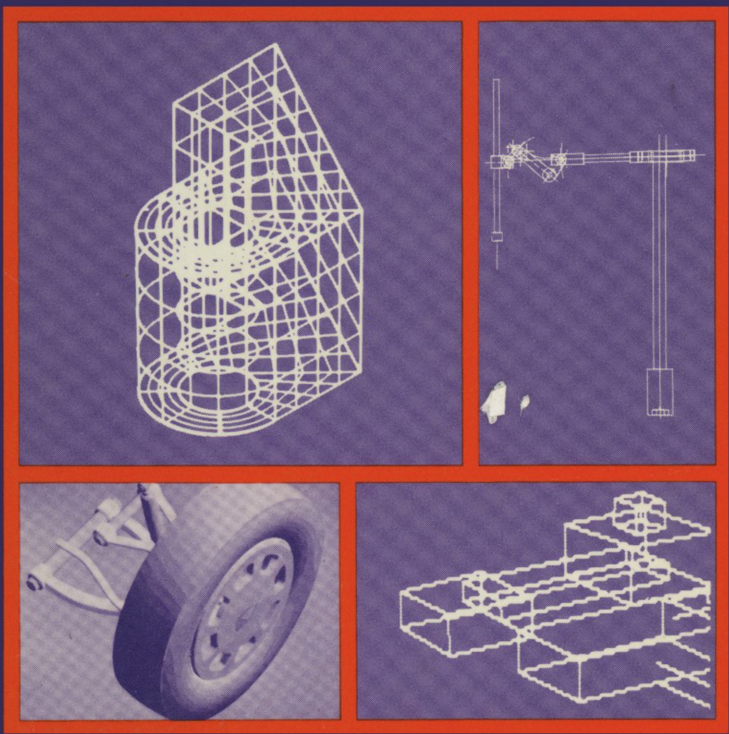
CADCAM IN PRACTICE

A Manager's Guide to Understanding and Using CADCAM



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Kogan Page

Authors' Note

We have throughout used the personal pronouns 'he', 'him' and 'his' to refer to individuals such as 'the designer' or 'the manager'; this does not mean that we unthinkingly assume that all such people are likely to be male, and certainly not that we believe such a state of affairs to be desirable. It merely reflects the fact that we feel the convolutions of usage that are required to produce a text that is totally non-sexist often represent a cure that is worse than the original disease.

A Note on the Figures

Except where otherwise noted in the captions which accompany them, all the figures in the book were produced on one of the CAD systems currently in use in the Department of Engineering and Management Systems at Brunel University. We would like to thank Computervision who helped by making the other figures available to us, or by creating them to our specifications.

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Introduction

Little more than a decade ago computer-aided design and manufacture (CAD/CAM) was a very esoteric field indeed, not one that was of much practical concern to a manager or industrialist unless his business was on the scale of, say, a major automobile manufacturer or in a field of high technology such as aerospace. Like so much else, this situation was revolutionized by the invention of the silicon chip, the arrival of the microprocessor and the dramatic fall in the cost of computer hardware. Today, CAD/CAM has spread down the market, and down the price scale, to the point at which it is both a feasible and an affordable technology for a wide range of small- and medium-sized companies in areas as various as architecture and general engineering, plastic moulding and consumer electronics.

But the explosion – there is no other word for it – in the variety and capabilities of CAD/CAM systems, and their spectacular climb to the top of the hi-tech hit parade, has placed the potential purchaser and user of the new technology in a difficult position. On the one hand he is assured, not least by the manufacturers of CAD/CAM equipment, that a failure to invest in it will leave his company stranded in the industrial Stone Age. But, on the other hand, if he tries to discover exactly what CAD/CAM is all about, and to determine why and how it could be applied to his particular business, he will quickly find himself deluged with a flood of technicalities, swamped by whole alphabets of acronyms and floundering in a morass of competing claims and conflicting advice.

Between the high-level technical works produced by and for those actually engaged in researching and producing CAD/CAM systems (which will tell the average manager rather more than he either wants or needs to know about the technicalities of the subject) and the glossy manufacturers' literature (which may tell him rather less than he would like to know about the relative merits and demerits of the various systems on offer and their relevance to his problems) there is an almost total void. It is that space which this book is designed to fill. Our intention, in short, is to provide a guide, written in plain language, for the prospective user of CAD/CAM who wants to take a careful and considered look at the implications and the options before committing his money, his staff and his business's future prospects.

In the first part of the book we have set out to provide a layman's guide to CAD/CAM – a clear, non-technical summary of its underlying principles and present state of development. This is a prerequisite, since there is, even among practitioners, considerable lack of clarity about the precise meaning of many of the terms employed, the real advantages and disadvantages of different kinds of system and, above all, the way in which the technology is best employed. As some companies which plunged recklessly ahead have already discovered, it is all too easy to be seduced into purchasing a very expensive collection of 'space age' technology, only to find out, too late, that you have bought the wrong kind of system, that you are using it in the wrong way or, in some instances, that you have no genuine use for it at all.

The second half of the book tackles the question of how CAD/CAM is best deployed, how it can fit into a company's existing operations, and how far those operations have to be rethought and reorganized to ensure that the full potential of CAD/CAM is realized. This last point is a vital one. It is fatally easy to assume that CAD/CAM is merely a modern substitute for traditional methods, or a useful adjunct to them, whereas the fact is that, properly used, CAD/CAM requires a radical rethinking of the entire sequence of operations that takes a product from drawing board to market place.

It would, of course, be foolhardy to pretend that any one book can provide a manager with all the information he needs to go out and buy and install a CAD/CAM system to his best advantage. What we have provided, we hope, is a text that will clarify the issues and problems involved so that the reader knows what questions to ask, what difficulties to anticipate and what sort of further information and advice he requires, as well as where it may be obtained.

Chapter 1

CAD – What is it All About?

With the advent of the cheap, mass-produced silicon chip in the early 1970s the rising tide of information technology which had been steadily seeping into industry for the previous 20 years suddenly became a surging flood. One of the consequences of the dramatic growth in the availability and application of computers which followed has been the opening up of a 'generation gap' separating those who ride the fast-moving waves of 'hi-tech' from those whose feet remain planted upon the terra firma of the pre-silicon age.

In the case of CAD/CAM, those who develop, manufacture, sell or apply the technology – the 'insiders', as it were – are by definition on the 'hi-tech' side of this gap; but many of their potential customers are 'outsiders' who find themselves stranded on the other side, baffled and bewildered by unfamiliar ideas and impenetrable jargon. Insiders are full of enthusiasm for the new technology and the visions of the future which it opens up. Among themselves they will talk with relish of the pros and cons of solid modellers, the use of parametrics or the algorithms needed to handle B-spline curves. But they find difficulty in communicating with outsiders, for whom such monologues might as well be conducted in Sanskrit for all the meaning they convey.

Experience suggests that outsiders are seeking answers to questions which, from the insider's point of view, seem almost embarrassingly naive and elementary. First and foremost, they would like to be told 'what CAD/CAM is all about' – and to be told it in plain language. This is not a demand which insiders find easy to fulfil: partly, no doubt, because they have difficulty in imagining what it is like to be ignorant of ideas which they themselves have long taken for granted, and partly, it must be said, because they, like many other 'experts', cherish their monopoly of expertise.

In our opinion, however, the outsiders have a point! Apart from anything else, a grasp of the basic principles involved in CAD/CAM is the indispensable foundation without which no one can be expected to understand the technology or to appreciate the ways in which it might be applied to their problems. We have, therefore, set out to provide in these first two chapters the sort of explanation which outsiders seem to stand most in need of. Essentially, we shall try to explain in the simplest possible terms and in the plainest possible language what CAD/CAM is, what it does and how, in principle at least, it does it.

Those readers who feel confident that they have a firm grasp of these basics may wish to skip ahead to Chapter 3. But we hope that the majority will bear with us even if some of the points that we make seem obvious or simplistic. By first clearing the ground and staking out the territory to be covered we hope to ensure, even at the cost of some impatience on the reader's part, that the detailed exploration which follows will be both easier and more rewarding.

Concepts and Descriptions

Before anything, be it a jack-knife or a jumbo jet, can be designed, let alone manufactured, someone somewhere must have conceived of it – imagined, even if only in very general terms, what it will do, how it will do it, what it will be made of and what it will look like. This initial step, forming the *concept* of an object, can only take place inside a mind and, so far at least, no computer can contribute anything to it.

A concept may be a very simple idea – no more, perhaps, than the realization that an existing component will suffice to meet a new specification if it is made of a heavier gauge material. It may also be an extraordinarily elaborate idea such as, let us say, the space shuttle. A concept may be very general, or extremely precise, dazzlingly original or utterly mundane. The invention of a new concept may be the principal role of a designer, as is, for example, the case with an innovative architect or an engineer who tackles a completely novel problem; but it may also be a step in the design process which is so trivial and routine that the designer is barely conscious of taking it.

But whatever the nature of the concept and however great or small the degree of creativity involved in generating it, it will depend for its existence upon its creator's knowledge and experience of the 'real world'. Any object, however original in form or function, will be 'like' some other existing object or combination of objects and will have some purpose which can be defined in terms of known objects or events. Even if, for example, one set out to invent a *totally* new kind of mousetrap, one would still have to know something of mice – what size they are, where they live, what they eat, perhaps, or whether they are inquisitive.

This kind of knowledge, apparently so simple because it is the stuff of everyday life, is something which computers have yet to master. The existing generation of CAD systems, for instance, have such a limited knowledge of the real world in which people exist that they cannot understand, in the same sense as their users understand, that some of the shapes they deal with represent material objects while others represent space in and around those objects – still less do they have any understanding of the purpose of even the simplest of these objects.

To insiders, this point may seem so obvious as to be scarcely worth making. But experience suggests that it is a source of much misunderstanding, and this is not really surprising. Most people have, after all, got used to coexisting with computers which, in other applications, cope with information that seems far more complex and sophisticated than ideas which any infant can master, such as the fact that boxes are hollow and blocks are solid.

A fairly typical example of the sort of misapprehensions that can exist came to light during a seminar at which senior industrial managers were being familiarized with the potential of CAD/CAM techniques. One of the participants, having watched a CAD terminal being demonstrated in operation, then turned to his mentor with a brisk, business-like instruction. 'Right,' he said, 'tell it to design me a telephone!' To the executive concerned, an 'outsider' in our terms, such a request might well have seemed utterly reasonable – after all, his office probably contained a computer which could deliver annual cash-flow forecasts, predict inventory requirements or provide sales statistics more or less ad lib. But, as an 'insider' knows, today's CAD systems are not only unable to deal with a relatively complex concept such as 'a telephone', they cannot even grapple with those such as 'a lever' or 'a crank' which are the small change of any designer's thinking.

But there is, of course, one kind of concept which a CAD system can 'think about' with a speed and skill which far exceeds that of human beings – a geometrical concept. The machine may be unable to share our understanding of the very 'fuzzy' and amorphous rules which we call 'common sense' or 'experience', but it has an enviably complete grasp of the formal and precise rules which make up constructive and projective geometry. It may know nothing of the hardness or softness of materials, of their texture or weight, of the beauty or otherwise of the objects which the images on the display screen represent or of what purposes they are intended to serve, but it knows a very great deal about tangents, cutting planes and skew surfaces. For this is exactly the kind of knowledge – abstract, mathematically rigorous and rigidly codified – which can be packaged in the form of a computer program.

It is also, of course, the kind of knowledge upon which designers rely in order to perform their principal function – the translation of a concept, which may be vague, ill defined and confused, into a design, a *description* which must be precise, formal and unambiguous.

The Design Process

The design process is the sequence of operations which links a concept, the idea of a thing existing only inside someone's head, to a description, the complete design of that thing which specifies it with sufficient accuracy and in sufficient detail for someone to go away and actually make one of them. It can, roughly speaking, be broken down into the following phases:

Drafting. Creating the various geometrical elements – lines, arcs, surfaces etc – which together make up the graphical description of an object.

Checking and evaluation. At regular intervals the designer will have to 'stand back', as it were, to check that the description that is taking shape actually matches the concept with which he started out and that it is satisfactory in other respects – ie that it meets the necessary specifications and falls within the constraints that have been set, that it can be built, that it will do what is required of it, etc.

Correction and amendment. As and when errors are detected, or the designer decides to try a different solution or to modify some part of the description in order to improve it, it will be necessary to delete and redraft some elements – or, in some cases, to start all over again from scratch.

Analysis. Once the description has reached the stage at which, provisionally at least, the designer is satisfied with it, the chances are that it will have to be analysed in more detail. If the object in question is to form part of some larger mechanism or structure, for example, it may be necessary to produce assembly drawings in order to check that all the components will fit together properly and that they will not interfere with one another. It may also be necessary to calculate the object's resistance to physical or thermal stress, and if this process involves techniques of finite element analysis it may well be the longest and most labour intensive part of the entire process.

Manufacturing information. Finally, it will be necessary to make sure that the description contains all the information – dimensions, tolerances, etc – needed at the manufacturing stage. This may well require the production of additional, supplementary descriptions – alternative views of the object, or cutaway or exploded drawings of an assembly, etc.

Although each of these phases represents a stage in the design process, in the sense that there is a progression from a first stage, through intermediate ones, to a final stage, they do not form a fixed and rigid sequence of steps. Instead, as every designer knows, the process is an iterative or cyclical one in which the different phases intermingle and in which progress occurs only in a very general sense. The flow chart shown in Figure 1 represents the enormously complex and often repetitive process of to-ing and fro-ing between different phases which may underlie the broad forward thrust of the designer's work.

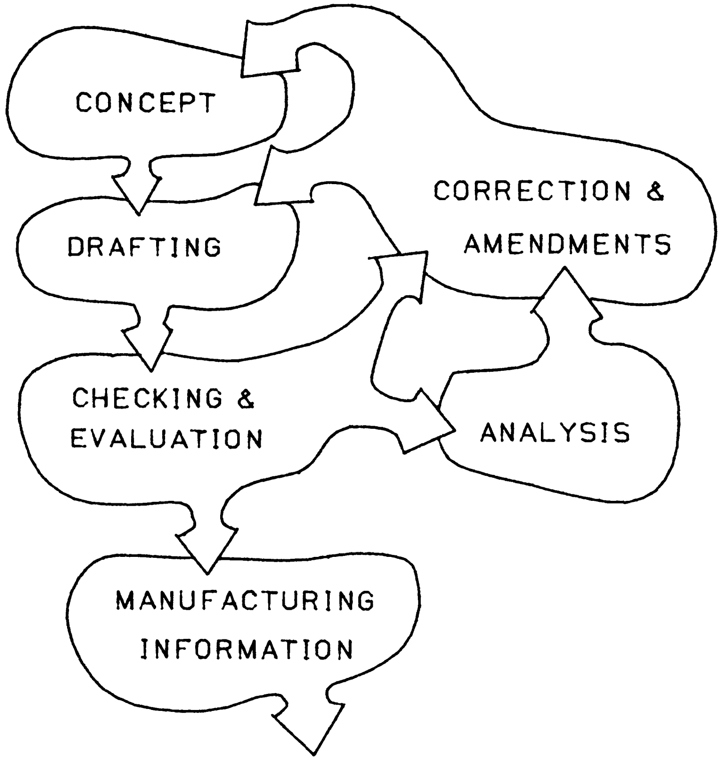

Figure 1. *Although the design process can be broken down into at least six principal phases (and subdivided, if required, into many, many more), it is profoundly misleading to imagine that any piece of design work will follow a linear progression directly from the first phase to the last. On the contrary, as this flow chart shows, the original concept will only become a finished design as a result of a complex series of iterations in the course of which it may well be altered almost out of recognition.*

The Origins of CAD

Computer-aided design, as it is practised today, can be traced back to at least three quite distinct sources, each of which sprang from an attempt to 'computerize' a different part of the design process.

The first of these tributaries, indeed the one which today might be described as the mainstream of CAD, was concerned with automating the creation of graphical information. Those who developed this approach were principally interested in helping the designer during the first three phases – drafting, checking and evaluation, and correction and amendment by devising basic graphics programs that would generate and combine geometrical elements.

Although much of the research that led to today's graphic programs was done in the early 1960s, notably by Dr Patrick Hanratty then working for General Motors Research Laboratories, it did not find much immediate application. At a time when the term computer was still synonymous with one of the vastly expensive giants which we today call a mainframe, designed to perform dozens of functions and service hundreds of users simultaneously, CAD was not a very economical proposition because of the high demands it makes on a machine's processing time and memory capacity. It was not until the arrival of the minicomputer and, subsequently, the microprocessor made it possible to dedicate a single computer to, first, a multi-user CAD system and, later, a single terminal, that graphics programming was able to realize its potential as a general-purpose design tool.

Rather different economic imperatives influenced the development of the second source of today's CAD programming – that concerned with the analysis of designs. The point in this case was that in those industries (like aerospace, say, or semiconductor manufacture) which were extending the frontiers of high technology, the analytical and production techniques which had been developed during the 1950s and 1960s were already stretching human resources to the limit. Only the speed and number-crunching capacity of the computer could make feasible the routine use of, say, finite element analysis. Moreover, since cost considerations were likely to be secondary in these hi-tech areas, the economic constraints on the development of this branch of CAD tended to be relatively unimportant.

In the early days, of course, many of the analytical programs tended to be developed 'in house' to meet the needs of a particular company, and to some extent this is still the case. But a finite element package is now a standard part of most CAD manufacturers' software, and other, more specialized, programming is also beginning to be generally available. The programs designed to simulate the flow of material in a mould (see page 151) or those intended specifically for the design and analysis of pipework are excellent examples of this trend.

The third and final source of CAD development arose out of the effort to use computers to improve and speed up the flow of information from design office to factory floor by building upon the existing numerical control (NC) technology which had been widely adopted by the mid 1960s. This is, of course, the bridge which links CAD to CAM, and we shall be returning to the subject in the next chapter. For the moment, the important point to note is that although many current CAD systems still tend to show clear evidence of having been derived from one or other of these three sources, they all share a common reliance upon the computer's ability to construct and store representations of geometrical *models*.

The model which a graphics program constructs and displays is the CAD equivalent of the traditional, plans-on-paper description which a designer produces with the aid of pencil, paper and drawing board. It is the geometrical model of an object, contained in mathematical form in computer memory, which an analytical program operates upon. And the programs which generate NC data, specifying the path to be followed by a tool, are designed to reproduce in real life the geometrical forms represented by the computer's model.

The nature of a geometrical model is fundamental to virtually all aspects of CAD/CAM and, more than any other factor, is responsible for its advantages over traditional methods. The way in which models are constructed and the uses to which they can be put are, therefore, subjects which we must look at in some detail.

Automated Drafting: Creating a Model

The designer using a CAD system, just like his counterpart sitting at a drawing board, creates graphic descriptions by combining various geometrical elements of which the most basic are lines, arcs and circles.

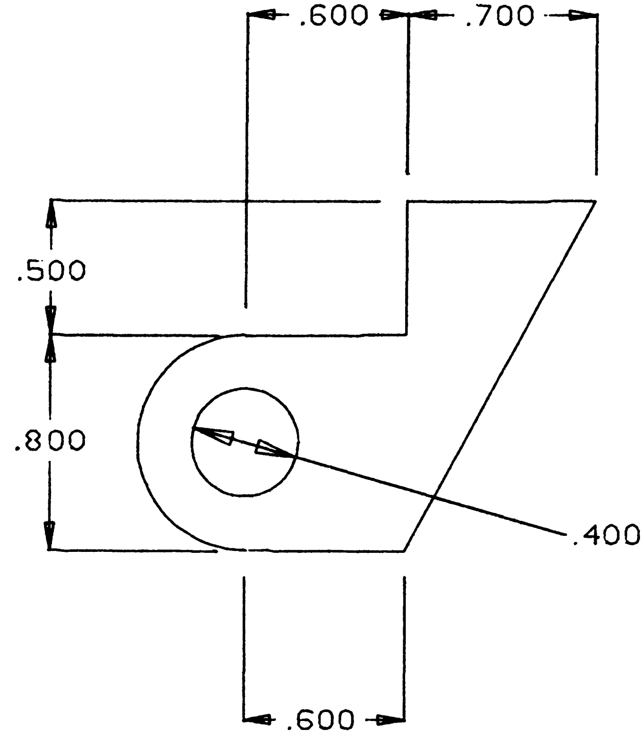

Figure 2. *A simple two-dimensional model made up of seven entitities – five lines, an arc of 180° and a circle. In order to construct this model on a CAD system the designer need only specify the position of each entity and its size – see text for a more detailed account.*

'Drawing' on the display screen, using one of the input/menu arrangements described in Chapter 3, is not very different in principle from drawing on a bit of paper. Consider, for example, the simple, two-dimensional (2-D) model shown in Figure 2. This is made up of seven *entities*: five lines, an arc of 180° and a circle.

In order to construct the model, the designer would start by designating a point, say the centre of the circle, in terms of a set of coordinates along the system's x and y axes. (For convenience, the x axis can be thought of as a horizontal line across the display screen and the y axis as a vertical line from top to bottom of it.) Given the radii of the circle and the arc which is concentric with it, the CAD system can then be instructed to 'draw' these two elements. Further simple instructions will then cause it to generate the five straight lines which complete the model.

Looking at the image of this model as it appears on a display screen or is drawn by a plotter, it is not immediately obvious that it differs in any significant way from the comparable image that might be drawn on a sheet of paper. But if we go on to look at what the system can do with even an elementary design of this kind, it becomes clear that a model, made up of entitites recorded in computer memory has many advantages, from a designer's point of view, over a plan made up of lines on paper.

To start with, once the model has been created it can itself be treated as a single entity. This allows the designer to duplicate and reduplicate it in a variety of ways. Figure 3, for example, was produced by 'mirroring' the original model, while Figure 4 shows how, once the model has been designated as a 'macro', the system can quickly and easily reproduce it in a variety of positions, orientations and combinations.

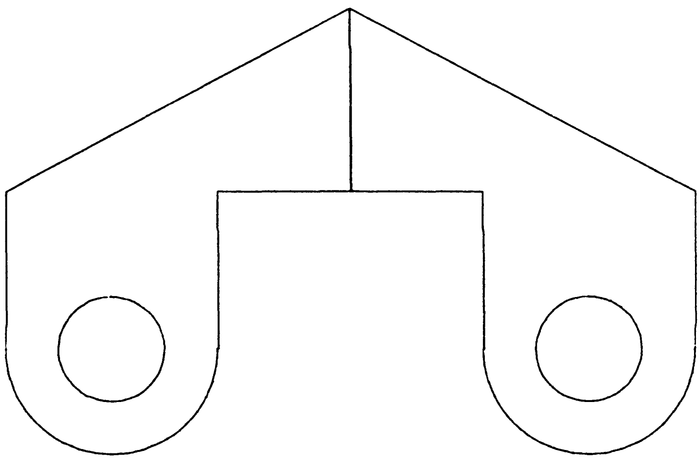

Figure 3. *This image was created by simply instructing the CAD system to 'mirror' the original shape shown in Figure 2, a far simpler process for the designer than laboriously repeating the entire sequence of drafting operations.*

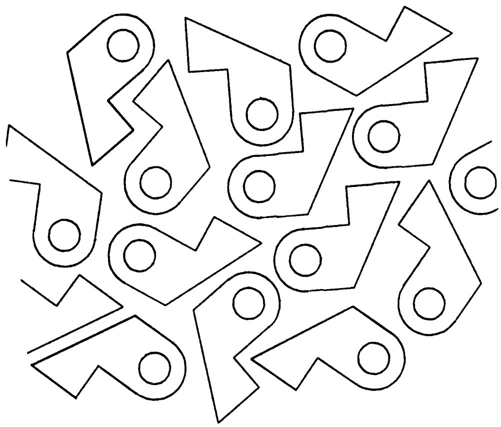

Figure 4. *In order to produce this image the CAD system was first told that the shape shown in Figure 2 was to be treated as a 'macro' and it was then instructed to reproduce that macro in a number of different positions and orientations in order to produce a larger and more complex model.*

Figures 5 and 6 show how new images can be created by 'zooming in' on an area of the model or by using the technique of parametrics (see pages 108-111) to alter the sizes of the component entities while retaining the basic relationships between them.

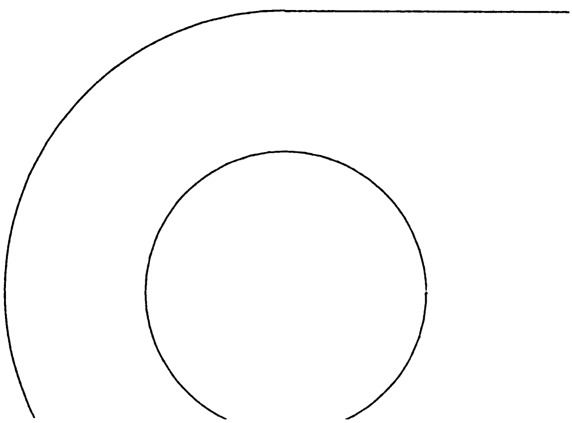

Figure 5. *By zooming in on one small area of an image the designer can inspect it in greater detail or, perhaps, elaborate it by adding details which it would have been impossible to 'draw' clearly while working on the original scale.*

The 'forest' shown in Figure 7 offers a striking example of the way in which parametrics can be applied to a model consisting of just six entities – five lines and a diamond – (itself created from a further four lines) – used over and over again in slightly different forms.

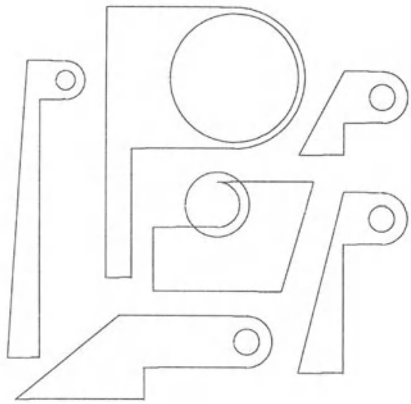

Figure 6. *Each of these images is a variation on the original one shown in Figure 2. Using a CAD system with parametric modelling ability, it is possible to create such variations* ad infinitum *by simply varying the dimensions of the individual entities. In the case of the image in the centre, for example, the radius of the circle was increased so that it was larger than that of the arc while the length of the line joining the bottom of the arc to the line running diagonally across the display space was given a negative value.*

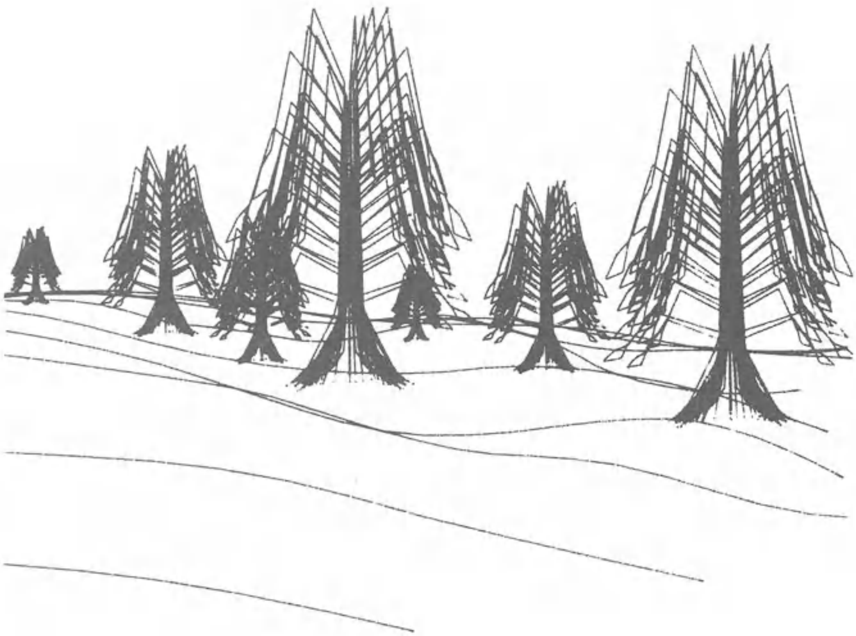

Figure 7. *This 'forest' of trees was created by multiple use of a single macro made up of six entities with constant adjustment of the parameters. The use of such techniques can achieve dramatic economies of time and effort since each repetition of the macro requires the designer to do no more than provide the system with a few elementary instructions.*

These few examples should make it clear that a CAD system can make the initial drafting phase of the design process a great deal easier simply by taking over much of the painstaking work that previously had to be done manually using the traditional paraphernalia of ruler and set square, compasses and dividers. The advantages become even more obvious when correction or redrafting is necessary, for the tedious and messy business of erasing and redrawing lines is replaced by the comparatively painless one of issuing instructions to the system which is capable of drawing, redrawing and re-redrawing without complaint or so much as a trace of a smudge!

Representations and Simulations

But the most significant advantage of a model, as opposed to a plan or set of plans, can be seen when we add a third dimension. For it then becomes clear that, unlike a 2-D plan, which can never be more than a representation of just one aspect (out of the infinity of possible aspects) of an object, the model stored in a CAD system is a *simulation* of that object.

The point may become clearer if we consider a more familiar example of the computer's ability to simulate reality – say a game of video table tennis. Most people will have played such a game at one time or another and will be familiar with the way in which the dot of light, representing the 'ball', 'bounces' backwards and forwards across the screen simulating the behaviour of a real ball. The machine is able to present this illusion of reality because its program contains a set of rules for calculating the motion of the ball (the trajectory along which it should rebound, and with what speed, etc) which are very similar to the rules governing the behaviour of real-life table tennis balls.

In rather the same way, a CAD graphics program contains a set of rules (essentially the rules of projective geometry) which allows it, once it has been given a geometrical definition of an object, to simulate the appearance of that object in a variety of attitudes and according to a wide range of graphical conventions.

To illustrate the point, let us return to the simple 2-D model which we started with in Figure 2 and extend it into a third dimension. We could, for example, project a duplicate of the model a set distance along the z axis (for convenience, again, the z axis can be thought of as a line running back 'into' the display screen from its surface). The result will be two identical models arranged as in Figure 8. (In fact, of course, the models are not stored inside the display unit in graphical form, but in computer memory in mathematical form.)

If we now join up the two models, we will have constructed a single model of a 3-D object, as shown in Figures 9 and 10.

Assuming that the system we are using has 3-D capability, it will now