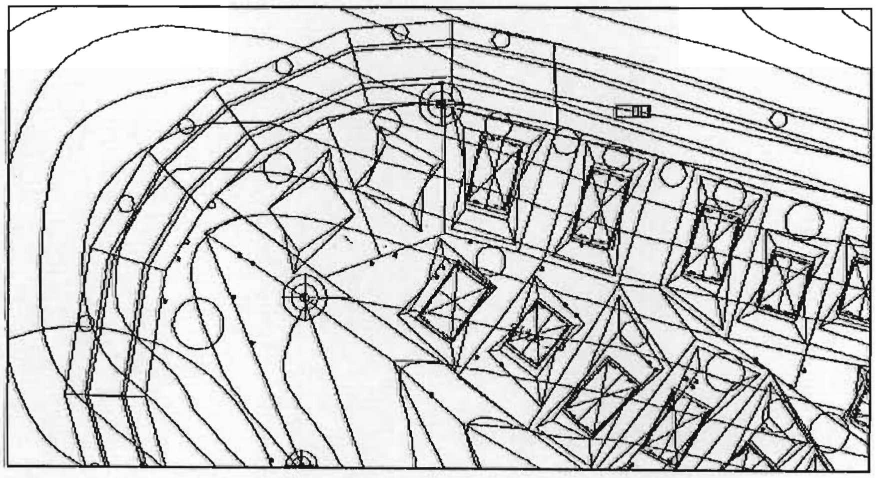


Figure 12.2 Segmented road objects simulate curved sections.

Panels.

Panels are special cases of sites that have no platforms, banks, or built form on them. They allow infilling of three dimensional fabric between other object types, and represent open, undisturbed land. (See Figure 12.1)

Buildings, trees, cars, and People.

Visual clues such as buildings, trees, cars, and people all help in simulating depth of field and in determining relative scale within a perspective. (See Figure 12.3) An added benefit of inserted human figures is that the creation of perspective views is greatly simplified. It is far easier to conceptualise 'this person' looking towards 'that car', rather than trying to calculate and enter the co-ordinates of a camera and target point for a perspective. (See Figure 12.1)

Figure 12.3 Shadows, trees, human figures, and cars provide visual clues to enhance the perception of reality.

The building block system has a certain degree of extensibility. It is possible for designers to add their own preferred building types to the tool box, and have them be available in all projects.

THE PROGRAM IN USE.

The first guideline for the program structure was that it should be easy to use. A lot of effort went into achieving this goal. Three main principles were followed in this respect.

1. All commands are accessible via Menus and Dialogue Boxes, as used in AutoCAD. As the name implies, dialogue boxes allow interaction between user and computer. In this instance, all parameters relating to an object class are visible at a glance for easy editing. Figure 12.4 shows a sample screen, and Figure 12.5 shows a typical Dialogue Box in detail. Refer to Appendix 6 for further examples.
2. Wherever possible, computer tasks and actions should be analogous to manual ones. Designers immediately feel more confident about using a tool when they are comfortable with the underlying concept. A caveat in this respect was discussed in Chapter Seven; if a computer model follows manual systems too closely, the potential of the new system will be limited.
3. Wherever possible, three-dimensional tasks should automatically be simplified by the program into two-dimensional ones. This removes a large burden of conceptualisation from the user, while building on skills most designers already have. All of the respondents in Chapter Eleven made use of two-dimensional CAD in their offices.

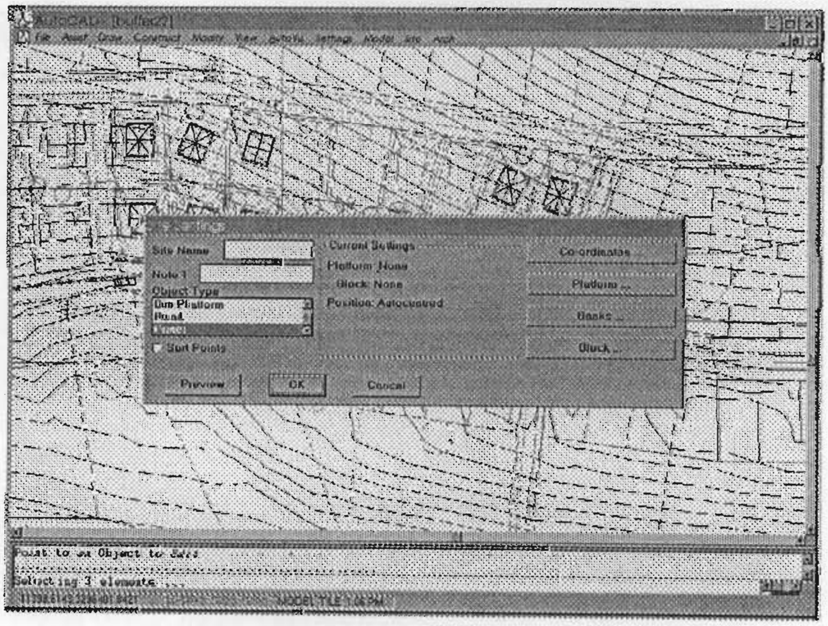


Figure 12.4 inSITE screen and Dialogue Box.

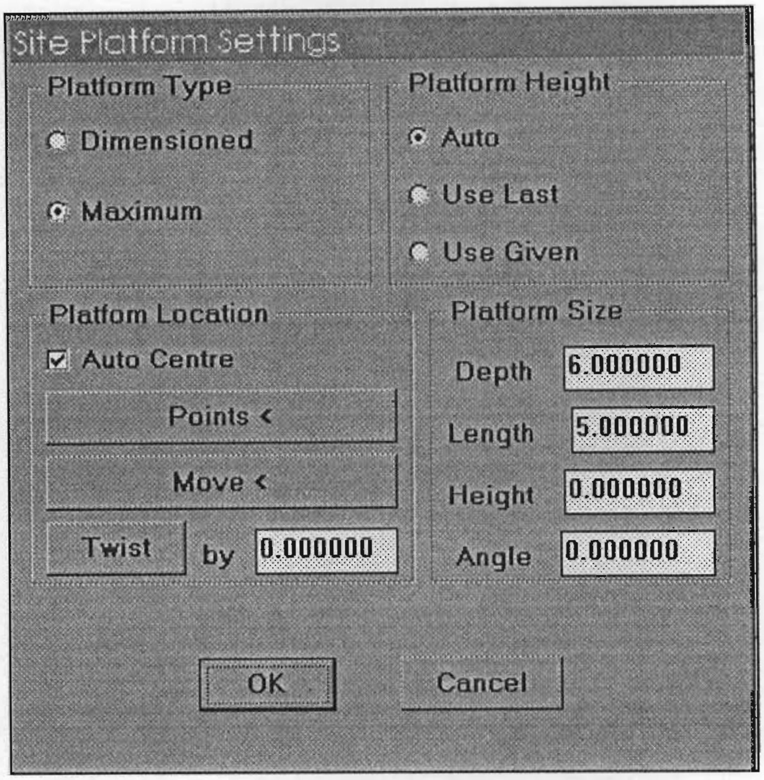


Figure 12.5 inSITE Dialogue Box detail.

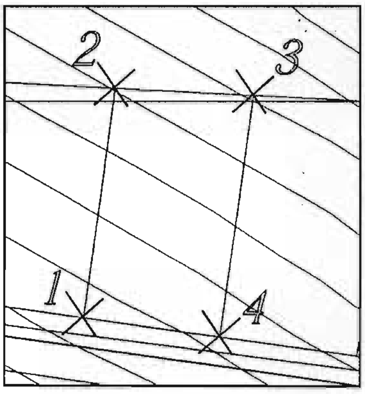
Before a designer can start testing micro-scale optimisation, it is necessary to begin with a layout plan. This may be obtained in various ways.

- By creating the layout from scratch within inSITE as a new design.
- By working with a previous design stored on computer.
- By scanning in a manually drawn layout.

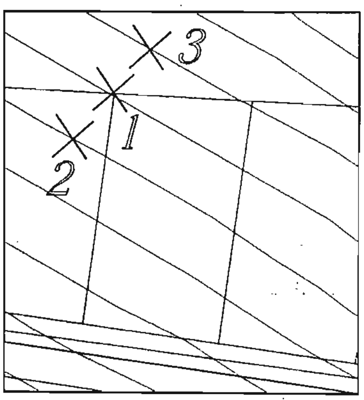
The second two options are effectively using an Iconic model on which to base new investigation.

In creating a site object, all that a designer need do is point to the four corners that define a sub-division boundary. As long as the current default settings for platform, size, soil conditions, and built form are acceptable, no further input is required. The corner points may be indicated in a variety of ways, in keeping with the stated goal of flexibility. The easiest method is by laying out sites in plan view, (i.e. a two dimensional view) and obtaining height information by pointing to contours on either side of each boundary point. (see Figure 12.6) This is probably the most intuitive method, as it is very similar to the manual process of laying out sites on a drawing board. It is necessary to have a three-dimensional contour model of the site, but this is usually available from the surveyor with z heights already assigned to contours.

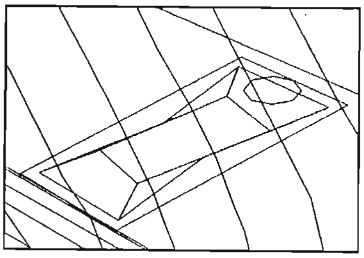
The sequence shown in Figure 12.6 indicates the ease of creating a site with only 16 mouse clicks, and illustrates two of the stated principles: using a method that is analogous to manual ones, and converting three dimensional tasks into two dimensional ones.



1. Point to each site corner point to define the area of the site. (a two-dimensional task.)



2. To set the height, indicate a corner, and then point to a contour on either side of it. (a two-dimensional task.) Repeat for the remaining corners.



3. When the view is changed to a perspective, it can be seen that the program has automatically created the three-dimensional site, platform, and banks.

Figure 12.6 Creating a site.

DESIGN OPTIMISATION.

Objectives two and three at the beginning of this chapter defined two areas of optimisation to be investigated:

1. Finding what sub-division sizes are required for a particular platform size.

2. Finding a suitable position for the platform on a sub-division.

The sequence of operations to achieve the first objective can be defined in terms of Jones' (Jones, 1981) search strategies as follows. (See Figure 12.7)

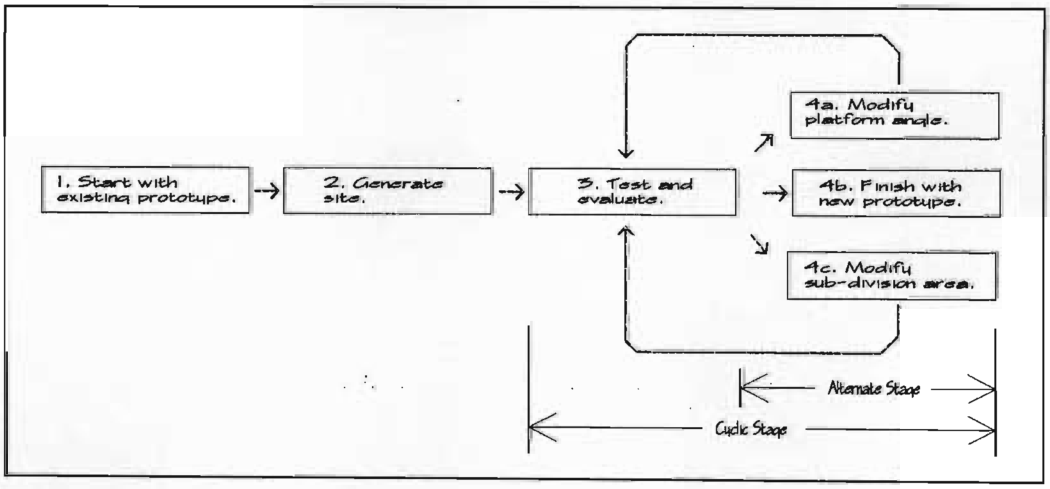
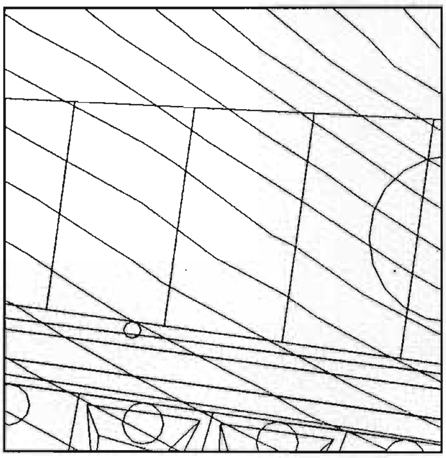


Figure 12.7 Alternate and cyclic search strategies for determining sub-division sizes.

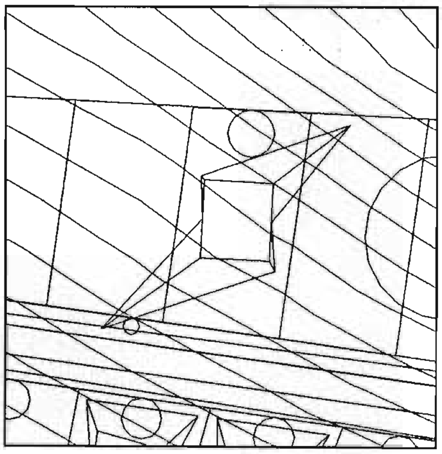
A typical design problem might look like this.

> Is it possible to fit a 56 m² platform onto a 271 m² subdivision, given the supplied topography and proposed grid layout plan? If not, what is the maximum platform that can be fitted onto such a sub-division, and what is the minimum sub-division that would accommodate such a platform?

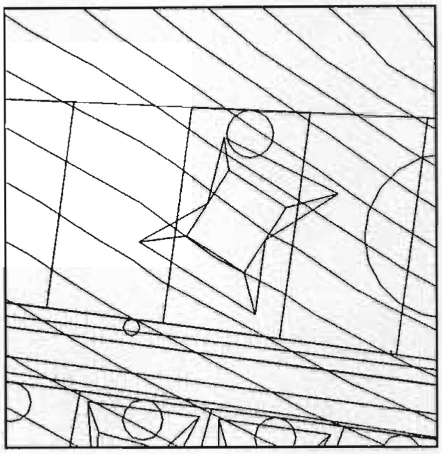
The sequence of operations making use of inSITE as an optimising and evaluation tool might look like this. (See figure 12.8)



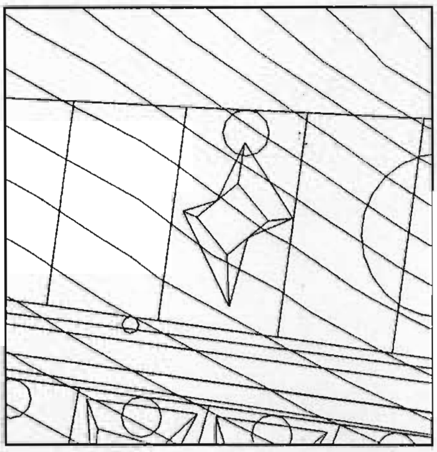
1. Start with a proposed layout plan and contours as a basis for investigation. The first time the program was used, this layout would be based on manual experience. From then onwards, each design could be saved as a template for future use. This particular layout (kwaDabeka) is rather problematic, as the slope falls diagonally across the grid. Each sub-division is currently approximately 272 m^2, the desired design area.



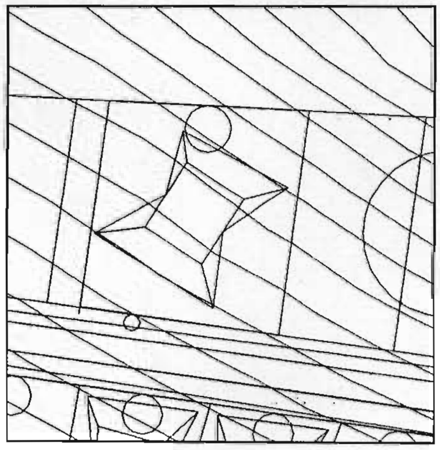
2. Let inSITE generate a first attempt at the platform automatically, based on a required platform size. (56 m^2) The angle inSITE uses to calculate the platform is obtained by averaging the angle of the top and bottom boundaries. In this case, a cross-fall site, the default platform angle is not suitable.



3. By changing the platform angle parameter, a far more suitable layout can be achieved. The platform follows the contours, and banks are more symmetrical. It can be seen that the banks still encroach. In order to solve the problem with a standard Cut and Fill solution, two options are available: decrease the platform area, or increase the sub-division.



4. By decreasing the platform area to 27.5 m² and rotating it a further 10°, and letting inSITE re-calculate, the platform banks can be accommodated within the site area.



5. Increasing the sub-division size to 461 m² allows the required platform area to be accommodated. Note that at this stage, changing sub-division sizes is a manual process of lifting up a boundary line and moving it until the resulting area can be seen to accommodate the required platform and banks. Future plans for automatic calculation of subdivision sizes are discussed in Chapter Fourteen.

Figure 12.8 A typical design optimising and evaluation exercise.

The design implications of the analysis are that a platform of 56 m² will not fit onto the desired sub-division area of 272 m². Some options available to the designer are:

- Increase the subdivision area to 461 m²
- Decrease the platform area to 27.5m².
- Change the grid layout to follow the contours.
- Bench platforms across more than one site.
- Look at a building system not based on Cut and Fill platforms.

Important benefits are gained with computerised calculation of Cut and Fill platforms. Checking is built into the design cycle; it is done automatically by the program, and reported visually. If banks encroach over boundaries, the site ID tag turns red, if banks are all right, the tag turns green. Success or failure of a set of parameters is fed back immediately to the designer allowing an immediate response. It is not necessary to perform a slope analysis in order to design classes of sub-divisions and platforms; every sub-division instance is handled on the basis of actual site conditions. For the same reason it is not necessary to construct test cross sections. As every sub-division is tested, the fear of unusable ones on-site is allayed.

In addition to manual optimising, two automatic functions are provided.

Angular optimisation changes the angle of the platform in relation to the highest boundary line. (See figure 12.9) With each change, the platform is recalculated, banks are tested for encroachments, and the volume of cut to fill soil compared. Any viable solutions are drawn lightly on screen, with the platform with the lowest difference of cut to fill selected as optimum. The number of options evaluated, the angular step, and the arc of rotation are all adjustable parameters.

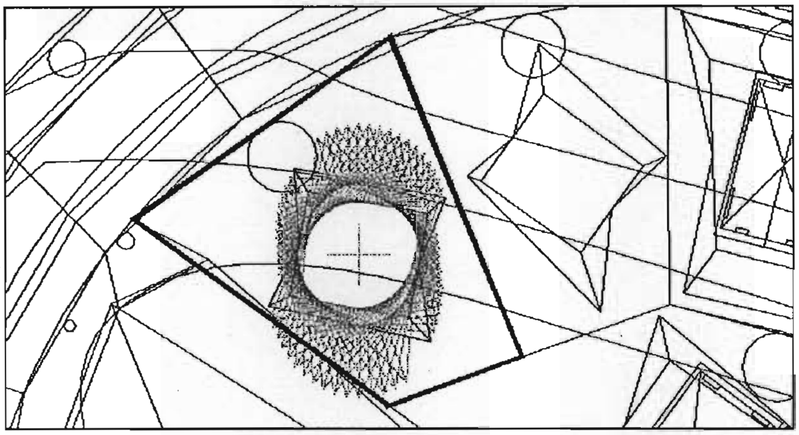


Figure 12.9 Automatic optimisation of platform angle to fit within boundary constraints. As the program finds a situation that fits the criteria, it lightly draws in a trial platform. This repetition and darkening over the platform, starts to give the feeling of 6B pencil emphasis on important design aspects.

Planar optimisation shifts the platform in the x and y planes to determine any options whose banks do not encroach into neighbouring sites. (See figure 12.10) The distance away from the centre of the site, the increment step, and the total movement are adjustable parameters.

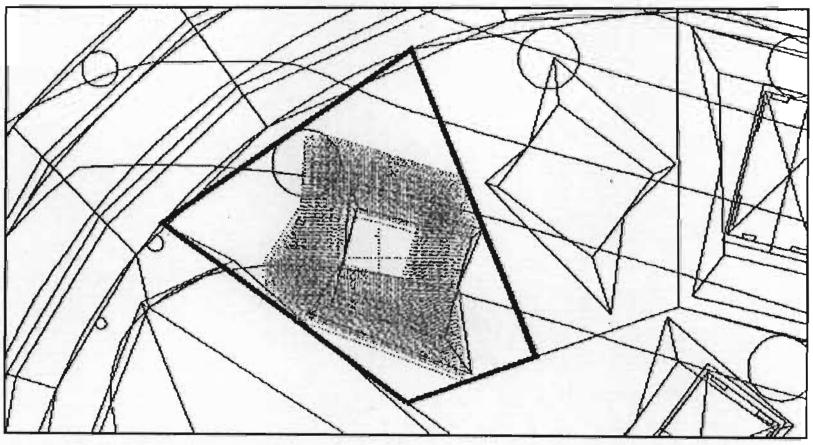


Figure 12.10 Automatic optimisation of xy platform position. The program lightly draws in any possible options, once again giving the feeling of emphasising likely avenues of investigation.

These automatic optimising tools merely give an indication of the breadth and power of testing that is available with computer tools. Further possibilities are discussed in Chapter Fourteen.

VISUAL EVALUATION.

In any profession concerned with spatial design, visual evaluation is vitally important. inSITE draws on the three-dimensional tools offered by AutoCAD to provide powerful, easy to use perspective viewing facilities. AutoCAD uses the analogy of a camera; by establishing a camera position and a target point, any desired view may be obtained. It is possible to set the camera lens focal length, thereby allowing perspective distortions to be simulated. What inSITE adds to AutoCAD's generic perspective tools is ease of use and functions tailored specifically for architecture and planning.

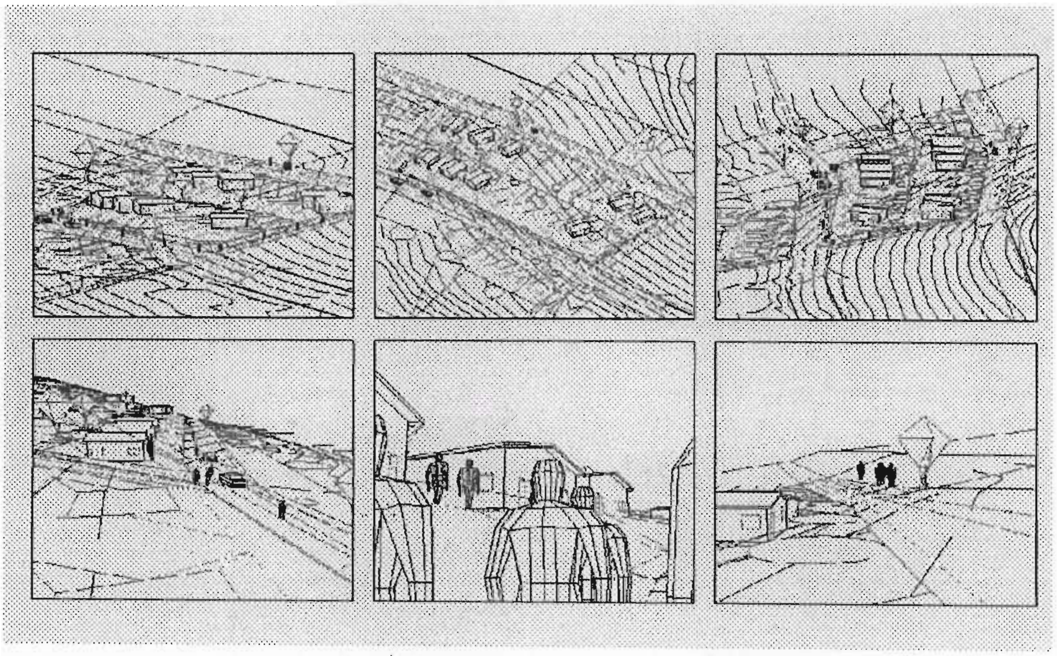


Figure 12.11 Perspective views of the proposed kwaDabeka Buffer.

Perspective views such as those in figure 12.11 allow various design issues to be investigated. An important goal was to provide rapid visual form prototyping capabilities. To this end it is possible to create a surface map of an entire township, with a good indication of built form, in a short space of time. The resulting model can be viewed from any angle, in perspective or orthographic mode. These visual tests function at a macro-scale of a group of a number of sites. It is possible to establish specific viewpoints to answer particular questions, such as:

- Is it possible to see neighbouring houses from a particular site?
- Will this building cast a shadow on that one?
- Does this cul-de-sac create a community space, or will banking to roads and building platforms mean that each site is isolated by banks?
- Is vehicular access possible to this site?

NON-GRAPHICAL EVALUATION.

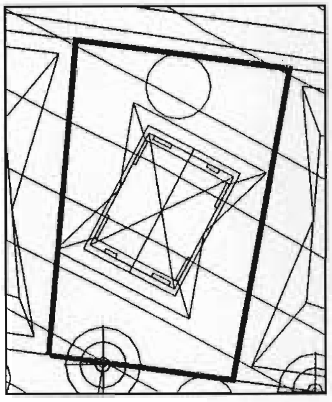
Statistics are automatically updated by inSITE regarding every object in a project. This allows qualitative assessment of:

- The area covered by sub-divisions and platforms.
- Sub-division road frontages.
- Road lengths.
- Amount of soil to be moved.

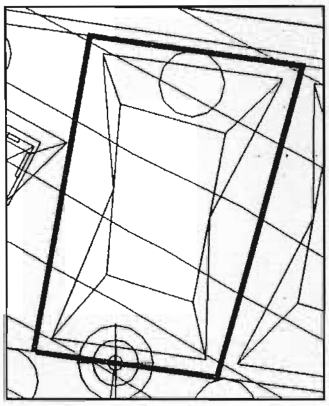
These are just some of the values that can be extracted. More categories will be added in a later release of the software.

PROGRAM ENHANCEMENTS.

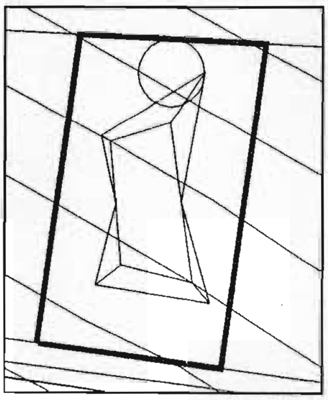
The initial program implementation allowed only rectangular platforms of specified dimensions, or trapezoidally shaped ones which resulted if the maximum platform for the site was requested. (see figure 12.12.2) The program now accommodates specification of a free-form four-sided platform merely by indicating the four corner points of the platform in plan. This is a much simpler and more powerful mode of entry, and is of particular benefit in informal settlement upgrade developments, where platforms of random size and shape need to be modelled.



1. This platform has been specified with a given width and depth. The program calculates the banks and draws the platform. A visual indication is given of whether the banks fit within the boundaries: green - everything is okay, red - there are encroachments. This 'traffic light' indicator means that problems can be dealt with by exception.



2. The program has been instructed to calculate the maximum platform that can fit onto the site, based on specified soil conditions, and allowing a specified safety border within the boundaries.



3. This irregular platform has been specified by indicating its corner points on-screen. This is useful for informal upgrade developments, where existing oddly-shaped platforms need to be modelled.

Figure 12.12 Three different platform types.

ADDITIONAL FUNCTIONS.

Two additional tools are provided for processing of graphical data.

1. Many older CAD packages (or inexperienced CAD operators) produce contour maps in two dimensions, with each contour being made up of hundreds of line segments, instead of one polyline, as is more useful. Manually picking each segment is very time consuming, boring, and error-prone. This first function will automatically find all connected segments of a line and give them a specified height or z value.

2. This function will automatically remove any point primitives it finds in a drawing. This is useful in instances where the drawing provided by the surveyor still contains all of the spot shot points. These take up a large amount of drawing space, and can lead to errors in positioning new objects, which tend to snap onto these points.

It is possible to move information of various types into other programs for further processing. This may be graphical information which may be in a variety of formats, such as TIFF, GIF, BMP, PCX, EPS, DWG, or DXF. The first five are bitmap or raster formats. Images of this type may be imported into word processors for the creation of reports. Most of the illustrations in this document were produced by inSite in this format. DWG and DXF are vector file formats, and allow the transfer of information between other CAD packages. Information was imported from several other CAD packages for processing by inSite into three dimensional models.

Non-graphical information, such as site positions, Cut and Fill volumes, and site owners may be exported either for inclusion in reports or databases. inSite will also accept x,y,z co-ordinates in ASCII format from which to build sites.

LIMITATIONS OF THE PROGRAM.

There are obviously restrictions to what functions the program can perform. Some of these are due to limitations of programming time, while others have deliberately been incorporated into the program because the simplification they provide has benefits in terms of speed and ease of use.

- Sites are limited to four-sided quadrilaterals. It is planned that future versions of the software will support more object types such as multi-sided sites and discreet banking elements. This will allow the construction of far more complex layouts than is currently possible.

- Modelling of Cut and Fill planes is an approximation. Any sites with very irregular topography will not be accurately represented. This is thought to be an acceptable limitation, given that the program emphasis is on a macro-scale resolution of issues of design rather than construction.

- The capturing of three-dimensional information is rather laborious. This is not too much of an issue for new projects, as most surveyors will supply data in the correct format. A lot of existing contour information, however, is in two-dimensional format. There is a facility in the program to convert this into a three-dimensional model, but it is fairly slow. At worst it is possible to use any of a number of third party digital terrain modelling packages to create contours from spot shots.

- Because the package does not incorporate digital terrain modelling, it is not able to infer three-dimensional positioning of points from wire frame contour drawings. It is able to interpolate points between two adjacent contours, but this involves selecting the desired plan position, and picking each of the contours. This involves some approximation of data, but greatly simplifies the use of the program, and speeds up its operation. The program brief specifies the emphasis on small area sites, and under these conditions, errors due to interpolation are likely to be small.

CONCLUSIONS.

The following stated objectives have been met.

- The program calculates Cut and Fill platforms for a various soil conditions. It is able to accommodate cross-fall layout plans.

- As the example in figure 12.8 demonstrated, it is possible to calculate maximum platform yield for a given sub-division with particular soil conditions, as well as to calculate the required sub-division for a specified platform. It is also possible to optimise the position and orientation of platforms and top structure on the sites thus created.

- The ease of creation of perspective views of proposals allows evaluation at a micro-, meso-, and macro-scale. Relationships between elements such as houses, roads, platforms, and banks can be visually analysed to resolve issues such as vehicular access, privacy, and enclave creation.

- Together with AutoVision, it is possible to test and evaluate climatic influences on the built environment.

- Because the model is created in a vector format, it may be used as a basis for accurate two-dimensional construction drawings.

- Information may be extracted from the model in graphical or textual format. Textual reports allow listing of all non-graphical information of the model: site names, site areas, platform areas, platform heights, and Cut and Fill volumes and differences.

- Data can be input and output in a number of formats, allowing the flow of information to other programs.

The program has achieved all of the objectives stated at the beginning of the chapter. It now remains to evaluate the program in the field. This will allow testing of whether the program is easy to use, and whether designers find benefit in its features.

CHAPTER THIRTEEN - INSITE PILOT STUDIES.

This chapter outlines the pilot study of a computer generated model of the proposed kwaDabeka/New Germany buffer, produced with inSITE. The intention of the study was to ascertain the usefulness of the inSITE program in practice, and to ensure that the provided tools handled design issues with sufficient depth to be relevant. Specific objectives were:

- To test the usefulness of the Cut and Fill platform creation tool.
- To test the usefulness of the three-dimensional modelling design evaluation tools.
- To gauge the ease of use of the program in order to determine if this objective, stated in Chapter Eleven, had been attained.
- To evaluate whether computer-generated three-dimensional perspective drawings are easier to interpret than traditional two-dimensional orthogonal drawings, particularly in relation to end-users.

The proposed kwaDabeka/New Germany Buffer was chosen as a vehicle for the study. The site forms a buffer between New Germany and Clermont. It is a green fields development for the kwaDabeka informal settlement. Reasons for the choice included:

- The involved parties were prepared to participate in the study: planners, engineers, and end-users.
- Electronic layout plans were available as a basis for the investigation.
- The proposed site incorporates very steeply sloping land with difficult topography - a perfect test of the program's capabilities.
- There was a specific desire for end-users to understand the implications of the difficult site.

The presentation took the form of a demonstration of a three-dimensional model of one of the more difficult sections of the development. (See appendix three for a layout plan) Viewers were first shown a series of plan views, representing traditional communication techniques, and were then shown rendered perspective views of the model. If the audience contained designers, the optimising facilities were demonstrated. Lastly, viewers were shown an animated walk along a road in the development and a simulation of the movement of shadows cast during the course of a day. Presentations were given to various categories of people. (See appendix one for contact details)

Planners: Adrian Masson, John Forbes, Robynne Hansman, and Mark Townsend.

Civil engineers: Mike Archer, Mark Hallowes, and Miguel Menezes.

Development Facilitators: Madoda Dlamini.

End users: Jimmy Matolo and representatives of the kwaDabeka Civic Association.

CONCEPTUAL FRAMEWORK.

In general, respondents had no difficulty in understanding the conceptual framework of the model; a toolbox of objects out of which a model of a design proposal can be built. There were requests for objects other than those currently available, but this was to be expected. Given the time constraints of the study, it was necessary to test the program with currently available objects. The area of design addressed by the program, Cut and Fill platform analysis, was also seen as being particularly appropriate for present development in this country. All of the designers were comfortable in general with the broad principle of analysis-synthesis-evaluation, and specifically cyclic and alternate searches in evaluating options, as outlined in Chapter Eleven.

Platform Analysis.

Designers were impressed by the ease of creating Cut and Fill platforms, and in particular, the ability to cope with cross-fall sites. The ability to test all sub-divisions of a proposal in a short period of time, with an easy to use program was particularly welcomed. The computer model was also seen as being more accurate than currently used manual means.

"Design by parameter", the ability to start with a reasonable assumption of what suitable sub-division values should be, and then fine-tune these in a graphical way for a specific occurrence was regarded as being a more efficient and much simpler process than manual analysis. Parametric or pro-forma design of this nature builds on the concept of iconic design; instead of the icon existing in the designer's head, it is manifest in the parameters stored in the program's templates.

In moving from a micro- to a macro-scale to consider bulk services and access, viewers were impressed with the ability to calculate sub-division statistics, such as platform area and height, road heights, and Cut and Fill volumes and differences, i.e. the movement of soil onto or off the site. One group that included engineers, asked about the ability to include major service pipe runs, so as to be able to compare the relative efficiency of rival layouts, and calculate approximate costs per site. This is not available at present, but is certainly feasible for a future release of the software.

Three-dimensional Model Evaluation.

Moving from the essentially two-dimensional world of platform analysis to a three-dimensional view, particularly one that was rendered, evoked a very favourable response. Most of the viewers had never seen three-dimensional presentations of specifically planning related models, and those that had, felt that inSITE emphasised planning issues in a clear and accessible way. The animated walk-through along a road in the development was regarded as being of great benefit, particularly in conveying a clear indication of the proposed spatial 'feel' of the development. It was also useful in showing up problem areas, for example in this case just how steep the banks between the road and the first platforms would be. The climatic analysis was not viewed with much enthusiasm, but would probably appeal more to urban designers and architects.

The main issues raised during discussion can be summarised in five points:

- The importance of clear communication with end users and the benefit of three dimensional perspective views was emphasised by all designers. This was seen as one of the major benefits of using inSITE.

  > "The usefulness of this facility (testing platforms) is however vastly overshadowed by the programs capacity to provide a variety of perspectives and orthogonal views of the development. There is a major problem in presenting plans to people who cannot read them. The use of aerial photographs or orthophotos is one way around this problem but even these do not provide a readily understood three dimensional understanding of development proposals. The program's capacity to draw perspectives can provide the end user with a good idea of what is proposed and will be a major advance to communicating plans and proposals" Adrian Masson.

"The ability to simulate reality through a perspective is an extremely exciting and relevant function, in particular when it can be used to inform the choices of the people who will ultimately take ownership of the land." Robynne Hansmann.

"The ability of it to also enable the client body to obtain a bird's eye view of a proposal with simplified structures is also a tremendous advantage, which will hopefully avoid possible recrimination at a later stage when the development on the ground does not turn out like the 'pretty coloured' layout plan." John Forbes.

- The ability to model platforms on small, steep sites was seen as a very useful tool. Two planners specifically mentioned the embarrassment caused by unusable sites only being detected during construction, and the fact that this tool should obviate this problem.

- Communication among members of the design team could be enhanced by using three-dimensional models. One of the civil engineers remarked upon seeing a perspective view of a road frontage showing sub-divisions, that he hadn't previously realised the extent of the design problem. It also became clear by another comment he made that he was not too clear in his mind about whether contour lines represented a vertical or a horizontal measure of distance. This uncertainty would no longer be a concern if he were able to test his design proposals in three dimensions.

- The ability to analyse individual sites quickly and accurately in a recursive manner, observing the effect of parametric changes was seen as a useful feature.

- By using a computer optimising tool, information which previously was unavailable or arrived at the wrong time in the progress of the project to be of use could now be fed in during the next iteration of the design process. This is typical of information supplied by the engineer regarding initial proposals for major services. Using manual methods, planners must wait for proposals to come back from the engineer to see whether the overall layout plan is feasible. The computer model can supply visual implications in three dimensions of proposed earthworks, major physical elements such as road access, and of social issues such as privacy and sight lines during the first, investigative stage of design. This effectively extends the active period of design, meaning the designer does not have to commit to a solution as early in the project as with manual techniques. The cost of evaluating alternatives is reduced, or conversely more alternatives can be evaluated for the same price.

PERCEIVED PROBLEMS OF THE PROGRAM.

A number of problems emerged in the course of the presentations. The first was the issue of perception and interpretation of computer generated perspectives with regard to end-users.

The presentation to members of the kwaDabeka civic consisted of a slide show of computer images, starting with the existing planners' two-dimensional layout plan, then zooming in to detail plans of blocks of sub-divisions, showing Cut and Fill platforms and road banking. The final stage was to demonstrate perspective views along the proposed roads, and aerial views showing site topography and the resulting banking from platforms on such terrain. The audience was particularly quiet during the demonstration, but this may have been partly due to the fact that the presentation was in English, and their first language was Zulu. During the question period after the formal presentation, it became clear that viewers were struggling to interpret the relative sizes of houses, plots, and banks represented by the images on the computer screen. This was resolved at the time by pacing out sample dwellings, platforms, and banks. When viewers were asked whether they found the computer images easier to understand that traditional plans, they replied that the computer images were better. This problem was addressed more fully by including in the program the ability to insert human figures, cars, and trees, and casting shadows from all objects, which had previously been absent. These visual clues greatly enhanced the perception of scale, perspective, depth, and height. In a follow-up session, rendered prints of perspective views with these additions were interpreted by the community far more easily, who now said that they preferred these paper images to those on the computer screen. This may be due to the fact that paper is a recognised medium, whereas a computer screen is somewhat foreign, or because of a feeling of ownership; the paper drawing could be kept, whereas the computer image would disappear. The drawings were pinned up in the kwaDabeka site office and apparently received a positive response from all visitors.

The emphasis on solutions of Cut and Fill platforms with individual dwelling units of a conventional small house type was seen as a shortfall of the program, in that even though this is the predominant form of low cost development in Natal, it may not be the most appropriate for steep land conditions. Other options such as stilted or split level dwellings may be more suitable. This problem was caused more by the content of the interview, rather than a limitation of the program itself, as inSITE can model "stilted" top structures.

The fact that the program will only operate from within AutoCAD was wryly noted as a criticism - in this instance from a planner whose office owned only a competitive CAD package. This is valid comment, but as noted in appendix five, AutoCAD is the only currently available development platform for a program of this complexity.

Conclusions.

On the whole, the results of the study were encouraging. The initial concern expressed at the start of this chapter, that of whether designers would find the program to provide deep enough analysis of design issues was allayed in that every one of the designers who submitted a written response felt that the program provided significant improvements over traditional methods. Three out of four commented on the usefulness of the platform generating tool, and all felt that the three-dimensional modelling and perspective generating capabilities were a vast improvement over current manual means. This addresses the first two objectives of the study, to test the usefulness of the Cut and Fill platform creation tool, and to test the usefulness of the three-dimensional modelling design evaluation tools.

The third objective, to assess the ease of use of the program, proved to be a more difficult task. None of those interviewed had had any experience with existing CAD programs or computer design tools, and so had no basis for direct comparison. All had general computer experience, and in this way were able to compare inSITE to other programs in terms of generic functionality. These included ease of finding and understanding commands, legibility of dialogue boxes, and implementation of generic Windows functionality such as mouse support and 'drag and drop' features. One respondent commented that the program was relatively straightforward to use, and this probably summed up the general feeling. It would be fair to say that viewers felt that inSITE was easier to use than other CAD programs, but that there was room for improvement. Of the concerns that respondents voiced, it was clear that most of them were due to a lack of sufficient instruction in the use of the program. This can be seen as a failing of the demonstration, rather than inSITE itself.

The last objective was to evaluate whether computer-generated three-dimensional perspective drawings are easier to interpret than traditional two-dimensional orthogonal drawings. It was clear that designers found perspectives not only easier to understand, but far more informative than separate plans, sections, and elevations. Spatial relationships between elements were much easier to evaluate. Fairly straightforward design questions, such as whether vehicular access would be possible to a given site, or whether neighbours on either side of a road could see each other, were easily answered. The difficulty came in assessing end-user response to computer models, and in particular assigning some kind of qualitative relative value to two-dimensional and three-dimensional drawings. End-users definitely said they found the computer drawings easier to understand. This may have been because they did not want to appear old fashioned.

One disappointing aspect of this section was the lack of detailed or specific feedback from designers regarding the operation and usefulness of the program. There were two reasons for this. In hindsight it is clear that the demonstration could have been more specific in emphasising the features of the program for which a specific response was required. It is also now clear that the designers needed more time to experiment with the program on their own projects. This would no doubt have resulted in more meaningful dialogue. In spite of this, all of the stated objectives for this section were met. Once the ability to model scale elements was included in the program, readability of the computer perspectives was vastly improved. The other major criticism - the emphasis of inSITE on Cut and Fill platforms - needs to be viewed in the light of the stated objectives of the program, the primary one defining the scope of the program as being to analyse Cut and Fill platforms. Within the parameters of the objectives of the program, the study was successful.

CHAPTER FOURTEEN - CONCLUSIONS.

In introducing this dissertation, four questions were posed. How does design take place? What processes do designers currently use to solve problems, and specifically how do they handle the problem of Cut and Fill platform design? What computer tools are currently available to aid in this problem? and Is there a better way of handling this problem? Some areas of investigation suggested by the questions have been covered in more detail than others, but the answers might be summarised as follows.

Design tools have been evolving for the last 4800 years, but it is only in the last ten years that dramatic changes have occurred. Whereas scale drawings, scale models, and hand-generated perspectives have played a valuable part in the design process, these techniques are no longer sufficient to cope with current design requirements. Added complexity of design problems, the demands for user participation, and the world wide trend towards concurrent engineering practices are all addressed by the use of computer generated three dimensional models. Up until the late 1980s computer aided design programs focused on two dimensional production drawing creation. The current wave of programs all address the requirements of three dimensional modelling tools.

Most planning design tasks are currently performed manually. In investigating the specific problem chosen for this dissertation, the calculation and evaluation of Cut and Fill platforms, a number of drawbacks to the existing methods emerged.

- The current process of manual calculation of Cut and Fill platforms and sub-divisions is very time consuming.
- It incorporates underdeveloped facilities for iterative testing of options.
- Each step of the process is discreet, allowing little chance for jumping backwards or forwards in the chain; for employing alternate or cyclic evaluation of design options.
- Checking is either left undone, or left to someone other than the designer.

A computer program, inSITE, was developed to address these problems in particular, and to investigate computerisation of the design process in general. The program was based on two important input sources, the design principles covered in the first part of the dissertation, and the design practices investigated in the third. The resulting program met the following objectives:

1. To calculate Cut and Fill platforms for a variety of soil conditions, for site topography ranging from good to difficult. In the pilot study, platforms were calculated for a range of sites over very difficult conditions. Tests were also performed on flatter land with similar results. (See Chapter Twelve for a specific example)

2. To suggest sizes of sites for specified or required platform or building sizes. A range of platform sub-division sizes were used in the pilot studies to investigate the design process involved. (See Chapter Twelve for a specific example)

3. To optimise the position and orientation of platforms and top structure on the sites thus designed. A variety of housing types were employed in the pilot studies to investigate the effects of shifting houses around on platforms and breaking away from the stereotypical house in the centre of a platform in the centre of a sub-division.

4. To evaluate the proposed platforms and sub-divisions at the micro scale of the individual site environment created. This led on directly from the investigations into the previous objective, and relied heavily on three-dimensional perspective views. Evaluations of this kind are subjective by nature; the measure of the attainment of this objective was gauged by the response of viewers during the pilot study, which was favourable.

5. To evaluate the urban fabric created by multiple sites, roads, and infill panels at a macro scale, in other words the total effect of the design. This evaluation also relied heavily on perspective views and the response of viewers of the pilot study, which was positive.

6. To test and evaluate climatic influences on the built environment in terms of sun exposure and shadowing. The animation of the pilot study site over the period of a day indicates that complete and accurate analysis is possible.

In direct response to the problems of the manual methods listed above, inSITE has the following advantages:

- The computerised process of calculation of Cut and Fill platforms and sub-divisions is very quick and relatively accurate. A large development may be modelled and tested in a matter of hours, as opposed to a matter of months.

- Advanced facilities for iterative testing of options are available. Parametric modelling allows ranges of options to be tested iteratively; either manually or automatically.

- The design process is integrated, branching, looping and jumping backwards or forwards in the chain is allowed. The program allows a designer to change context rapidly and easily.

- Checking against defined criteria is part of the design cycle; it is done automatically by the program. Success or failure with regard to a set of parameters is fed back immediately to the designer allowing an immediate response.

- It is not necessary to perform a slope analysis in order to design classes of sub-divisions and platforms; every sub-division instance is handled on the basis of actual site conditions. For the same reason it is not necessary to construct test cross sections. As every sub-division is tested, the fear of discovering unusable ones on-site is allayed.

- The program copes with large amounts of data, presenting it in a form that is easy to assess visually, performing a data filtering function.

inSITE builds on the functionality provided by existing CAD programs, but provides this in a format that is aimed specifically at planners and architects, rather than CAD operators or engineers.

FUTURE AREAS OF INVESTIGATION.

As the investigation for this dissertation progressed, it became clear in hindsight that certain sections could have been improved upon.

- The interviews investigating design in practice should have been more goal directed, and more formal in their execution.

- The pilot study period should have been longer, with designers being able to experiment with inSITE for a number of months by themselves.

This doesn't necessarily reduce the validity of the findings from these sections, but rather indicates directions for further study.

The dissertation has concentrated on just one part of one stage of the design cycle, that of evaluating and testing rival solutions. A stated objective was to avoid contention concerning BLACK BOX/GLASS BOX design issues. An interesting, if complex, area of investigation would be to examine design stages two and three, strategy formulation and interim solution creation. This would involve a more in-depth study of intuitive processes, data modelling, and user interfaces.

There is a lot of scope for development of inSITE. As with all computer programs, (and in fact any design) there are always improvements that could be made. Several features are planned for future releases of the program.

- The ability to model complex platforms, such as ones with split levels.
- The ability to include multiple platforms on one site.
- Additional building blocks to complement the existing toolbox.
- Sub-divisions with more than four sides.
- More accurate roads with true curved sections.
- True digital terrain modelling.

A more radical change would be to modify the scale of emphasis. At present the sub-division is the basic building block, and parameters, testing, and evaluation relate to this micro scale. The next level would be a meso scale; parameters and testing would relate to a block or group of sub-divisions with related access and services. This could result in the following scenario:

- Define approximate sub-division and platform areas based on space requirements in the brief.
- Select a services model, such as major access roads running with the contours.
- Define an area on the plan.
- The program suggests a layout option, attempting to get the maximum number of sub-divisions that fit the parameters into the defined area.

The designer could then experiment with different space standards, service models, or shape of block, to fine-tune for the particular situation.

General Conclusions.

A number of general points apply to the use of computers in three-dimensional visualisation.

- Computer design tools allow projects to be modelled far more quickly than by manual means.
- The time to evaluate any one solution is greatly reduced, meaning that many more alternatives may be evaluated. Evaluation of possible solutions is more complete.
- A computer model frees the designer from undue commitment to a particular scheme already presented due to re-presentation time constraints.
- A computer model is usually less ambiguous than traditional disjointed two-dimensional drawings, and ensures that all members of the professional team have the same interpretation of a proposal.
- By making the design process more explicit and transparent, possible discontinuity caused by staff turn-over during long-running projects is minimised.
- Any number of accurate perspective or orthogonal views of a scheme may be created at short notice, even during a presentation to a client.
- Computer models are easier to understand than traditional orthogonal projection drawings. Users who may have no experience with piecing together discreet plans, sections and elevations, find perspective views easier to interpret. This was borne out in the presentation to members of the kwaDabeka civic. It is clearly easier even for professionals to interpret computer diagrams, as indicated by the mistake made during a presentation by an engineer in relation to two-dimensional contour lines.

Design comprises explicit and intuitive phases. It is far easier to implement a tool to explore the explicit functions which can act as an aid to the designer during the intuitive processes. As computer hardware and software becomes more powerful, computer aid in all phases of the design cycle may be feasible, but at present the stages of design evaluation and presentation can benefit from computerisation. There are programs currently available that provide tools for use in these stages, but they are not widely used. There is a perception among designers that they are costly to implement, difficult to use, and stultifying to the design process. The response of designers to inSITE was encouraging. All respondents felt that the program could make a positive contribution to planning design. The computerisation of Cut and Fill platform creation showed clear benefits over manual methods, with no obvious disadvantages. Existing computer usage is largely limited to presentation and construction drawing production. This represents a first phase of computerisation, one that has taken approximately eighteen years to implement in this country. None of the companies interviewed would consider returning to the drawing board for this phase of design. As appropriate tools become available for other stages, a return to manual methods will be equally unthinkable.

Appendix One - List of Interviewees.

John Forbes, Chief town planner, Development Service Board.

Robyne Hansman, Town planner, Seneque, Maughan-Brown, SWK.

Mark Hallowes (and members of the kwaDabeka civic), Civil engineer, Exter Construction.

Adrian Masson, Town planner, Harber, Masson, and Associates.

Neil Klug, Urban designer, SWK Planning and Development.

Mark Townsend - Town Planner, CUSSP Durban.

Madoda Dlamini, CUSSP Durban.

Mike Evans, Civil Engineer, CUSSP Durban.

Miguel Menezes, Civil engineer, De Leeuw Cather.

APPENDIX TWO - DESIGN IN ACTION INTERVIEW.

Designing with Computers.

Nick Alexander.

This interview forms part of a masters dissertation which aims to investigate the possibilities of using a computer program as a design tool, particularly in the layout of sites in township development. The focus is not on the entire design process, but rather on optimising plot layout, specifically on steeply sloping land with small sites. For the purpose of the dissertation, it is not necessary for the program to address all aspects of the design process. It is in fact important to concentrate on a specific part of this process; in this case the optimising of sites once a layout has been proposed.

In order to test the usefulness and validity of the tool, it is necessary to understand current techniques used at this stage of the design process, to see if the program offers any advantages over existing tools. If it is possible to unravel this process and list a series of explicit steps or processes that are generally followed in a typical design solution, then evaluation of this tool becomes possible.

While the steps are discreetly listed, in practice they usually take the form of iterative loops, either as simple cycles through the same process, or as complex loops with varying entry and exit points.

Issues that affect the design.

Physical constraints.

- Soil conditions.
- Slope.
- Site topography.
- Existing access or services.

Planning Considerations.

- Minimum plot and building sizes.
- Standards of services to be provided.

Structural Considerations.

- Finance and phasing of implementation.
  * Site and service.
  * Finished units.
  * Self help
  * Existing development or upgrading.
- Building technology to be employed.

Client/End user requirements.

- Built environment.
- Community creation or fostering.

Design Process.

Evaluation of the site.

- Topography.
- Existing services or structures.
- Local Precedent?

Generation of possible site layouts.

- How to generate?
  * Experience.
  * Precedent.
- How to evaluate rival solutions?
  * Physical evaluation - site density, simplicity of services.

* User amenity - access, extensibility, elegance.
* Visual evaluation - sight lines, elegance.
* Social amenity - enclaves, hierarchy, privacy, ...

- How to optimise promising solutions?
    * This hinges on how to evaluate rivals above.
    * Micro-optimisation - minimum earthworks, maximum building area, site services.
    * Macro-optimisation - bulk earthworks, minimum wasted inter-site space, economical services.
- Selection of the best option.
    * A definition of how to optimise rival solutions would also provide a basis for selection of the most promising solution.

Presentation of the scheme.

- To the professional team.
    * A computer model frees the designer from undue commitment to the particular scheme already presented due to re-presentation time considerations.
    * A computer model is usually less ambiguous than traditional disjointed two-dimensional drawings.
    * By making the design process more explicit and transparent, possible discontinuity caused by designer turn-over in lengthy projects is minimised.
- To the client/end users.
    * Any number of accurate perspective or orthogonal views of a scheme may be created in a very short period of time.
    * Computer models are easier to understand than traditional orthogonal projection drawings. Users who may have no experience with piecing

together discreet plans, sections and elevations, should find perspective views easier to interpret.

Benefits of a Computer model.

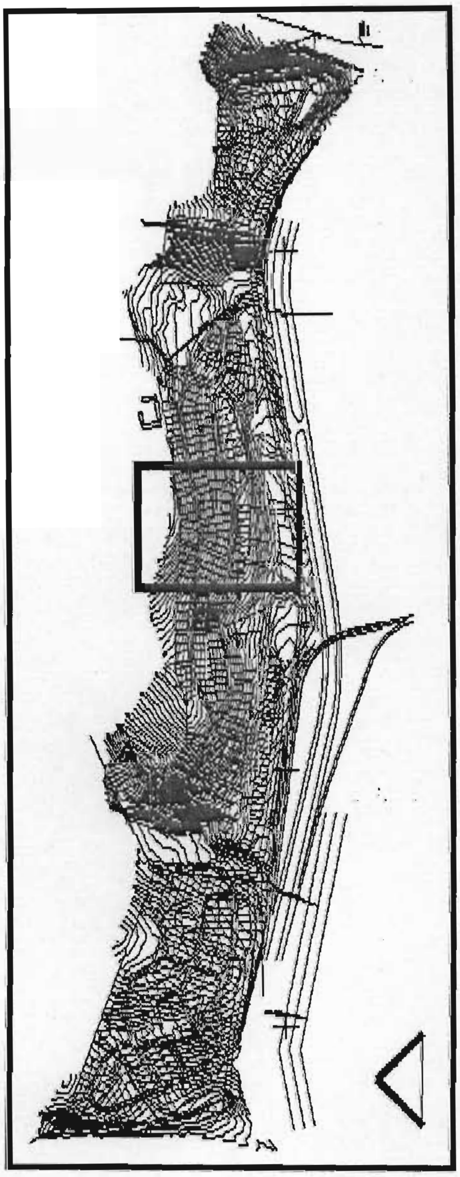
Information which previously was unavailable or arrived at the wrong time in the progress of the project to be of use can now be fed in during the next iteration of the design process.

- Visual implication in 3D of proposed earthworks.
- Physical implications such as road access.
- Social issues of privacy and sight lines.

This effectively extends the active period of design meaning the designer does not have to commit to a solution as early on in the project. The cost of evaluating alternatives is reduced.

- The time to evaluate any one solution is greatly reduced.
- Many more alternatives may be evaluated.
- Evaluation is more complete.
- The emotional commitment to a particular alternative, merely because it has been painstakingly presented is reduced, as presentation time is dramatically reduced.

APPENDIX THREE - SAMPLE INTERVIEW DRAWINGS.



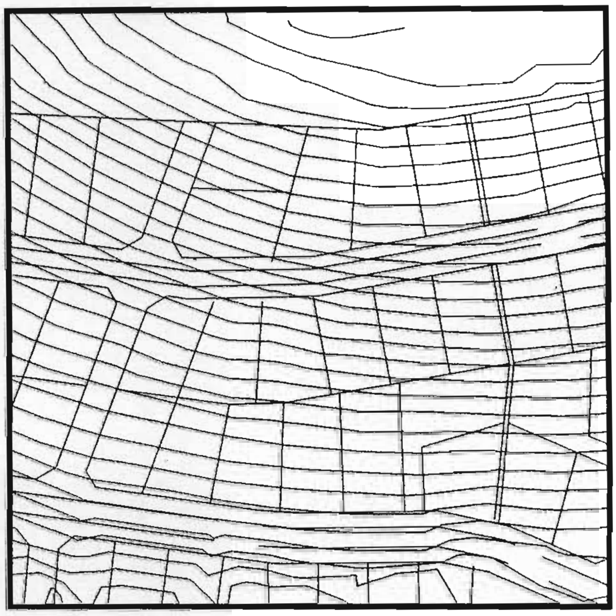


Figure a3.1 kwaDabeka buffer Layout plan and detail.

Figure a3.2 Plan of proposed kwaDabeka buffer.

Figure a3.3 Perspective of proposed kwaDabeka buffer.

APPENDIX FOUR - 2D TO 3D TRANSLATIONAL ISSUES.

One of the problems involved with moving design drawing to the medium of computer is that many complex mathematical tasks are undertaken automatically by a person drafting an object by hand. Consider the action of measuring off distances from one side of a drawing or the other side. In a computer drawing, an explicit instruction must be given to change the origin point of measurements, and a similar instruction given to re-establish the previous origin. For someone using a drawing board, these changes of base reference points are made automatically. Where point references are sometimes absolute, and other times relative to other defined points, people switch reference almost without thought. A whole series of commands is necessary to instruct the computer to perform these same operations.

Lines other than orthogonal ones are particularly difficult to work with. This is a problem associated with any 3-dimensional work, rather than specifically with computer simulation. This task is accomplished by a powerful function that has only been introduced in CAD packages fairly recently - the ability to change the orientation and location of the reference axes of a drawing. User co-ordinate systems are described in chapter nine. On the drawing board, the task can be achieved quite simply by rotating the piece of paper. A drawing machine functions as a two-dimensional analogue UCS computer.

Working in three dimensions with a two-dimensional viewing device (a computer screen) is more of a disadvantage than working in symbolic three dimensions (plan/section/elevation) in a two-dimensional medium, such as drawing on paper. Take for example the task of testing whether banking on a site encroaches over the site boundaries. On a drawing board it is a simple task to draw the site, and visually check on plan if the lines of the banks cross over the boundary lines. A computer model of the same situation requires a great deal of calculation to perform the same test. Simplification of site conditions is required to be able to model the site, because the lines representing the site and platform have no thickness. It is not merely a matter of asking the computer if the lines of the platform and the site boundary intersect, because the computer regards intersection as crossing in the same plane. This is very unlikely to be the case in the model of an actual site. It is therefore necessary to duplicate the functionality of the two-dimensional paper medium and remove the z components of the lines in question to be able to apply an intersection test.

There are difficulties associated with specifying three-dimensional points with a two dimensional device (a computer mouse or graphics tablet) through a two-dimensional viewing device. (a computer screen) A reasonable simplification made on the part of most CAD modelling software packages is to set the z value of any point entered by pointing in the drawing to the z value of the current origin point. This can cause confusion to a user who thinks they are pointing to something in the attic of a house, and in fact they pick an object in the garden lying on a line drawn from the user's eye through the object in the attic to a point lying at a z of 0. (see diagram a4.1) On the other hand, this is an amazingly powerful tool in simplifying three-dimensional drawing, because in combination with the selection of an appropriate UCS, it reduces the complexity of a three-dimensional task to a two dimensional one.

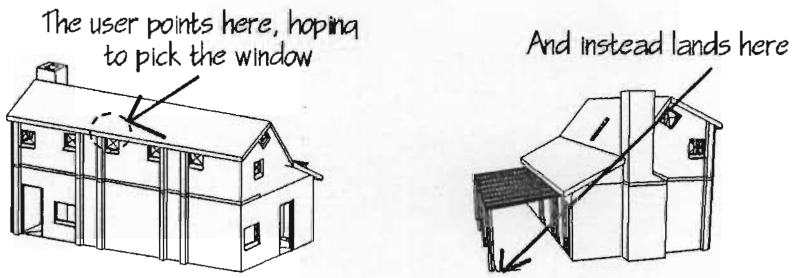


Diagram a4.1 Two-dimensional error.

APPENDIX FIVE - CHOICE OF PROGRAMMING ENVIRONMENT.

A number of CAD packages were reviewed to ascertain their suitability to the task in terms of fulfilling the defined requirements. (AutoCAD, AutoSolid, Datacad, DesignCAD, Drawbase, Genesis, TurboCAD, and Ultimate CAD.) AutoCAD was picked as the package that had the highest overall performance. This is not to say that it is necessarily the only package capable of the task, but that it suited this task best. Various criteria were considered in this choice:

1. Power and flexibility of general drawing facilities. AutoCAD has a complete set of drawing tools, including the ability to model complex geometries with customisable co-ordinate systems, and support for model and paper space.

2. Three-dimensional facilities. AutoCAD has support for wireframe, surface, and solid models. With the inclusion of AutoVision, an AutoCAD add-on, rendering, applying of textures and colours, and casting of shadows is available.

3. Programming language support. AutoCAD supports both C and AutoLisp. Other packages offer at best macro language customisation which allows standard drawing commands to be strung together, with no access to low-level mathematical or other programming functions.

4. Interface customising facilities. No other package offers such complete control over screen, menus, dialogue boxes, and command interface.

5. Data compatibility with other systems. One of the most common formats for sharing drawings, DXF, or drawing exchange format, was designed by AutoDesk. The AutoCAD drawing format is published, so it is possible to query a drawing database directly.

The program was initially written in AutoLisp, but soon outgrew the language's memory and resource handling capabilities. It was rewritten in C which resulted in a far faster and more stable application. At present the program consists of over 4300 lines of code.

APPENDIX SIX - INSITE DIALOGUE BOXES.

An important objective in developing inSITE was to make it easy to use. One of the concerns in this regard was the programming interface. inSITE makes extensive use of Dialogue Boxes, the idea being that all parameters relating to a particular object are accessible from one interface point.

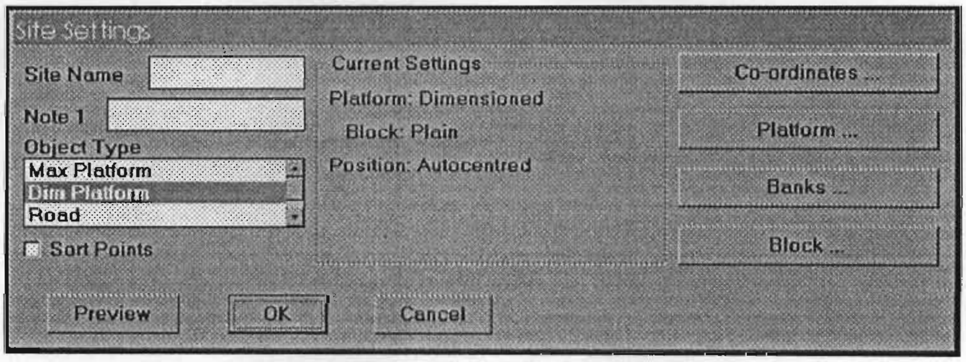


Figure a6.1 Main object parameter Dialogue Box.

This box allows the user to choose the object to create, or change the type of an existing object. Notes about the object may be saved. Current settings of various parameters are displayed in the centre of the screen. The four buttons on the right give access to the other Dialogue Boxes.

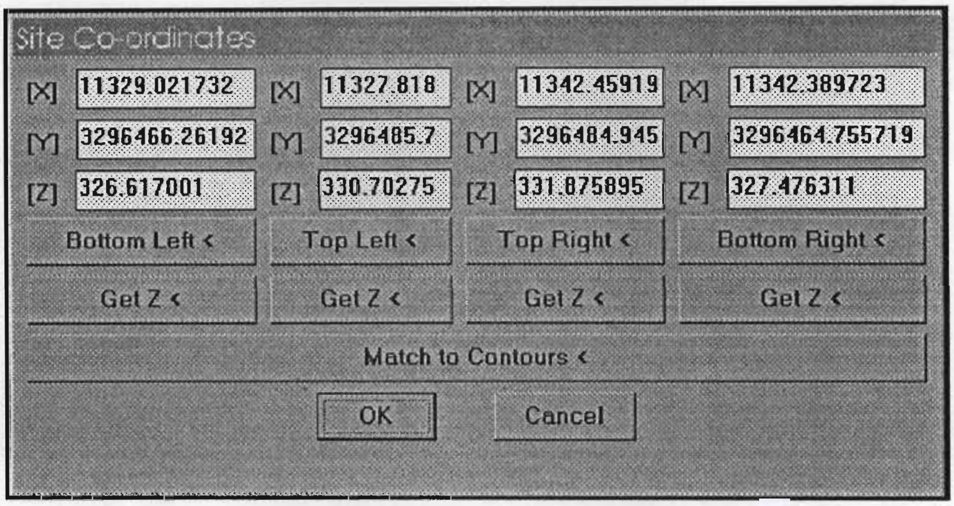


Figure a6.2 Site Co-ordinates Dialogue Box.

This box displays the current positions of the site corner points. Any one point may be changed at any time, either by typing in co-ordinates, or by selecting the appropriate button below particular point and indicating with the mouse on screen. The "Get Z" button allows the user to set a corner height to another object by clicking on it, and "Match to contours" will interpolate corner heights from adjacent contours.

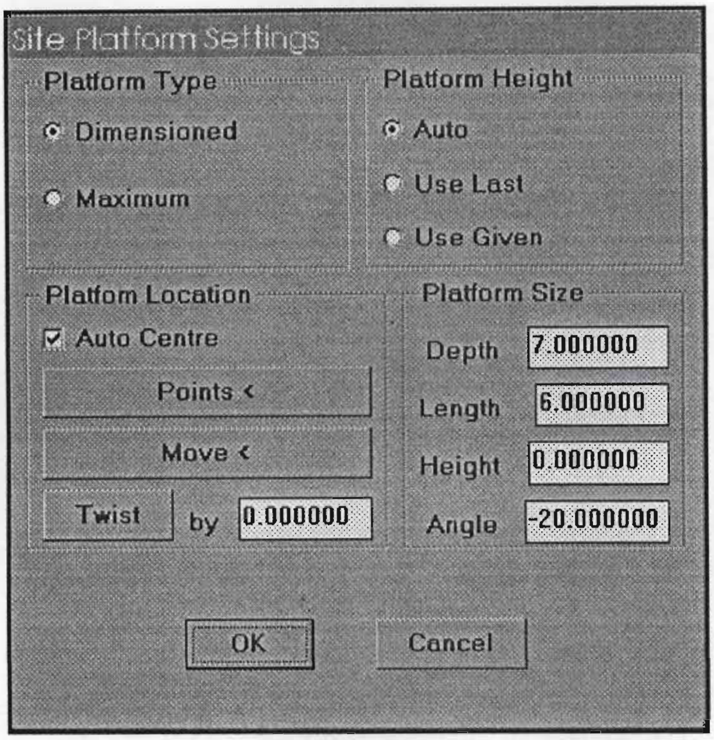


Figure a6.3 Site Platform settings Dialogue Box.

Various platform parameters may be modified. The type may be set to dimensioned or maximum. (See Chapter Twelve for details) The height of the platform can be calculated automatically by inSITE. It can be set to the same as the last platform that was created, so as to create a bench at one height across more than one platform. The height can also be specified by the user. The platform can either be automatically placed by inSITE, or moved to any location with a "drag and drop" function. If the "Points" function is used, it is possible to specify a platform of any four- or three-sided shape. The size of the platform may be specified as long as it is a "Specified" type. The platform angle parameter allows the platform to be rotated to run with the contours.

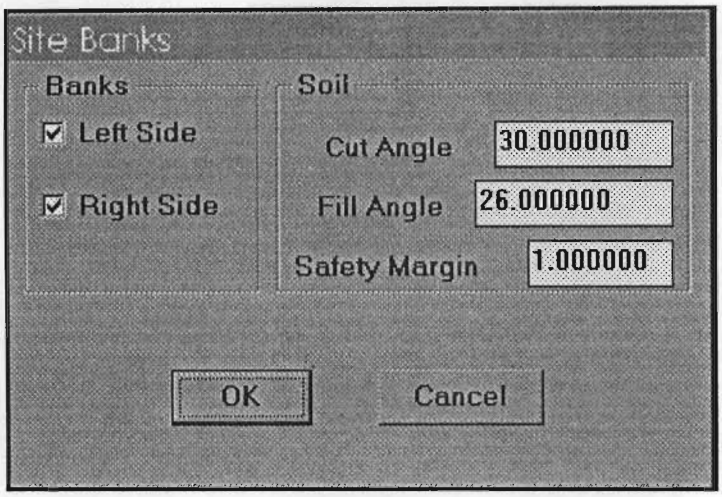


Figure a6.4 Site Banks settings Dialogue Box.

By changing the soil cut and fill angles of repose, various soil conditions may be modelled. The Left and Right Side settings allow the creation of benched platforms that span multiple sites.

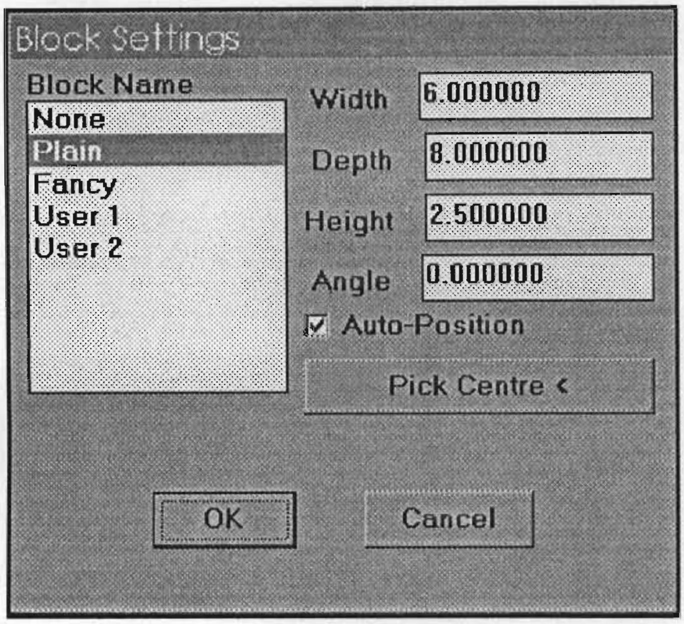
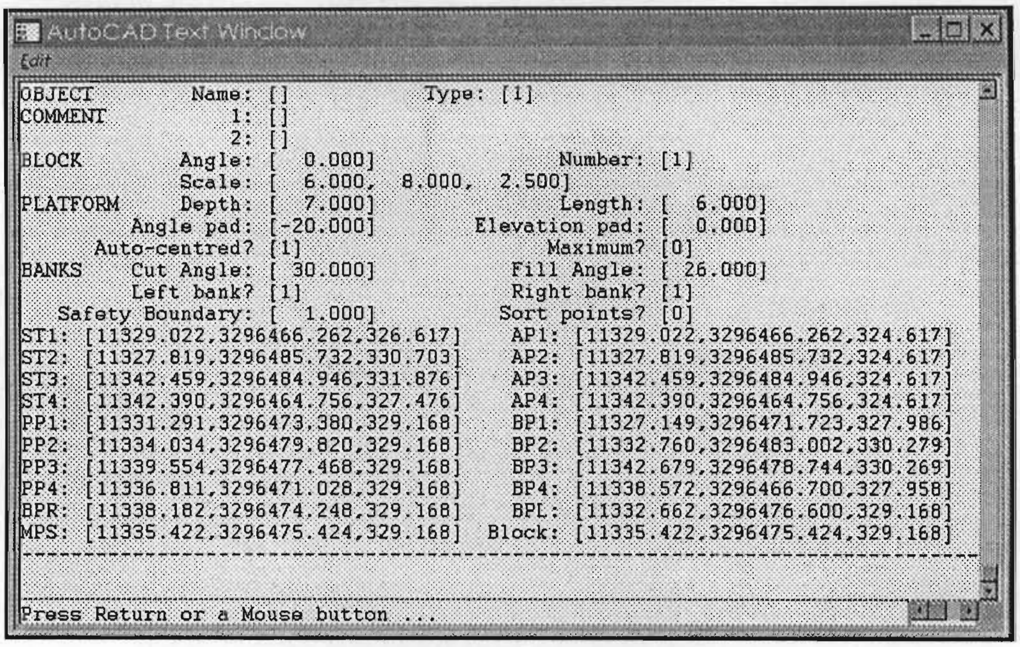


Figure a6.5 Site Building settings Dialogue Box.

The Building Dialogue Box allows selection of the type of top structure to insert on a site. inSITE comes with predefined building types, but it is possible for users to define their own types and have them available as options on the dialogue box menu. The width, depth, and height of the building may be specified. The location of the building is by default in the centre of the platform, which for most small sub-divisions is the only option, but it is possible to drag the location to any point on the sub-division.



```
AutoCAD Text Window
Edit
OBJECT        Name: []             Type: [1]
COMMENT          1: []
                 2: []
BLOCK        Angle: [   0.000]                Number: [1]
             Scale: [   6.000,   8.000,   2.500]
PLATFORM     Depth: [   7.000]                Length: [   6.000]
         Angle pad: [-20.000]          Elevation pad: [   0.000]
      Auto-centred? [1]                     Maximum? [0]
BANKS    Cut Angle: [ 30.000]             Fill Angle: [ 26.000]
        Left bank? [1]                   Right bank? [1]
   Safety Boundary: [   1.000]          Sort points? [0]
ST1: [11329.022,3296466.262,326.617]    AP1: [11329.022,3296466.262,324.617]
ST2: [11327.819,3296485.732,330.703]    AP2: [11327.819,3296485.732,324.617]
ST3: [11342.459,3296484.946,331.876]    AP3: [11342.459,3296484.946,324.617]
ST4: [11342.390,3296464.756,327.476]    AP4: [11342.390,3296464.756,324.617]
PP1: [11331.291,3296473.380,329.168]    BP1: [11327.149,3296471.723,327.986]
PP2: [11334.034,3296479.820,329.168]    BP2: [11332.760,3296483.002,330.279]
PP3: [11339.554,3296477.468,329.168]    BP3: [11342.679,3296478.744,330.269]
PP4: [11336.811,3296471.028,329.168]    BP4: [11338.572,3296466.700,327.958]
BPR: [11338.182,3296474.248,329.168]    BPL: [11332.662,3296476.600,329.168]
MPS: [11335.422,3296475.424,329.168]  Block: [11335.422,3296475.424,329.168]
----------------------------------------------------------------------------

Press Return or a Mouse button ...
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Figure a6.6 Non-graphical information display for a sub-division.

Information is available about any object in the model. This window shows some of the parameters that are stored for a typical object.

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