Visual Descriptors:

A Design Tool for Visual Impact Analysis

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Presented by

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Abstract

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This study is concerned with the development of a practical and effective form of computer-aided analysis of the visual impact of building development in rural areas. Its contribution is fourfold. Firstly, a conceptual model has been developed for the process of seeing in the context of visual impact analysis. Secondly, a mathematical model for a consistent series of visual descriptors has been devised. Thirdly, a suitable design tool has been devised to make use of visual descriptors in visual impact analysis. Fourthly, visual descriptors have actually been implemented as computer software.

The concept of visual impact analysis is defined and placed within the wider context of landscape research. The problems faced by a designer in the context of visual impact analysis are identified and the concept of a 'design tool' is introduced and defined. A number of existing computer software packages, intended or used for visual impact analysis, are reviewed critically. The concept of 'visual descriptors' as measures to be used by designers is introduced and examined critically. A conceptual model is presented for the process of seeing in the context of visual impact analysis. A range of possible measures for use as visual descriptors is presented and developed further into a series of precise definitions. A method of implementing visual descriptors is presented together with formal algorithms for the derivation of eight visual descriptors. A software package incorporating these descriptors is presented and verification and case studies of its use carried out. Visual descriptors, as implemented, are assessed for their effectiveness as a design tool for visual impact analysis.

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Chapter 1

Introduction

Introduction

1.1 Context

This study is concerned with the development of a practical and effective form of computer—aided analysis of visual impact in rural areas. It takes as its starting point the work carried out in the 1970's and early 1980's by Graeme Aylward and Mark Turnbull.

Aylward and Turnbull developed a suite of computer programs concerned with the visibility or potential visibility of buildings and other developments in rural landscape. This suite was devised principally for use in making design decisions with regard to projects involving potentially severe impact upon the visual environment, enabling analyses to be carried out to determine possible sites with regard to minimising intrusion, or to test proposed solutions for intrusiveness. Their intention was to continue the work to cover other aspects of the problem of visual impact analysis. Some initial investigation was carried out into visual descriptors (measures for use in the appraisal of visual impact) and this concept was further developed by Cameron Purdie. The work was, however, cut short by Aylward's untimely death in 1982.

1.2 Scope

The topic of visual impact in the landscape covers a very wide range of issues. Almost any change in land use or management and almost any building or construction work will have some visual impact on the landscape. Even limiting the scope of the study to the investigation of the effects of the addition of features to the landscape, there is still a wealth of possibilities. The features may be wholly man-made such as buildings, electricity pylons, roads or dams. Alternatively, they may be natural but introduced by the hand of man such as forests, arable crops or bodies of water. Limiting the scope still further to wholly man-made objects, many possibilities remain: single isolated structures in landscape, many structures in landscape, one new object among many pre-existing, linear objects, chains of objects and numerous other possibilities.

This study is only able to deal effectively with a small subset of these possibilities. The scope dealt with in this study will be that of single isolated large structures or closely-grouped large structures in rural landscape. This limitation deliberately avoids much potential complexity while still introducing the more general issues to do with structure and landscape. Specifically, the issues are reduced to those which may readily be verified by conventional manual or analytical techniques. The issues involved in generalising the work presented in this study will, however, be examined.

1.3 Issues

This study addresses three principal issues with regard to the visual impact of structures on the rural landscape: the visibility of a new object in landscape; the change to the landscape brought about by the introduction of such an object; and the visual properties of the object in its landscape context.

The visibility of an object is dealt with from two principal standpoints. First is the establishment of the zone of visual influence, the area of the earth's surface over which the object makes some discernible change to the visual environment. The zone of visual influence is analysed not simply for extent but in more detail, determining the characteristics of various parts of that zone. Second is the visibility of an object considered from specific viewpoints by the use of visualisation techniques.

The change to landscape is similarly considered both in zonal terms and in terms of specific viewpoints: first, the comparison of the extents and characteristics of the zones of visual influence of alternative objects in a landscape; second, the comparison of the effects on individual viewpoints.

The visual properties of objects in context are considered by analytical techniques on a zonal basis. These properties are considered from specific viewpoints by the use of visualisation techniques similar to those used to establish visibility but incorporating more sensitive graphical methods.

1.4 Themes

This study has two main themes which colour and, to a degree, bias the direction of the research undertaken.

The first of these themes is the design tool. The study was undertaken by a designer and this is reflected in the concerns underlying it. The concerns of the study and the computer software developed as part of it are specifically aimed at the designer. The intention throughout is to establish methods to improve the control exercised by the designer working on large structures in the rural landscape by providing analytical tools which may be used directly as part of a methodical design process. The design tool is characterised by being more concerned with changing the environment than with explaining or describing it and its analytical components are also biased in this direction.

The second theme is visual simulation. As mentioned above, the study considers visual impact both on a zonal scale and from individual viewpoints. Both of these are, however, handled in exactly the same way by simulated visualisation of the object under consideration in its landscape context. Consistency is thus maintained and verification made possible in all cases. This approach is essentially linked with the concept of the design tool, allowing the designer to know and understand the tools and methods by which he works and to measure automated or semi-automated techniques against those which are known and tried.

1.5 Methodology

This study divides into two main areas of concern: theoretical and practical.

Firstly, the concept of 'visual impact analysis' is examined and defined within the context of landscape research generally and within the closer confines of this study. Aylward and Turnbull's idea of 'visual descriptors' is examined and compared with other systems of measures for landscape analysis. The concept of 'visual descriptors' is taken and developed into a consistent set of visual measures obtainable either directly from the real world or indirectly from an algorithmic model based on a computer simulation of the visual world.

Secondly, the study involves the development of a suite of computer programs. This is complementary to Aylward and Turnbull's suite of programs, and includes semi-automatic data capture and conversion; facilities for landscape visualisation and mapping; visual descriptor derivation and mapping. Where practical, an interactive user interface is adopted.

1.6 Structure

The structure of this thesis is as follows:

Chapter 2 introduces and defines the concept of visual impact analysis. The discipline of visual impact analysis is discussed and placed within the context of other topics of landscape research. The applicability of the computer as an aid to visual impact analysis is discussed.

Chapter 3 examines the problems faced by a designer in the context of visual impact analysis. The types and range of information required by him are identified. The concept of design tool is introduced and defined and a performance specification for the elements of a design tool for visual impact analysis developed.

Chapter 4 examines the problems of modelling human vision adequately to simulate the various elements of visual experience discussed in this thesis.

Chapter 5 is a critical appraisal of a number of existing software packages which are intended for, or have been used for, visual impact analysis.

Chapter 6 examines various measures, which have been devised by various researchers, as an aid to the analysis of the visual environment. These measures are assessed primarily on the basis of their suitability as design tools.

Chapter 7 introduces Aylward and Turnbull's concept of visual descriptors. The various descriptor measures proposed by Aylward and Turnbull are assessed critically for their applicability as design tools and for the practicability of implementing them as mathematical algorithms.

Chapter 8 proposes a physiological and psychophysical model for visual descriptors, which is also suitable for computer simulation. A range of measures, which may be suitable for use as visual descriptors, are presented and discussed.

Chapter 9 discusses alternative means by which the visual model, required for the simulation of visual descriptors, may be implemented. A strategy for implementing such a model is presented, together with the necessary procedures for measuring the required visual phenomena. Formal algorithms for the range of visual descriptors to be implemented are presented.

Chapter 10 presents a software package incorporating visualisation, mapping and visual descriptors.

Chapter 11 describes a series of tests to verify the accuracy of the visual descriptor software on simple test data.

Chapter 12 describes a fuller case study, in which the siting and orientation of Hinkley Point Nuclear Power Station is considered retrospectively. Alternative sites for the Power Station are identified by means of an intervisibility analysis. These alternative sites are compared with the actual site by carrying out an analysis using visual descriptors.

Chapter 13 is an assessment of the performance of visual descriptors as a design tool in the light of the preceding verification and case studies. Visual descriptors are considered both theoretically and as actually implemented in software. The assessment criteria are those established in the earlier chapters of the thesis.

Chapter 2

Visual Impact Analysis

2.1 Introduction to Chapter 2

'Visual impact analysis' is the term used for the assessment of the visual component of the overall change to the environment brought about by development. It is a subset of the wider issue of environmental impact which includes aspects such as pollution of air or water, noise and ecological disruption. Similarly, social and economic changes brought about by development are also excluded.

This chapter examines the need for some means of visual impact analysis, the wider question of the relationship of visual impact analysis to other more established fields of study and, lastly, the applicability of the digital computer as a tool for this purpose.

2.2 The Need for Visual Impact Analysis

Rural landscape is a finite resource, and, particularly in densely populated parts of the world such as Britain, is one under increasing pressure.

Historically, land was seen purely as an economic resource. In comparatively recent years, perhaps the last century and a half, its value has broadened far beyond this. Demand for land comes from many directions. Primary, wealth-producing requirements of agriculture and mineral extraction require land as they always have done. Expanding population and improving standards of housing have combined to increase the pressure on land for building, particularly on the fringes of settlements. Industrial development has also increased its consumption of land, particularly with the trend to relocate factories outside towns and cities. Communications, particularly the increasing motorway and major road network, also take large areas of land. The diminishing rural areas, regarded as 'unspoilt' or as 'undeveloped' have thus acquired a certain scarcity value. Increased mobility of the population and increased leisure time have allowed access to the countryside by many more people than was formerly the case. This, in turn, together with a generally increased awareness of the natural environment, has brought a new pressure to preserve the visual amenity of the landscape.

The preservation of visual amenity is clearly not the responsibility of any one body, but rather falls into the hands of all who are concerned with development in rural areas. These range from government departments and local planning authorities, through those who actually carry out development, to the designers who determine exactly what will be constructed. There are two main issues of control here. The first is that of policy, where those in authority, who are responsible for maintaining planning control, need to ensure the quality of development in areas under their control. The second is that of design, where the designer of a new development needs to have some means of assessing the implications of his design decisions in terms of effects on the surrounding environment. These issues are related and indeed overlap. The questions of design testing to assess compliance with some imposed standard, and testing by the designer as part of his creative process are not, however, identical, nor are their needs exactly identical.

More accessible methods of visual impact analysis are needed both as a means of controlling the visual quality of new development in the rural environment and as a design tool, enabling better or, at least, more informed decisions to be made by the designer. While visual impact analysis is valuable as a tool to prevent or ameliorate the effects of design blunders in the rural landscape, it also has a positive role to play in providing another means by which a designer may have finer control over his work.

2.3 <u>The Place of Visual Impact Analysis in Landscape Research</u>

There is no single, clearly defined discipline of landscape analysis. Instead, the subject falls into a number of other fields of study, some overlapping, others not.

Punter [1982] describes an area of concern which he calls *'landscape aesthetics'*. This area addresses the question of preference, taste and evaluation of the experience of landscape. He finds no coherent field of study or body of expertise, but identifies three principal areas of research into landscape aesthetics. The first of these is that of *'visual perception'*, concerned with the physiological, psychological and behavioural aspects of landscape. The second is *'landscape interpretation'*, concerned with the historical, social and political meaning of landscape. The third is the *'visual quality'* of landscape, concerned with the formal and artistic aspects of landscape. While this division of areas of concern in landscape is open to criticism on the grounds that it emphasises boundaries within a discipline which is itself not contained within clear boundaries, it does provide a convenient means of looking at the influential research covering the whole question of landscape.

Punter's subdivision of the topic provides a convenient means of examining the areas of research which bear most directly upon landscape analysis and on the present study in particular. This section seeks to identify the place of visual impact analysis, as a research paradigm, within this framework.

2.3.1 Visual Perception

The perception of landscape is a field incorporating a wealth of research in the biological and behavioural sciences. The field is subject to a certain degree of confusion in the use of differing terms by different researchers for identical or overlapping concepts, and, indeed, the same term for entirely different things [Wood 1970]. In common with a number of other writers, Rappoport [1977] identifies a series of distinct stages in the process of seeing. He offers a useful terminology for these stages: they are termed by him *'perception'*, *'cognition'* and *'evaluation'*. They represent, respectively, the physical process of seeing, the mental process of recognition and, lastly, the response or reaction of the observer to the scene.

The mechanism and physiology of seeing (Rappoport's *'perception'*) is well researched and documented [Gregory 1977, Caelli 1981, Pirenne 1967, and others]. This area is central to the selection of methods for representing or modelling a scene and the visual stimulus received by an observer in order to predict his response. As the subject matter of this research is intrinsically amenable to objective and rigorous study and measurement, using the same methods as the physical sciences, there is little dispute between authorities regarding the fundamentals of the field.

The study of the way in which the mind interprets visual sensations (Rappoport's *'cognition'*) is largely the province of psychology. This area is very much less open to conventional experimental verification. Different schools of psychology have differing theories regarding this element of perception, and have had varying degrees of influence on other disciplines.

Gestalt theory arose about 1912 with the work of Wertheimer. The theory deals with the phenomenon of perception on a much broader front than simply considering individual properties of observer or visual stimulus. The German word *Gestalt* means 'form' or 'shape' in both the literal and figurative senses. The perception of form was a major preoccupation of the Gestalt school [Koffka 1922, Kohler 1947]. The concept of form was extended by proponents of Gestalt to encompass all aspects of the perceived world, all perception being regarded by them as the recognition of shape or pattern in the visual world. The concepts of differentiation, figure-and-ground and closure all originate in the work of Gestalt psychologists.

Parallel with the Gestalt school was the Behaviourist school, based largely upon the experimental work of Pavlov and those he influenced. Some work on visual stimuli was carried out in this area [Hull 1943]. The basis of the Behaviourist school was the assertion that all perception (indeed, all mental phenomena) can be explained in terms of the mechanisms of the nervous system and of related phenomena such as inherited and conditioned reflex. Although much valuable work was done by the Behaviourists, the underlying concepts of their work have largely been superseded by more recent research.

In recent years, the dominant movements in research into visual perception have been those of the Functionalist school, stemming from the work of Ames and Ittelson [Ittelson 1960] and the much larger field of psychophysics.

The Functionalists deal principally with man as a social being and look at the perception of the visual environment in terms of the needs and personality of the individual. This has been extended into a detailed descriptive technique involving the use of statistical and probabilistic methods. The Functionalist school has been most influential in the social sciences in the study of large populations and the modelling of their response to stimuli. The methods developed by the Functionalist school remain the mainstay of much psychological testing on groups or populations of individuals.

Gibson [1950] developed the psychophysical approach to perception on the basis that clearly defined physical laws may be discovered which link the external physical world and the behavioural response of the individual. This school of study has prospered largely because of the rigour which may be applied to the methods employed in such study. The underlying theory is that visual (and other) stimuli may be examined individually and their effects on the individual identified and measured, allowing perception of the physical world to be studied as a series of elementary experiences. Implicit throughout this work is the principle that a model of an observer's perceptive processes need not be complete in all possible respects in order to obtain meaningful results from experiments or to be used as a predictive tool.

The present study will draw heavily on the psychophysical school of thought, particularly as set out in Gibson [1950] and Stevens [1975], with regard to the modelling and understanding of the human 'seeing' process. The reason for this will become clearer in later chapters, but is basically that it will be necessary to consider individual visual phenomena independently of one another. The Gestalt view of 'seeing', on the other hand, would require a model which would be complete and comprehensive enough to represent vision as a holistic experience.

Rappoport's third stage of seeing, *'evaluation'*, the response to visual stimulus, is comparatively little researched as a psychological paradigm, but more as an area of concern in the social sciences, and then largely in terms of visual preference. Schafer *et al* [1969, 1977, 1973] developed methods of predicting preferences in rural landscape by statistical means by measurement of certain key features of a scene as represented in a photograph. They derived empirical formulae from surveys of preferences expressed for rural scenes depicted in photographs and then used these formulae to predict preferences for photographs of other scenes, obtaining good results within the population originally surveyed. No attempt was made to derive any mechanism for the preferences expressed and, although this work was extended to provide a design tool by Dearinger [1979] and Guldmann [1979], the applicability was severely limited by the method employed to work only with scenes similar to existing ones which could be polled to provide data.

2.3.2 Landscape Interpretation

The interpretation of landscape is a field concerned with the understanding of the landscape. The bulk of research in this area has been carried out by geographers and historians concerned with uncovering the underlying mechanisms which have shaped the landscape as it is found today. The aims are largely to understand the physical environment inhabited by man [Tuan 1971].

The search for meaning, as distinct from straight description, is much more diffuse. Different fields of study tend to look at their own aspects of the visual environment. It is also questionable whether the meaning inherent in any visual phenomenon is directly assessable, distinct from form. Lynch [1964] proposed that meaning could be separated from form as a means of analysing form objectively, but that in order to understand the significance of that analysis, its meaning must also be taken into account. The meaning of 'meaning' is also debatable. Lynch restricts it largely to Gestalt concepts concerning space and form. Other writers such as Ching [1967] apply linguistic connotations to the visual environment. Symbolic aspects of form also have a bearing on this question of meaning [Norberg-Schultz 1963].

Visual analysis certainly cannot be isolated from any meaning to the observer of the visual phenomena being analysed. It is, however, arguable that the measurement of these phenomena may be carried out on a purely physical basis without reference to any possible meaning which might be applied to them. The 'meaning' of visual phenomena is then understood as being the means by which the description of the phenomena is interpreted and used, distinct from the means by which it was derived.

2.3.3 Visual Quality

This area of study is concerned with describing the visual environment in terms of the subjective experience of being in it or of passing through it.

The seminal work in this area was carried out by Lynch [1964], Appleyard [1964] and Cullen [1967]. This work, as some of the first to tackle the post-war changes in the visual environment, has had a considerable influence on the policy and practice of planning design and conservation in urban areas. The methods used to model the visual experience of the surroundings and the criteria used to determine 'good' visual stimuli are based almost entirely on pattern- and scene-making attributes of the environment, with little attention paid to the underlying issues influencing those attributes.

The impact of change on the visual environment transcends purely visual qualities. The historical and geographical identity of the environment is also affected. This aspect is addressed by very few writers concerned with the visual quality of the environment. Rock [1979] and Cullen [1967] touch on this but limit the understanding required to an almost intuitive level covering no more than the superficial form-making aspects.

2.3.4 Conclusion to 2.3

Visual impact analysis does not fit comfortably into any one of the three areas of study in landscape aesthetics identified by Punter.

The primary area of concern and, indeed, the *raison d'être* of visual impact analysis, that of the conservation of the visual environment, clearly falls into Punter's third category, *'visual quality'*. However the techniques involved must entail some form of modelling of human perception and therefore fall into the first category, *'visual perception'*. In order to use the results of any visual impact analysis intelligently and effectively, understanding is required, on the part of the user or designer, of Punter's second category of study, *'landscape interpretation'*.

2.4 The Computer in Visual Impact Analysis

There is a conspicuous lack of generally-accepted methods available to tackle the problem of control of visual impact. Traditionally, for major developments, which are expected to have a major impact on the environment, the public inquiry is used as the organ to determine exactly how the prevailing policy is to be applied or implemented. For lesser developments, the regional planning authorities are entrusted with the task. The conventional tools used to assess visual impact, as distinct from other kinds of impact, are the model, the artist's impression and the photomontage. All of these tools have severe limitations. Models are extremely expensive to build and, for this reason, are generally only made to cover a very small area around the proposed development and are thus unable to be used to judge the effects of a development from more distant vantage points. Models are also very difficult to use to simulate the human viewpoint, and, even with the use of sophisticated devices, such as modelscopes, leave much to be desired in this respect. Photomontages and artists' impressions provide a much higher quality of visual image, potentially indistinguishable from photography. They suffer, however, from the common limitation that high levels of geometrical and optical accuracy are extremely difficult to achieve or verify. It is not an easy problem, given a view of a site which it is proposed to develop, to determine just where in the scene the new construction will appear, and how much of it will be visible. This is particularly the case in rural areas where the scene itself may well be largely devoid of those visual cues which would facilitate the task in an urban or semi-urban scene. Given such a scene presented as a planning submission, it is also, of course, an equally difficult task to determine its veracity. Computer methods, while offering a poorer visual product, are amenable to rigorous mathematical scrutiny of their results under controlled conditions.

There is plainly a place for more rigorous methods of ascertaining the presence and quality of the visual impact of development. There are no 'traditional' drafting techniques for deriving visibility over a large area. There are a few specialised methods for particular applications which have been developed, such as those described by Hebblethwaite [1973] and

Weddle [1973]. Computer-based methods have been developed and used heavily by Aylward and Turnbull [1977, 1978, 1979, 1982] in determining areas of visibility for proposed new developments to a very high level of accuracy, suitable for use as evidence in planning inquiries. Given that a new construction will be visible, that is, it will have some degree of visual impact, some clear method is required to assess the extent and quality of that impact.

While the actual visibility or invisibility of a new piece of development is an absolute measure, valuable both as information for the designer's own use and as an item of data for use by a planning authority, the quality of the impact made by such a development is less clear-cut. While hard data may be determined about the appearance of something, the importance placed on such information is more in the realm of personal judgment. Such information is likely to be of greater use to the designer if it is an evaluator or series of evaluators, enabling him to test the quality of his proposal against his actual intentions.

The quantity and degree of complexity of data involved in attempting any serious visual impact study make the digital computer a particularly useful tool in this context. Provided that the facilities are presented in a way that can be used effectively by the designer and provided that the information yielded by a study is presented in such a way as to inform the design process, the use of computing should enable more effective control to be exercised over visual impact at the design stage.

2.5 Conclusion to Chapter 2

Visual impact analysis provides a means of exercising the level of control, which is increasingly demanded over the visual resources of rural landscape.

No single discipline of landscape analysis exists to meet these needs. However, the areas of overlap with other, more established fields of study, which were discussed earlier, lends a degree of identity to the subject. These elements of overlap will be investigated further in succeeding chapters.

The complexity of the subject justifies the introduction of the computer into this study (and, in a sense, justifies the complexity of the solution offered in the study). Manual methods which have been used in visual analysis will, however, be considered and evaluated in later chapters.

Chapter 3

The Designer's Needs

3.1 Introduction to Chapter 3

This chapter examines the issues of computer-aided visual impact analysis from the point of view of the designer who is intended to benefit from these techniques. The designer in the context of this chapter is limited by the scope of the present study as set out in section 1.2 and is therefore assumed to be someone concerned with resolving the visual impact problems of a large structure in the rural landscape. The needs of the designer are examined in terms of the facilities required to complement and supplement conventional or manual techniques. The quality of user-interface needed in this context is also examined in performance terms.

The range and type of data required by the designer is examined in this chapter. This is used to establish criteria for the assessment of facilities in existing packages (including that of Aylward and Turnbull, described in a later chapter), and similarly to assess the facilities provided by the software developed during this project.

The concept of a 'design tool' is also introduced and defined in this chapter. The essential qualities of such a tool are described and a framework established for the implementation of the software described in later chapters.

3.2 The Range of Information Required by the Designer

3.2.1 Introduction to 3.2

The designer will, in general, only have open to him a small proportion of the range of options that might in principle be available [Weddle 1973, Hebblethwaite 1973, Kent 1986]. The constraints may be those of site, where there is little or no variation possible in the actual location of the structure. They may be those of form, where, for example, in the case of an industrial installation, the configuration of the construction might be fixed. They may be economic constraints, where some theoretically possible solution is not actually financially viable. In any case, the designer's role is to arrive at a solution which, amongst other things, must be visually acceptable. To do this, he must be reasonably certain that he understands the visual implications of his design fully, before construction commences.

In very simplistic terms, in cases where visual intrusion is known to be an issue, the designer's problem is twofold: he must minimise the zone of visual influence and within that zone he must minimise the actual impact. The conventional tools for this job are principally those of the draughtsman. There are proven manual methods for determining the zone of visual influence [Weddle 1973, Hebblethwaite 1973] but these are laborious and often imprecise on complex landforms. Within the zone of visual influence, the designer must rely heavily upon his own experience and judgment. Perspective casting techniques are well known and understood but laborious and error-prone. Photomontage produces a better visual product than straightforward perspective illustration. It is, however, subject to the same considerations regarding accuracy and these are further complicated by the problem of analysing the underlying photograph in order to identify foreground and background relative to the inserted elements in the scene. The cost of photomontage is consequently very high. Model making is often the most accurate conventional method available but is very expensive and, therefore, in practice only available for large projects where the high cost may be justified. All of these techniques address one or both of the questions: 'Where can it be seen from?' and 'What does it look like?'.

3.2.2 Where Can It Be Seen From?

Simple intervisibility analysis, either manual [Tandy 1971, Hebblethwaite 1970, 1973, Weddle 1973] or by computer [Elsner 1971, 1980, Travis 1975], answers the question of where an object (or proposed object) may be seen from. More sophisticated tools are needed to determine more subtle aspects of visibility.

The basic zone of visual influence may be derived by selecting a point of interest (either an object or a potentially intruded-upon viewpoint) and generating radial cross-sections outwards from that point. Potential lines of sight which are cut by the ground surface are easily identified. The zone is the same whether the lines of sight (rays) are looking inwards towards an object or outwards from a viewpoint. (This is the principle of intervisibility.)

The zone of visual influence determines the absolute limit of the area over which an object can be seen, but provides no information about the structure of the pattern of visibility within the zone. Further information, critical to the designer seeking to control visual impact, concerns the interaction of object with skyline. The areas where the object is visible against the sky and, conversely, where it is visible only against the landscape, would give improved understanding of the nature of the zone of visual influence.

All the foregoing items of information are essentially binary in nature, giving only a 'yes'/'no' response. It would, however, be useful to know how much of an object is visible and, similarly, how much is skylined.

Given that the intervisibility analysis may be carried out over several objects or several viewpoints, it is possible to carry out a sieve mapping operation to display the union of the different zones produced. Travis [1975] terms this *'times-seen'* mapping: Aylward and Turnbull [1977] term it *'contours of visibility'*.

Data in this form, typically presented as some form of map, enables the designer to gain a holistic understanding of the nature (but not the detail) of the impact of a proposed object introduced into the landscape.

3.2.3 What Does It Look Like?

The designer is always concerned about the appearance of his design products. Traditionally, visualisation of some form is central to the way in which the designer works, informing both himself and also those to whom he needs to communicate his design ideas [Ching 1979].

Conventional perspective drawing, whether done 'by eye' or set up geometrically, is a main-stay of this visualisation process [Walters and Bromham 1970]. This can be laborious but presents results of known or predictable accuracy. In an urban setting, the accuracy of such a perspective is relatively easy to assure by making use of the surrounding buildings and hard landscape as a frame of reference. In a rural setting, it is much more difficult as there are fewer such objects to use in this way and the visual geometry of the situation is in general both more subtle and more complex.

A key item of information is a perspective view in rural surroundings with known accuracy, allowing the relationship of the new object in the scene to its surroundings and to the landform to be determined.

3.2.4 Conclusion to 3.2

The output from a computer-aided visual impact analysis system needs to include both mapped information and perspective information.

Mapped output is essentially visibility information giving insight into the properties of the whole zone of visual influence on a structural level. This needs to include a variety of measures of visibility in order to provide the richness needed by the designer.

Perspective output is essentially visualisation information giving insight only into the visual properties of an object as seen from a single viewpoint. This needs to be capable of providing either realistic or analytical information in the view.

3.3 Design Tools

It is proposed that the methods and associated computer programs presented in this study should act as 'design tools'. A design tool is characterised by its role in the design process. The designer is principally concerned with the nature of the changes he is making to the environment. While analysis is essential to the process of determining the nature and extent of those changes, the designer is more interested in making changes and measuring their effects than in understanding or explaining changes. A design tool is a tool which assists the designer in this part of his role.

A design tool must, first and foremost, give the designer reliable and accurate information. The nature of the information must also be usable by the designer. He must be able to use such a tool or set of tools to test a design as it develops (against his own criteria in most cases, or against his own interpretation of set conditions to his brief). If the information is to be used in this way to correct a developing design, it must be framed in the terms used by the designer. It must also enable him to determine how the design must be changed to improve it, not simply inform him that some change is necessary.

The concept of 'design tool' is used as a criterion for criticism of existing computer-aided landscape design packages in Chapter 5. It is also central to the discussion of 'visual descriptors' in Chapter 7, forming the principal performance criterion for the development of the software presented in this study.

3.4 The Man-Machine Interface

3.4.1 Introduction to 3.4

This section is concerned with the nature of the designer's interaction with the computer and how it may be made sympathetic to the design process.

Three main areas of concern are identified with regard to the user interface: input, manipulation and output [James 1981]. 'Input' deals with all aspects of data gathering, the actual entry into the machine and any manipulation necessary to convert raw data for use in processing. 'Manipulation' consists of the actual interaction of the designer with his design or its environment through the medium of the computer software. 'Output' is the presentation of textual or graphical information to the user in such a way that it may readily be interpreted by him. 'Manipulation' overlaps both 'input' and 'output' to some extent.

3.4.2 The Input Problem

The accuracy and reliability of the results yielded from any visual impact study depend entirely upon the accuracy with which the digital terrain model (DTM) used represents the landscape in question. Terrain data is available from a number of sources, with varying standards of accuracy. This section is concerned with the mathematical and human-interface problems inherent in this issue.

The most easily accessible and widely-available terrain elevation data in Britain is that published by the Ordnance Survey. This data varies enormously in quality from one part of the country to another. The contours printed on published maps are derived from a large number of surveys carried out at different times by different methods [Harley 1975]. In general, those areas near to large centres of population were surveyed longest ago, often in the first quarter of the century using traditional levelling and chaining techniques, the final published contours being derived manually from the survey information. The most remote rural areas were not contoured accurately (and not at all above 1000 ft) until very recently and the contours in these regions are now most commonly produced directly, using photogrammetric techniques, from aerial photographs. Where maps have been republished with metric contour increments (as distinct from imperial increments with metric labels) the contours are sometimes the result of a genuine resurvey but are often interpolated from the old imperial contour data. The contours are thus very varied in their reliability both in terms of the survey methods used, and in the processes subsequently applied to the data to generate the published contours. The contours on small-scale maps (1:25000 scale and smaller) are also not simple reductions of the 1:10000 contours but are generalised to eliminate distracting detail.

Except where a detailed survey of an area has been carried out for some other purpose, there is no alternative in Britain to the Ordnance Survey other than to carry out one's own survey of the area of interest. The accuracy of this depends largely on the methods employed.

Stereo photogrammetry from aerial photographs yields the most accurate results provided that the terrain is reasonably uncluttered by buildings, trees or other large objects and also provided that sufficient ground-based control information is introduced [Turnbull Jeffrey 1983]. The process is, however, extremely expensive. Ground survey techniques, involving a series of levelling traverses across the area required, also provide good results but involve a great deal of manpower over a considerable period of time. Whatever source of data is used, the stage which counts most in the final reliability of the study is the conversion of the source data into the DTM.

Provided that photogrammetry is used, the grid of spot heights required may be derived directly from the survey photographs with loss of accuracy only encountered when a grid intersection falls directly upon some surface feature, such as a building. Skilled operators are able to make reasonably accurate compensation for this.

Terrestrial survey techniques rarely yield a grid of levels directly. Inaccuracies inherent in the methods used, and perturbations to traverses brought about by surface features, generally result in a ragged grid, which, analytically, is no better than scattered spot elevation data. Contoured data is also effectively scattered spot elevation data. The linking of the points along contour lines yields some additional information but still leaves the problem of extracting a regular grid.

The simplest in concept and, in many ways, the most satisfactory means of generating a DTM is to rely on the user's own insight and intelligence to achieve the conversion to gridded data. Manual interpolation, however, involves the user in a large investment in time both in preparation and in data entry. In the preparation of data, the user has to consider the data carefully and conform it to an overlaid grid using his own knowledge and experience of landscape to make intelligent decisions. The prepared data has then to be entered into the computer and checked both for gross errors in entry and possible errors in interpolation. Despite these limitations the method does produce good results and has been used regularly for small-scale studies.

Automatic or semi-automatic data capture requires the use of some input device which can deal directly with the form in which the topographic data is available. This may be some form of specialised device such as that used for laser-scanning of contour data, or a more generalised device such as a digitising tablet. The software part of the conversion must be able to relate the input data back to a probable generating surface and thence to a gridded interpolation of that surface [McCullagh 1981].

This conversion is, of necessity, a multi-stage process. The first stage is the input of data from the source form. This will generally need to be some form of sampling process as the source data is usually either in the form of contours, which theoretically contain an uncountably infinite number of data points, or as a scattering of a finite number of spot elevations. This data may be sampled either as a stream of isolated points or as a linked stream of points with the order of input being as important as the points themselves. While routine, this stage is important as the quality of all succeeding stages is dependent on the quality of information captured.

There are a number of methods which have been developed for conversion of raw data to an intermediate model. Most involve some form of triangulation [Yoeli 1977], linking the raw data points by plane triangles spanning across the required grid intersections and allowing a simple planar interpolation to be carried out. These triangles are either generated on an *ad hoc* basis in order to encompass each grid intersection as it is encountered or as a complete tessellation spanning the entire data set. In addition, such a tessellation may either be constructed randomly or may be optimised in some way, commonly using a Delaunay (Dirichlet) triangulation method [Rhynsburger 1973, McCullagh and Ross 1980]. Supplementary information describing folds, ridges and valleys, known as 'break lines', may also be included to conform the folds in the triangulation to known folds in the terrain. Methods incorporating more thorough optimisation yield better results but at the expense of higher demands on computer processing time and memory or filestore capacity [McCullagh 1983].

3.4.3 <u>The Manipulation Problem</u>

The issue of 'manipulation' is not as clear-cut as 'input' or 'output'. There is inevitably a degree of overlap between 'manipulation' and both 'input' and 'output': any act of manipulation must entail some element of input or output or both in order to be carried out. The actual extent of this overlap is less clear and somewhat arbitrary.

Manipulation is essentially an exploratory activity as a follow-up to an analytical activity. Given the results of a visibility analysis or a visualisation, the designer may wish to act either to correct a shortcoming which has become apparent in the design or to experiment with the design in order to understand the visual consequences. In any case, the manipulation involves the use of input facilities to make alterations to some part or parts of the data and the use of output facilities to see the effects of those changes.

Two criteria are required for effective manipulation of data. The first of these criteria has been mentioned in the previous section: the user interface must be sympathetic both to the user and to the problem in hand. The essential difference between input and this element of manipulation is the difference between data entry and data editing. While the activities are related, they differ in emphasis. The primary criterion for data entry, especially where large volumes of data are concerned, is that of efficiency. Editing, on the other hand, requires precision as its primary criterion. The user interface must present the data being manipulated to the user in his own terms (generally in drafting terms in the context of this study). It must also allow manipulation in those same terms, with the necessary facilities for identification, selection, alteration and monitoring of change in the data. These features are not necessarily available or required in a straightforward data entry tool.

The second criterion is that the user interface must allow accurate identification of change in the output following a change in the input data. This is a condition over and above that of simply displaying the visual properties of the data, and provides the feedback for further manipulation.

In order for these input and output elements to operate together effectively, it is desirable that the whole system operate rapidly enough to provide the user with a reasonably short design cycle.

3.4.4 The Output Problem

The two areas of concern described above: 'Where can it be seen from?' and 'What does it look like?' require two distinct types of output. The former question requires 2-dimensional output, the latter 3-dimensional.

The 2-dimensional output from a visibility analysis will typically consist of a grid of values corresponding to the DTM used. These may, on occasion, be useful in a numerical tabular form, but a graphical output such as plotted symbols, continuous or stepped tones, or even contour lines are more likely to be useful. Data of this type defines some measure of visibility with specific points on the ground having specific values. Such data is really only useful if it can be related back to the input data, which must, therefore, also be capable of being output using the same medium. It should also be possible to relate the results of a visibility analysis directly to a topographic map of the area being studied.

The 3-dimensional output from a visualisation will consist of a perspective view of the scene in question. This must be able to depict accurately both the DTM and the object or objects being studied for visual impact. It should also be possible to overlay such a perspective information directly on a photograph of the site being studied.

In addition to the above requirements, the 2- and 3-dimensional output must be capable of being used together. Perspective and planimetric information complement each other in that each allows the other to be understood more fully.

3.4.5 Conclusion to 3.4

The key issues in the man-machine interface of a design tool (or set of design tools) relate to the usability of the system as a whole. The designer must be able to operate using concepts familiar to him. He must also always be able to relate the results output by the system to possible changes to be made to the design and input back into the system. The recognition of two distinct types of output, 2- and 3-dimensional, also places a demand on the system that two potentially incompatible forms of output be usable together and, possibly, simultaneously.

3.5 Conclusion to Chapter 3

The designer's principal need is for responsiveness in any tools to be added to the battery of 'conventional' or 'traditional' tools normally available. While powerful design tools are desirable, their full benefit may be lost without an adequately sympathetic and flexible user interface at both input and output stages.

Where a number of design stages or an iterative process are anticipated, editing and feedback become critical and it becomes essential that effective communication can exist between the designer and his design tools in both the input and output directions.

Chapter 4

Modelling Human Vision

4.1 Introduction to Chapter 4

Visual impact analysis seeks to predict the key visual properties of a proposed development in a landscape. In order to do this, it is necessary to simulate human vision to a reasonable degree of accuracy or, at least to achieve a known relationship to human vision. This chapter examines the behaviour and limitations of human vision in this context and establishes the level of precision of simulated human vision which must be achieved in order to carry out an effective visual impact analysis.

4.2 The Geometry of Human Vision

The optical properties of the human eye are well known [Gregory 1969] but are complicated by the physical geometry and the physiology of the structures involved. Although the eye may be likened to a camera, the differences are many and fundamental. The curvature of the retina as compared with the flatness of a camera's film plane is the most obvious of these differences.

A photograph has quite simple geometry involving (with ideal lens characteristics) only linear transformations, which make it rapid to compute. The conventional draughtsman's perspective-casting method and the standard methods of perspective projection used in computer graphics [Newman and Sproull 1979, Foley and Van Dam 1982] imitate this geometry. The human eye has two lenses (cornea and lens proper), neither of which is close to ideal and which project the image onto the drastically curved surface of the retina. Guldmann [1980] recognised this difference between the properties of camera (or perspective) and eye as a potential problem, and considered the possibility of projecting onto a spherical surface, imitating the spherical surface of the retina, but concluded that more investigation was needed into this issue. The illusion of reality of a photograph, however, lies not in its match to the image cast on the retina of the eye but in its match to the scene which it represents. It is possible to place a photographic transparency of a scene in such a position that an eye, positioned where the perspective centre of the camera was, will see the photograph exactly mapped onto the real scene it represents [Walters and Bromham 1970]. Any measurements of angle or solid angle which may be made in reality may be reproduced exactly by measurement from a photograph by applying the appropriate inverse to the perspective transformation.

The perspective projection (and photography) preserves the straightness of lines in the scene but distorts angles, shapes and, particularly, areas towards the edges of the picture. Radial (S_R) and circumferential (S_c) scale factors at an angle ϕ from the principal point (centre point of the picture plane) of a perspective are given by the following formulae:

$$S_R = \sec^2 \phi$$

$$S_c = \sec \phi$$

This distortion somewhat complicates the process of measurement from a perspective drawing. The appropriate transfer functions may, however, be introduced as weightings applied to piecewise linear measurement operations [Petrie 1984]

If the photograph or its computer-generated simulacrum is regarded as being able to represent the stimulus arriving at the human eye, the complications of the internal geometry of the eye may be neglected as these are not apparent to the observer, nor are they directly observable in a living eye.

4.3 The Resolution of Human Vision

The pure geometrical model described above has arbitrary acuity. In principle all detail, however small, may be represented accurately. The human eye, however, has a finite acuity and resolution [Gregory 1969, Pirenne 1967, 1970] with the nominal 'normal' (20/20) vision allowing discrimination of detail down to about one minute of arc. This figure, however, only applies to the centre of the field of vision, with resolution diminishing rapidly away from the centre. This diminution is offset in practice by the movement of the eye, taking the high-resolution central zone to all parts of the field of view. Without moving the head, the field of view is limited by the geometry of the skull and by the limits of travel of the optical muscles, all but the left and right extremities being accessible to the highest available resolution.

The extreme visual field is about:	± 100° horizontally
	+ 60° vertically
	- 75° vertically.

[Pirenne 1967].

The limited resolution of the eye-brain system and the finite field of view make possible raster representations, which also have inherent resolution limitations.

On the basis of the above limiting angles and the normal maximum acuity of 1 arc-minute in the centre of the retina [Gregory 1973] it is clear that a raster image need never exceed 12000 × 8100 pixels: all sub-pixel detail would be too fine to be worth representing. A very much lower resolution is, however, almost certainly acceptable: rasters of 512 × 512 and 1024 × 1024 pixels have been used to produce very realistic images; a colour television picture in the UK is represented by only about 400 × 300 pixel-equivalents.

The field of vision actually represented in an image may usefully be limited to considerably less than the theoretical maximum, as any object under consideration in the context of visual impact analysis occupies only a very small part of the observer's visual field. The resolution may well also be diminished considerably at the expense of simulated acuity but to the gain of much reduced processing times.

4.4 Colour Vision

The colour vision of the human eye has been researched thoroughly [Gregory 1969]. The eye has receptors whose peak response is for red, green and blue light respectively. The frequency-response curves for these receptors are basically bell-shaped but obey no simple function. Similarly the function connecting illumination with response is non-linear, nor are the illumination-response functions for the three receptors linear with each other (hence phenomena such as Purkinje effect [Gregory 1969]). The behaviour of these three types of receptor is approximated by the use of three receptors, peaking on red, green and blue in the vidicons of video cameras and in the three colours of phosphor used in the screens of colour televisions and monitors. Photographic film similarly uses three layers of emulsion whose colour responses peak on red, green and blue. Neither television nor photography reproduce colours particularly well but, in practice, the eye accepts a high degree of tolerance to errors in the representation of colour and in the representation of the receptor response-curves [Gregory 1969].

4.5 Conclusion to Chapter 4

Conventional perspective projection will be used in all visual simulation work in this project. Measurements will be taken from images using appropriate scaling functions.

The use of rasterised images will be discussed in more detail in Chapter 9. There seems no reason, however, to discount the use of raster representations summarily on the basis of their low resolution.

Colour will also be discussed more fully in Chapter 9. On the basis of the visual acceptability of conventional RGB-based colour representation, either RGB, or systems which are linearly related to RGB [Foley and van Dam 1982], will be used throughout this study.

Chapter 5

Existing Software Packages for Visual Impact Analysis

Existing Software Packages for Visual Impact Analysis

5.1 Introduction to Chapter 5

A model for the process of analysis of actual or potential visual impact has been proposed in the preceding chapters. A number of design tools have been identified for use in this context. In this chapter, three existing software packages will be examined for their applicability as sets of design tools for visual impact analysis.

Landscape and Landscape Planning are disciplines which have not, to date, attracted much attention from software vendors [Lansdown 1987]. Of those few software systems which have been developed for landscape applications, fewer still are intended specifically for the assessment of visual impact. This chapter will examine four packages which have been devised specifically for, or used for, visual impact analysis and whose use has been published. Landscape design or drafting packages are specifically excluded from the reviews in this chapter.

5.2 Available Software Packages

The packages considered in this chapter are: GROUSE, produced by EdCAAD for William Gillespie and Partners; VIEWIT and Perspective Plot, produced by and for the US Forest Service; the *Landschapsbeeld* geographical information system, developed for and by *Stichting voor Bodemkartering* (Netherlands Soil Survey Institute); and the VIEW suite, developed by Mark Turnbull at USC, at W J Cairns and Partners, and then at Turnbull Jeffrey Partnership. The facilities offered by each package will be examined with reference to the criteria discussed in previous chapters.

5.2.1 GROUSE

GROUSE has been developed since 1981 by EdCAAD for William Gillespie and Partners [Swinson and Evans 1982, Evans 1984]. It was developed because Gillespie's could find no other package which met their in-house office needs, and which was also capable of being run on a system affordable by the practice [Evans 1984].

GROUSE is principally a ground-modelling system. Topographic data is entered via a digitizing tablet. Elevation data is entered in the form of contours and spot-heights. Other surface features, such as buildings, roads, trees, walls and fences may also be entered. The elevation data is interpolated into a square-grid DTM, which is used for all subsequent processing.

GROUSE provides three modes of graphical output: plan, section and perspective. The plan view displays the DTM as contours and optionally displays any surface features in plan. Sections may display more than one ground surface in order to compare proposed with existing landforms, or to compare alternative options for a scheme. The section may also optionally display elevations of surface features lying along the section line. Perspectives display the DTM surface as a warped mesh. Perspectives of surface features are drawn separately from the DTM using a different program and then combined on the drawing board.

GROUSE also provides earthworks calculation facilities. Cut-and-fill volume and cartage measurements are available, calculated on the basis of the volumetric difference between two DTMs. These facilities are, however, only of real use in the context of earthworks pricing or valuation.

For visual impact analysis, GROUSE is effectively limited to visualisation and sight-line analysis. Perspectives produced by GROUSE have been used effectively as a basis for photomontaging, but, as mentioned above, DTM and surface features may not be displayed together directly. Sight-line analysis, to determine intervisibility between two specific points, may be carried out using sections drawn by GROUSE. No intervisibility mapping is, however, provided.

5.2.2 VIEWIT and Perspective Plot

The use of computer techniques by the US Forest Service is part of a response to a statutory requirement for the Service to protect scientific, scenic and historical resources within its lands [Ross and Evans 1984]. The issue of visual impact is seen by the Forest Service as part of Visual Resource Management, a term used by the American Society of Landscape Architects (ASLA) [ASLA 1978]. The aim is to harmonise commercial, environmental and scenic aspects of land management.

VIEWIT is a visual analysis tool based upon the principle of intervisibility [Travis *et al* 1975]. This program is capable of plotting lineprinter maps of simple visibility from a given viewpoint, maps of frequency of visibility ('times seen') from a series of viewpoints and is also capable of weighting the results according to importance of viewpoint, orientation or steepness of terrain or distance from viewer [Araki 1980].

Perspective Plot [Ross and Evans 1984] is a perspective-drawing program, presenting a view of terrain as a warped mesh and also incorporating tree symbols, to give an impression of the effects of felling or re-stocking projects.

The two programs are independent but are seen as complementary [Tlusty 1980]. The use of these two, very different, programs in combination provides the user with a very powerful analytical tool. VIEWIT may be used to carry out studies over large areas, to assess the overall visual effects of a given proposal, to test alternative proposals or to identify critical areas. The actual visual effects may be examined by using Perspective Plot to simulate the present and changed views. VIEWIT and Perspective Plot also have a more subtle inter-relationship. The intervisibility patterns produced by VIEWIT may be referred to as a means of determining whether a given perspective view is representative of the view from a wide area or unique to a specific locality. Conversely, Perspective Plot may be used to draw a representative view, which is shown by VIEWIT to be typical of the views from a wide area.

5.2.3 *Landschapsbeeld*

Landschapsbeeld is a geographical information system developed at the Netherlands Soil Survey Institute (*Stichting voor Bodemkartering*) [Burrough and de Veer 1979, Buitenhuis and van Pruissen 1981]. It is primarily concerned with landscape planning and land management reform issues, and provides sophisticated database enquiry facilities combined with a comprehensive plan and map drawing capability. The system is unusual in that no DTM is used: all information is stored as discrete vectors and polygons. Surface features such as tree-belts, roads, canals and buildings are modelled in plan, with an associated height value where appropriate. Visual analysis is included as an application using the underlying information system. The topic of primary interest, in the context of the Dutch landscape, is the screening of high buildings by tree belts; no other screening being available on a flat landform. As the information held in the database for the information system contains height data, it is able to provide information for the construction of viewsheds for proposed buildings or to investigate ways in which the viewsheds of existing buildings may be contained (zones of visual influence of up to 10km radius are not uncommon in the Netherlands).

For analysis of a zone of visual influence, the output is plotted as a pattern of rays radiating outwards from the building (or other feature) in question (usually at 5° intervals). The lengths of the rays define the viewshed. In a basically flat landscape, it is possible to allow for relief by simply detecting intersections between the view rays and vector contour data, without seriously compromising performance.

Landschapsbeeld is unique among the packages considered in this study in not modelling the ground surface as a DTM and, also, in modelling other surface features both as geographical features and as obstructions to visibility. Being a strictly 2-dimensional package, it is only capable of presenting a planimetric view of the visual performance of a building. In Britain, the primary problem of visibility is the correct siting of the building relative to potential viewpoints and to the underlying landform; ameliorative measures such as on- or off-site tree-planting are only regarded as a secondary approach to the problem. In the Netherlands, the landform has generally little effect on visibility and existing or new tree-planting forms the principal line of attack on visibility problems. *Landschapsbeeld's* approach to intervisibility analysis is strongly conditioned by these unusual visual problems encountered in the Netherlands. These priorities would, of course, be applicable in certain parts of Britain, such as East Anglia or Romney Marsh, but are probably best considered as supplementary and secondary to a primary consideration of the visual interaction of building with landform.

5.2.4 The VIEW Suite

The VIEW suite was developed over a number of years. Individual programs in the suite were developed in response to specific projects or design requirements [Aylward and Turnbull 1977, Turnbull Jeffrey Partnership 1983]. The suite is essentially limited to the testing of visibility under a range of conditions, with a view to selecting sites for development and devising strategies to minimise visual impact. The programs which comprise the suite are described in the following sections of this chapter.

5.2.4.1 VIEW1

VIEW1 is the most basic program of the suite [Aylward and Turnbull 1977]. It is concerned only with intervisibility on a square-grid DTM.

The program uses the grid of the DTM to generate grids of measures of visibility. This may be carried out in a number of ways. The most basic of these ways is to generate a map of all points visible from a given viewpoint, giving a simple viewshed. This technique may also be extended to cover several viewpoints, generating a composite map of all areas which may be seen from one or more viewpoints, useful, for example, in investigating whether a site may be seen from a length of road. This information may be supplemented by indicating from how many positions each visible point is seen. In this instance a map of values, termed *'contours of visibility'* by Aylward and Turnbull, *'times-seen'* maps or *'visibility polls'* by other authors, is produced, with each value representing a poll of the viewpoints indicating how many can actually 'see' the point in question.

In addition to investigating the visible portions of the terrain, VIEW1 allows the invisible portions to be studied. The measure used for this is *'dead ground'* and is defined as being the height of structure which could be erected at a given point without being seen from the viewpoint. Like the visibility mapping, dead ground may be calculated either for a single viewpoint or for a series of viewpoints.

The input to VIEW1 is in the form of files containing DTM information together with files of run-specific and project-specific control parameters. The output from VIEW1 is available in a number of forms. Tables of values and lineprinter maps may be produced directly by the program. All maps may also be produced as files of values for input to other programs.

While providing rapid output, the lineprinter map is a severely limited form of presentation. Even with overlaying, the range of distinguishable symbols available is limited. This is compounded by the difference between the character- and line-pitches found on the majority of printers and by the limited carriage width.

5.2.4.2 <u>VIEW2</u>

VIEW2 is similar in scope to VIEW1 but also takes surface features into account. The surface features on a landscape are treated simply as a grid of numerical feature codes overlaid on the spot elevation model. Associated with each of these feature codes is a height which represents the height of the feature above the surrounding terrain. In this way a crude allowance for the 'thickness' of vegetation or groups of buildings may be made and the program is thereby able to adjust the results of the visibility analysis accordingly. Clearly, this technique is limited. No fine detail on the terrain is taken into account and any major features imposed on the terrain, such as electricity pylons, will not be represented in exactly the correct position but will be 'rounded' to the nearest grid intersection.

The output from VIEW2 is similar to that from VIEW1 and also consists of optional lineprinter maps or files of values.

5.2.4.3 VIEW3

VIEW3 carries out an analysis complementary to the analysis of surface feature and vegetation cover carried out by VIEW2. VIEW3 determines what height of barrier is required at what location or locations to screen a visible object from view from one or more viewpoints. VIEW3 uses the same methods as VIEW2 to represent the terrain and surface features. Because of this limitation, the results are somewhat lacking in refinement as no advantage can be made of small-scale perturbations in the terrain or of small surface features. However, it does allow a general strategy to be devised rapidly for screening a major development such as a road.

The format of the output from VIEW3 is similar to that of VIEW1 and VIEW2.

5.2.4.4 SYMCON

SYMCON is concerned with the graphical treatment of the output produced by other programs in the suite. SYMCON produces plotted output of the visibility and dead-ground information produced by VIEW1, VIEW2 and VIEW3. The data from the VIEW programs is plotted as a grid of blocks of varying density of hatching. This may also be superimposed on a contour map derived from the DTM. Other features such as the grid used by the

DTM, index numbers and titling may also be included. SYMCON is also able to carry out a simple direction-of-slope analysis, plotting the direction of fall of the terrain, rounded to 45° increments.

SYMCON is, however, unable to represent non-grid features such as roads or rivers. The representation of existing topographical features is, therefore, impossible without resorting to rasterisation of vector data to the underlying DTM grid.

5.2.4.5 PERSPX

PERSPX is a simple perspective-drawing program for use in combination with the other programs in the VIEW suite. PERSPX allows plotting of the DTM model as a warped mesh. It incorporates hidden line elimination but only allows viewpoints well outside the boundaries of the DTM grid in both the X and Y directions.

PERSPX is severely limited by the above constraints. It is impossible to use the program to generate human-eye views of scenes within the compass of the DTM. Also, no surface features, existing or proposed, may be included in a perspective view.

5.2.4.6 Other Programs in the VIEW Suite

In addition to the above programs, the VIEW suite also includes a program for the calculation of cut-and-fill volumes and cartage distances.

The VIEW suite also provides supplementary programs for the input, verification and editing of data. A number of tools have also been developed for the comparison and manipulation of sets of output data.

The VIEW suite, as it stood at the beginning of this project, incorporated no interactive, graphical means of data entry of the type described in Chapter 3. Instead, programs were provided for the direct keyboard entry of the required DTM grid and for the verification and editing of such gridded data.

It is often useful to combine or compare the results of two or more intervisibility analyses. The supplementary programs VCADD and VDIFF are, therefore, provided to take output files from the VIEW programs and to reprocess these to generate cumulative or difference maps. The output is optionally to the lineprinter or in the form of files, as is the case with the VIEW programs themselves.

5.2.4.7 Conclusion to 5.2.4

The VIEW suite is principally an intervisibility package. It provides a range of very sophisticated intervisibility measures, more comprehensive than, for example, VIEWIT. Effective input and output facilities, such as those discussed in Chapter 3, are, however, lacking. In particular, PERSPX provides no means of generating perspective views which allow intervisibility data to be interpreted. Also, neither SYMCON nor PERSPX provide any means of representing geographical features as a frame of reference to the study being undertaken with the package.

5.3 Conclusion to Chapter 5

The packages described above all use either intervisibility analysis or perspective viewing or a combination of the two techniques.

The VIEW suite and, to a lesser extent, *Landschapsbeeld* typify the use of intervisibility analysis. The VIEW suite, in particular, incorporates some highly sophisticated measures of visibility but provides no means of investigating the visual implications of these measures directly.

GROUSE provides only perspective viewing as a means of assessing visual impact. No facility is provided for determining the zone of visual influence of any feature, nor any means of forming an overall picture of the visual properties of an object in the landscape.

VIEWIT and Perspective Plot are primarily of interest in their complementary use. VIEWIT allows a user to develop an overall understanding of the visual properties of both landscape and object in landscape. Perspective Plot translates this understanding into the specific effect as seen from one viewpoint.

The combination of perspective view and intervisibility map appears to be promising and worth pursuing. The perspective view allows the visual implications of the intervisibility analysis to be determined. The intervisibility analysis enables perspective views to be tested to determine whether they are unique in their visual environment or typical of a wider area. This combined approach will be pursued in the software package presented in this study.

Chapter 6

Visual Measures for Landscape Analysis

6.1 Introduction to Chapter 6

A number of researchers have put forward various forms of quantitative or qualitative measures, derived from observation or measurement, and intended to be used to assess some aspect or aspects of the visual qualities of the environment. This chapter examines the most relevant work of this type with reference, in particular, to the techniques adopted and to the underlying assumptions made in relating both the methods and the conclusions to observed human experience. Their effectiveness in a design context is also examined.

6.2 Lynch, Appleyard and Cullen

As part of their studies in the urban visual environment, Lynch [1960, 1964], Appleyard [1964] and Cullen [1967] all developed various forms of notation. These notations are principally concerned with recording the subjective experience of the observer passing through the environment in question. Lynch [1960], in particular, is concerned principally with visual richness and the implicit 'meaning' to the observer of his surroundings. He identifies visual features such as *'edges'*, *'barriers'* and *'landmarks'*, applying a semantic connotation to them. Appleyard *et al* [1964] apply a similar approach to the serial vision of an observer moving along a road through an urban landscape. Cullen [1967] applies these methods to the finer detail of the urban environment, developing a means of describing and, to some extent, explaining the observer's experience of his surroundings. Cullen's approach has been applied successfully in development studies [Rock 1979].

While these notations are broadly related to the present study, they are concerned more with recording the subjective impressions experienced by an individual than in attempting to model the visual stimuli which bring those impressions about. They are intended to be used by designers but provide no means, other than intuition, of evaluating designs which are not yet built.

6.3 Schafer

Schafer *et al* [1969] devised a statistically-based method of predicting preference in rural scenes. This was based upon a series of 100 ground-based monochrome photographs of natural rural landscapes, taken in various parts of the continental United States.

The photographs were shown to volunteers in randomly-selected packets of 5, each interviewee being shown 4 packets. The population used to obtain preference scores was a sample of 250 people drawn from campers in the Adirondacks during 1967. The object of the exercise was then to find a means of deriving the mean scores returned for each photograph from certain measures obtainable directly from the photographic prints.

The measures selected were as follows:

'1 *The perimeter of the immediate tree-and-shrub zone, where individual leaf and bark characteristics may be discerned.*

'2 *The perimeter of the intermediate non-vegetation zone, where the outline of rocks, grass or soil is visible, but not in fine detail.*

'3 *The perimeter of the distant tree-and-shrub zone where the shapes of the individual trees and shrubs cannot be distinguished.*

'4 *The area of the intermediate tree-and-shrub zone where the outline of the individual trees and shrubs is visible, but not in fine detail.*

'5 *The area of the water zone including all visible water, lakes, ponds, streams, waterfalls, etc.*

'6 *The area of the distant non-vegetation zone, where rocks, grass or soil are visible but no details of their features may be discerned.'*

From these measures it proved possible to derive an empirical formula which yielded a preference score for each scene corresponding very closely to that derived from the original survey data. No model was proposed at this stage for how these measures related to the way in which an observer actually perceived and interpreted a scene. This work has been replicated in Utah [Schafer and Mietz 1970] and in Scotland [Schafer and Tooby 1973]. Guldmann [1980] points out that one of the most significant features of Schafer's work is the stress in his formula upon the interaction of measures, often more important than the measures themselves.

Schafer and Brush [1977] provided a description of the way in which the formula might be interpreted and justified. This was no more, however, than a series of five verbal descriptions of the intuitive operation of each term in the formula as follows:

'1 *The use of the three distance zones accounts for the sense of depth established by textural gradients and overlapping land forms; this sense of depth is a major factor in scenic preference.*

'2 *The perimeter measurements stress the prominent edges separating masses of contrasting textures and tones, and it has been proven that the viewer's attention focusses at points along such edges.*

'3 *The perimeter of immediate vegetation enhances scenic quality, but excessive amounts of such vegetation penalise the scenic value; likewise, when the intermediate or distant zones are largely forested, the presence of foreground vegetation detracts from the scenic quality.*

'4 *Water in combination with forest vegetation in the intermediate or distant zones, strongly enhances scenic quality; however, if the water occupies a proportionately large section of the scene, it detracts from the quality of the scene, which means that, without the contrast of* *dark vertical masses of trees in the distance, the presence of water is detrimental to scenic quality.*

'5 *Large values of the intermediate non-vegetation zone enhance scenic quality; however, the opposite effect occurs if large amounts of open ground are present in the distant zone.'*

While this verbal analysis of Schafer's formula makes the sense of the interaction of the various measures clearer, their degree of inter-dependence is so high and their effects so non-linear, that it is doubtful whether it could be used effectively as a design tool. It is far from obvious what effect on the overall score would be brought about by any given change in the objects contained within the scene or in their disposition in space.

While certainly yielding repeatable results and providing a good match with results obtained by polling a population, Schafer's model has serious limitations when applied to analytical applications. The complexity of the formula ensures that it is extremely difficult to use the scores obtained from a proposed scheme to improve it, although Schafer and Brush [1979] suggested that it could be used as a management tool. The inherent dependence upon the similarity of largely unspoilt and unpopulated rural scenes also makes it doubtful if it could be applied to situations where the object of the exercise is to provide a means of assessing the change brought about by some significant intrusion into the scene. Finally, the use of preference as the measure is subject to data being obtained about particular types of object, in particular types of surroundings, before any prediction could be made regarding the visual impact of any proposed solution.

6.4 Dearinger

Dearinger [1979] also devised a statistical model of visual preference in rural landscape. He refined this approach by setting out a number of semantic differential scales (e.g. good - bad, warm - cold). 105 of these scales were initially proposed with the list being reduced to 21. An experiment was carried out to gather data regarding these scales from a sample of 139 students. A series of 15 rural scenes were shown to them projected as colour transparencies.

It proved possible to obtain three factors, expressed as empirical formulae, as in the case of Schafer's work, from the data obtained. These three factors were together able to account for no less than 93% of the observed variance between the mean preferences obtained for different scenes.

These factors were as follows:

1 *'Natural scenic beauty'* covering scales such as *'natural - artificial'*, *'beautiful - ugly'* and *'colourful - drab'*. This was regarded as an *'evaluative factor'*.

2 *'Natural force'* covering scales such as *'wild - tame'* and *'rugged - delicate'*. This was regarded as a *'potency factor'*.

3 *'Natural starkness'* covering scales such as *'warm - cold'* and *'barren - fertile'*. This was regarded as an *'activity factor'*.

These results suffer from the same intrinsic constraints regarding their use as a design tool as does Schafer's work.

6.5 Guldmann

Guldmann [1979, 1980] extended the type of work done by Schafer and Dearinger into a 3-dimensional form based on intervisibility analysis of a scene. This is carried out by laying a horizontal grid over the area under consideration, and then characterising each cell of this grid by the ground elevation and the land use or structure within it, together with its associated height above datum. From a given observer point, it is then possible to test each element of the scene for visibility, approximating all objects as cuboids. All of this work is carried out using a computer to hold the data and to carry out all of the complex calculations which are required.

The intervisibility test, employing a notional perspective transformation, is then available for use as a means of obtaining the areas of different classes of object as projected upon a picture plane. The classes used by Guldmann are derived from those used by Schafer: soil, water and trees. An empirical formula is used to obtain a predicted preference score from the values obtained. From this score it is possible to predict, within certain limitations, the effects of intrusions into the scene. Guldmann terms this a *'calibrated visual preference function'*, implying no more than that it has been normalised by reference to survey data.

Guldmann points out that, while promising, a great deal of work needs to be done in this field. He also indicates that other characteristics of objects in landscape should be investigated, such as colour, lighting, shape and *'visual absorption'*. He further suggests the preparation of a number of such studies in order to accumulate a large amount of visual preference data so as to be able to apply known calibrations to results obtained in predicting the preference scores for proposed changes to landscapes. As such, he suggests, the technique offers a potentially very powerful tool for use in landscape planning and management.

Guldmann's method does seem to be very promising. He handles changes to a landscape only in terms of land management changes and not in terms of the introduction of some alien addition. This, as with the case of Schafer and Dearinger, leaves the problem of not having any base data upon which to predict the effects of the intrusion unless some preference study can be carried out on some similar intrusion in similar surroundings. His computer modelling of vision is very interesting and potentially very powerful as it models both present and possible future configurations of a scene in precisely the same terms. He points out, however, that much more investigation into the modelling of the human eye is required in order to be certain of how best to solve this problem.

6.6 Canter and Hill

Canter and Hill [1979] present a digest of a large number of what they term *'assessment variables'* for use in determining the environmental impact of change or the environmental quality of an existing locale. These are generally presented as graphs mapping some measurable quantity to a *'quality index'* running from zero (undesirable quality) to unity (desirable quality). These variables are generally derived from research papers and environmental design guides from a wide variety of research institutions.

The variables presented are divided into four main groups: *'terrestrial'*, *'aquatic'*, *'air'* and *'human interface'*. Of these groups, only the last is directly relevant to the present study. It is subdivided into the following four subsections: *'noise'*, *'aesthetics'*, *'historical'* and *'archaeological'*. The *'aesthetic'* variables are concerned with the form of river valleys, variety of vegetation types, presence and variety of domestic and wild animals, the appearance and odour of open water, the clarity and odour of air and, lastly, the presence and quality of sounds. These variables are all based upon work carried out at Battelle-Columbus Laboratories [Dee *et al* 1972].

The authors offer their book as a reference source for preparing environmental reports or studies. They advise that the use of the information contained in it requires professional judgment in its application. The book provides a very rapid and easy-to-use means of obtaining an overall picture of an environment both in terms of the general quality and in terms of particular shortcomings or desirable features. It also has many of the attributes of a good design tool in that the results of its use clearly show which of a number of independent variables need to be modified and in what way they need to be modified.

6.7 Conclusion to Chapter 6

Measures predicting visual preference are only partially relevant to the present study. While visual preference is, indeed, an important factor which must be considered in the course of design development, a single numerical score does not assist the designer in determining which elements of a scheme may be causing problems and how best to correct them.

Canter and Hill's *'assessment variables'* provide a more manageable and adaptable tool to the designer. Only relevant variables out of the set offered need be used in any given situation. The critical elements of the design may be identified and corrected independently.

In the following chapter, the concept of *'visual descriptors'*, as advanced by Aylward and Turnbull, will be introduced. The measures introduced in this chapter will be discussed further in comparison with *'visual descriptors'*.

Chapter 7

Visual Descriptors

Visual Descriptors

7.1 Introduction to Chapter 7

This chapter introduces the concept of visual descriptors as proposed by Aylward and Turnbull [1978]. The conceptual definition of visual descriptors is set out and the definitions of the set of visual descriptors proposed by Aylward and Turnbull are examined in detail. The visual descriptor concept is further discussed and compared with the other visual measures which were discussed in the previous chapter.

7.2 The Visual Descriptor Concept

Aylward and Turnbull [1978] introduced the concept of *'visual descriptors'*, defined below. They were concerned that one of the principal problems in the whole area of visual analysis of new development was the difficulty of communicating design intentions and, consequently, of determining the performance of design in visual terms. Their paper put forward a possible answer to this.

It is their contention that decisions regarding the visual appearance of a building cannot be separated from the qualities of the landscape in which the building is to be sited. For this reason, their intention is much broader than simply to provide a means of describing buildings, but also has to encompass the qualities of the landscape in the same terms in order that change may be identified and quantified. The elements of such a description they propose should be called *'descriptors'*.

They put forward the following nine descriptors, dividing them into three groups of three:

	Descriptor	Summary definition
Form:	*1 Shape*	*unique profile*
	2 Size	*the visual area*
	3 Edge	*discernible perimeter*
Relation:	*4 Overlap*	*apparent overlap of objects*
	5 Position	*location, foreground/background*
	6 Rotation	*changing shape and orientation*
Light:	*7 Colour*	*hue, greyness and weight*
	8 Reflectivity	*surface brightness and texture*
	9 Shadow	*detailed information of object*

Aylward [1978] regarded these as being neither unique nor exclusive but found them to be *'useful in practice'* and *'communicable to others'*.

These descriptors are a mixture of global attributes of the object in question, attributes specific to a unique observer position and attributes relating to an observer moving through a scene. Of the three groups of descriptors, the second one, *'relation'*, is applicable principally to an observer passing through the scene under consideration. The other two groups apply equally to static and moving observers.

The descriptors were not claimed to be in any way complete in terms of the psychology of perception. They appeal to the work, in particular, of Gibson [1950], whose concepts of visual *'contours'* and *'gradients'* have a close relationship with Aylward and Turnbull's visual descriptors. The more general psychophysical concept of *'thresholds'* [Snodgrass 1975] is developed from *'contours'* and is central to much modern sensory investigation. Gibson also holds that visual phenomena may be considered independently as components of the whole experience, a position at variance with the Gestalt school who held that the visual environment is only experienced and understood in a holistic way [Koffka 1922]. This independent consideration of phenomena is a prerequisite for the validity of the visual descriptor concept. It is still largely supported by modern psychophysical work [Stevens 1975].

The concept of providing a consistent, repeatable and communicable framework of description for both an existing and a modified environment is extremely powerful. Little consideration is given, however, either to relating the proposed descriptors to the physical mechanics of seeing an object (as distinct from the psychophysical process which is mentioned), or to how these may be related to quantitative (rather than qualitative) measures taken from the physical world.

The applicability of the descriptors as a design tool is fundamental to their conception, design being both Aylward and Turnbull's primary concern. The descriptors were put forward as providing a means of testing a proposed design either for acceptability on the part of some planning authority, or as evidence of acceptability to such an authority. They were also seen as a powerful design aid, enabling a designer to assess the performance of a proposal at an early stage and to enable him to modify it to meet his own criteria, eliminating much of the guessing and luck so often involved in the realisation of a design.

7.3 Aylward and Turnbull's Visual Descriptors

7.3.1 Introduction to 7.3

Aylward and Turnbull provided no algorithmic definitions of their proposed visual descriptors but provided verbal descriptions in their 1978 paper. This section examines each of the descriptors in detail, discussing the implications of the definitions.

7.3.2 The Descriptors of Form

7.3.2.1 Shape (Descriptor 1)

'Shape' (figure 7.1, after Aylward and Turnbull) was regarded as the fundamental descriptor of form, defining the *'unique form of an object by means of its profile'*. The assertion that the actual profile received by an observer necessarily communicates the full 3-dimensional nature of the object is not discussed fully. It is, however, admitted that familiarity of the observer with the object in question is important in interpreting the received shape. The relevance of contrast of shape to the surrounding shapes of background and environment is also mentioned as being important in determining the degree to which the actual shape may be discerned.

No attempt was made to define any way by which *'shape'* could be defined or communicated in any clear and unambiguous way, nor was it made clear whether the descriptor was to be concerned with the actual 3-dimensional shape of the object or the 2-dimensional profile received by an observer.

7.3.2.2 Size (Descriptor 2)

'Size' (figure 7.2) was regarded as being secondary to *'shape'* and as qualifying it. The description given is relatively unambiguous. *'Size'* is described as *'the visual area objects present to the viewer either individually or in visually connected groups'*. The question of scale defined as relative size is specifically excluded from this definition, but is re-introduced in a discussion of the assumed size of an object as a distance cue. In this respect, weight is placed upon the contrast in size between object and surroundings or background.

The clear definition of *'size'* is therefore clouded by the introduction of another consideration, that of *'scale'* and, although it is stated that they are distinct, no clear distinction is drawn.

7.3.2.3 Edge (Descriptor 3)

'Edge' (figure 7.3) was defined as describing *'the discernibility of an object's perimeter as perceived against its background'*. The way in which the discernibility was to be described is not discussed. The relevance of the descriptor is seen, however, as being the final determiner of the visibility of an object. If its edge cannot be discerned, the object cannot be discerned.

The 'sharpness' of the edge appears to be the principal consideration here. It is not made clear, however, how this is to be measured, nor how it is distinct from the questions of contrast raised by the *'light'* descriptors.

7.3.3 The Descriptors of Relation

7.3.3.1 Overlap (Descriptor 4)

'Overlap' (figure 7.4) is concerned with the overlap of the received images of two or more objects in the visual field. This is identified by Aylward and Turnbull as being an important property in providing depth cues as to the relative distances of objects. They point out (citing Gibson [1950]) that certain conditions have to prevail in order for this to happen. Firstly, the edge which forms the apparent line of overlap must itself be discernible (see *'edge'* above). Secondly, the actual forms of the objects must also be discerned or surmised (see *'shape'* above) in order that continuity of a partly eclipsed form may be interpreted as such and not simply as contiguous forms.

No clear measure is given for *'overlap'*. Its effects and its importance in the interpretation are described. The critical issue appears simply to be the fact of visual overlap (and the consequent visual linking of objects in the observer's experience of the visual environment) rather than the degree of overlap.

7.3.3.2 Position (Descriptor 5)

'Position' (figure 7.5) is introduced as a descriptor defining *'the location of objects in a field of vision in relation to foreground or background'*. It is further described in terms of the way that the position of an object relative to an observer may be perceived. Aylward and Turnbull cite Ogle [1964] in stating that beyond the effective range of stereoscopic vision (about eight metres) the apparent position of an object on the visual field is an increasingly important depth cue (i.e. the further up the visual field an object's base appears, the further away it appears to be). They also, however, point out that other factors complicate this issue. If the terrain is not level or the line of sight not horizontal, the effects of distance on visual position will be distorted. Similarly, if the actual size of an object is misinterpreted (see *'size'* above) the interpretation of depth will also be distorted.

It is not at all clear just what the issue here is. It may be as simple as the question of how far up the visual field an object appears, but, in this case, the complications brought about by so many other issues must render such a measure much less effective. The severe interdependence of this descriptor on others such as *'size'*, *'shape'* and *'overlap'* for its relevance in a given situation must render it very difficult to use in a practical situation.

7.3.3.3 Rotation (Descriptor 6)

'Rotation' (figure 7.6) is a descriptor which *'defines the apparent changing shape of an object viewed from different viewpoints, establishing its three-dimensional form'.* This descriptor is seen by Aylward and Turnbull as augmenting the information provided by the descriptors of relation, *'overlap'* and *'position'.* It is the fact of the known constancy of the actual form in question and the extra visual information yielded by the changing profile as the observer moves that is important, also varying the properties of the other two relational descriptors and, possibly, redefining them.

It is again unclear as to the exact property that is proposed to be used as the descriptor here. The phenomenon itself is self-evident, but how it might be used is not. The constancy of form and the changing of profile is mentioned, but it appears not to be this property that is regarded as critical, rather the effect on the other relational descriptors, confirming or denying their contribution to the visual whole.

7.3.4 The Descriptors of Light

7.3.4.1 Colour (Descriptor 7)

'Colour' is a descriptor described as being *'interpreted in two ways. The first is what might be a scientific description .... The second is through the perception of colour in a more subjective sense'.* The colorimetric definition embodied in British Standard 4800 [1972] for paint colours is described in some detail as an example of the 'scientific' way of interpreting colour. The effects of viewing distance are discussed, with reference to Ittelson [1960] and others regarding the question of whether the colour of an object has any influence upon its apparent distance. Aylward and Turnbull conclude that from the practical point of

view (citing Cairns [1974] and Aylward [1975]) the principal factor determining whether or not an object merges with its surroundings is the colour contrast between object and visual background, with the intrinsic colour properties playing a much smaller part.

The actual quality under consideration here could be any of a number of things. The actual colorimetric properties of the materials and finishes used in the object are cited, as are the apparent colours received by a distant observer. The contrast between object and background is also identified as important. The question is probably even more complex than this as colour contrast affects a number of other issues. The merging of an object with its background by means of reducing the colour contrast between them is one of the principles involved in camouflage. The 'visibility' of an object is also to some extent dependent upon the degree to which its shape can be recognised. An object may be 'broken up' by the pattern of colours applied to it, or its shape or orientation may be disguised in this way, another of the principal techniques used in camouflage [Hodges 1973].

7.3.4.2 Reflectivity (Descriptor 8)

'Reflectivity' is introduced as a modifier to *'colour'*. It is pointed out that contrast in reflectivities of adjacent surfaces brings about a difference in their apparent brightnesses and consequently has an influence on the visibility of an object against its background. This is regarded as being particularly important because of the high reflectivity of many building materials in comparison with the much lower reflectivities to be found in most of the natural environment.

The intimate inter-relation of *'reflectivity'* with *'colour'* is not fully discussed. The fact that reflectivity is an element of the colorimetric properties of a surface seems to be ignored, as contrast in reflectivity is discussed as being a phenomenon independent of colour contrast. Specular reflectivity is mentioned by reference to some of the phenomena associated with it, such as the loss of surface colour information, and influence of surrounding colours. The fact that the presence of highly reflective ('shiny') materials has highly unpredictable consequences is not mentioned. Large areas of such materials, for example bodies of water or large glasshouses, tend to adopt the colour of the sky as the colour seen by an observer, changing their brightness and colour enormously with changing weather conditions and seasons. Shape is also significant: an object may become suddenly highly visible for a few minutes if the sun is in exactly the right position to be reflected and the sky is also clear, but the frequency of such an occurrence is dependent on the number and orientation of highly reflective elements in the object.

7.3.4.3 Shadow (Descriptor 9)

'Shadow' is a descriptor which is concerned with shading and the tonal effects of light in general, not simply with the presence of shadows. Aylward and Turnbull cite Gibson [1950] here with regard to his concepts of *'gradients'* and *'inlines'*. (An *'inline'* is a visible line within the profile of an object, discernible because of some sharp change in the *'gradient'* of colour, tone or texture across the surface.) They point out that, in the majority of buildings, the orthogonal nature of the forms involved ensures that shadows or changes in tone enhance the lines seen by an observer and make the form clearer and resolve many possible ambiguities of distance and orientation.

While undoubtedly a vital element of the visual interpretation of the environment, it is not clear how this phenomenon can be isolated sufficiently to be used on its own. The effects of tonal change are so intimately entwined with the whole question of identifying an object and being able to recognise edges, colours and shapes that it must be an integral part of many of the other descriptors. Indeed, it is questionable whether *'shadow'* can be considered separately from these other phenomena.

7.3.5 Conclusion to 7.3

The descriptors, as proposed by Aylward and Turnbull, have many inconsistencies. Some descriptor definitions are in terms of actual properties of the object: *'shape'*, *'size'* and *'colour'* are partly described in this way; *'reflectivity'* wholly so. Other definitions refer to properties as received by an observer (again either in whole or in part). Some definitions refer to a specific observation point: *'size'*, *'overlap'* and *'position'* are partly described this way; *'edge'* wholly so. Other definitions are functions of movement through the scene in question: *'rotation'* can only be considered this way; *'overlap'* and *'position'* partly so. *'Colour'* is partly considered as a function of distance, irrespective of actual position in space. Some descriptors can be considered as single-dimensional measurable quantities, such as *'size'* and *'reflectivity'* or multi-dimensional quantities such as *'colour'* (in one of the senses in which it is described). Some other descriptors also have object-background contrast considerations, such as *'size'* (in the sense of scale), *'colour'* and *'reflectivity'* (in the sense of contrast). Others are descriptive terms which have no obvious means of measurement, such as *'shape'*, *'edge'*, *'overlap'* and *'position'*. *'Rotation'* is particularly difficult to deal with, as it is a phenomenon common to all objects and could only sensibly be applied on its own in applications where an answer to 'Does it matter that this can be seen from a series of contiguous viewpoints?' would be important. *'Shadow'* seems to deal with such a fundamental quality of the visual environment that it underlies rather than complements the other descriptors.

While the concept of the visual descriptor seems, in principle, to be very powerful, the detailed outworking of the concept into unambiguous and accurately quantifiable measures is present only in a very small part. Aylward's death left much to be done in this field. In particular, no work was carried out to make the visual descriptor concept workable as part of Aylward and Turnbull's computer-aided design suite. No detailed algorithms for any of the descriptors had been evolved, nor had any consideration been given to how they might be used in practice in a CAD environment.

7.4 Purdie's Visual Descriptor Algorithms

7.4.1 Introduction to 7.4

As part of a PhD thesis encompassing a broad investigation of computer-aided visual impact analysis, Purdie [1983, 1984] proposed algorithmic definitions for some of Aylward and Turnbull's visual descriptors. His definitions are described and discussed in the following sub-sections.

7.4.2 Shape

Purdie proposed no single measure for *'shape'*. Instead, he discussed a number of possible measures, finally identifying three as being suitable for use in visual impact analysis. These were *'compactness'*, *'angularity'* and *'directionality'*. *'Compactness'* was defined as the ratio of area to perimeter of the visible profile of the object under consideration. *'Angularity'* was defined as the sum of the edge internal angles of the silhouette of the object. *'Directionality'* was defined as the fourth moment of area of the profile of the object, yielding a measure running from zero for an object with finite height but zero width to infinity for an object with finite width but zero height.

'Compactness' and *'directionality'* would both appear to yield numerical values which measure, in some way, the proportions and irregularities of a profile. *'Angularity'*, on the other hand, is only a measure of the number of vertices in the polygon which describes a visible profile: an n-sided polygon will always have an internal angle-sum of $(n-2)\pi$ radians.

7.4.3 <u>Size</u>

Purdie proposed that *'edge'* be measured in millisteradians (the steradian is the SI unit of solid angle). His algorithm calculates a solid angle from the overall angles subtended vertically and horizontally by the visible profile.

This method of measurement makes no allowance for the actual shape of the profile, but only measures what is, in effect, a bounding rectangle.

7.4.4 <u>Edge</u>

Purdie considered two aspects of *'edge'*. Firstly, the clarity of edge was considered, based on the relative luminance of object and background. A contrast threshold was to be specified, all edges identified at which the contrast exceeded that threshold, and the total length of edge calculated. The measure was to be the ratio of lengths found in this way to the total edge-length of the object. Secondly, the direction of edge was considered, based on whether the line segments making up the edge of the profile were more nearly vertical or horizontal. The total lengths of more-nearly-vertical and more-nearly-horizontal edge were to be calculated. The measure of edge direction was to be the ratio of vertical to horizontal components.

The measure of edge clarity seems somewhat suspect. The measure is effectively a ratio of visible to total edge. As the total edge is therefore by definition partly invisible, it cannot be experienced by the notional observer being considered in this context. Direction of edge seems to provide an alternative measure for *'shape'*, rather than describing any feature of the edge itself.

7.4.5 Overlap

Purdie considered *'overlap'* to be analogous to a set operation, where the overlap between two objects could be considered as the set intersection of the sets of points contained by the profiles of the two objects. The proposed measure in this case was the ratio of the overlapped area to the sum of the areas of the two profiles. The area, in the case of this descriptor, was to be the actual area measured in the picture plane of the notional observer.

The measure used in this instance seems strangely at variance with the measure used for *'size'*. *'Size'* is measured as an angle subtended at the viewpoint in millisteradians: *'overlap'* is a straightforward area measurement. On the other hand, *'overlap'* takes into account the areas of the actual profiles involved: *'size'* simplifies the profile to the bounding rectangle.

7.4.6 Position

Purdie considered *'position'* to be the positional relationship between object and visual field. The vertical angle from the viewpoint to the object was to be calculated and classified into nine ranges. The measure was to be the integer number of the range from 1 at the bottom of the visual field to 9 at the top of the visual field, with 0 for zero angle of elevation.

This descriptor alone is defined by Purdie on the assumption that the vertical angle of view is zero: the direction of view is absolutely horizontal. The measure proposed is simply a product of the underlying topography, taking no account, for example, of the relationship between object and horizon (Purdie does, however, suggest that a measure of backcloth may also be relevant). If the restriction on vertical angle of view is removed (it is reasonable to assume that the observer is free to move his head), the measure becomes meaningless: the object may appear anywhere in the field of view.

7.4.7 Rotation

Purdie did not attempt to define a measure for *'rotation'*. Instead, he contended that the property described by Aylward and Turnbull could be understood from the behaviour of other descriptors with changing viewpoint.

7.4.8 Colour, Reflectivity, Shadow

Purdie discussed these *'descriptors of light'* but made no attempt to define algorithms for them.

7.4.9 Conclusion to 7.4

Purdie's descriptor algorithms reflect the heterogeneous nature of Aylward and Turnbull's descriptors. It is significant that there is no single, consistent approach to modelling the five descriptors for which algorithms were defined (this has been noted in the cases of *'size'* and *'overlap'* discussed above). It is also strange that the *'light'* group of descriptors should be omitted, when issues of luminance were discussed in relation to the definition of *'edge'*.

Purdie proposed that a suite of computer programs should be written, implementing the descriptors defined above. The suite (to be called VIDERE, from VIsual DEscriptor RoutinEs), however, never progressed beyond preliminary tests of a few fragments of code.

One interesting concept, mentioned in passing by Purdie, was the possibility of mapping certain of the descriptors as contours. This was suggested as a possibility for coping with Aylward and Turnbull's *'rotation'*. Purdie, however, does not develop this idea any further. The concept of mapping visual descriptors will be discussed further in the next chapter, and will become a central element of the development of visual descriptors in this study.

7.5 Visual Descriptors Compared with Other Visual Measures

The workability of visual descriptors as a design tool is central to this study. Aylward and Turnbull contended, as did Gibson [1950] and other later researchers into psychophysics [Snodgrass 1975], that independent measures could be derived which, together, allow an overall assessment of some scene to be arrived at. As indicated previously, the feedback obtainable from such a set of measures allows the designer to see immediately which components are at variance with his design intentions. This is true even if, as is the case with many of the variables cited by Canter and Hill [1979], some of the functions connecting stimulus with response are non-linear or have mid-range maxima and minima.

Schafer's work [1969, 1970, 1973], on the other hand, suggests that no such clear independence of stimuli exists. His work points to complex inter-relationships between visual stimuli leading to the overall visual impression on the part of the observer. However little the theoretical psychological and psychophysical basis cited for this, it is, nevertheless, supported by experimental data. This makes the feedback to the designer very much more difficult, as it is then no longer clear what aspect of the proposal is contributing to what degree to the overall single-dimensional score emerging from the analysis.

This dichotomy is probably best resolved by looking at the information actually being derived from a study in each case. Schafer and Dearinger [1979] are both concerned merely to obtain and be able to predict a preference score. The measures used by Schafer have much in common with those used by Aylward and Turnbull, in that they are physical quantities obtainable from the real world by measurement; indeed those used by Schafer are the more concrete. Aylward and Turnbull, on the other hand, are not particularly concerned with an overall score. They see no absolute virtue in either minimising or maximising visual impact, allowing the designer to make his own choice. Aylward and Turnbull's descriptors, then, are devised to be used as a multi-dimensional array of measures to be used as such by a designer or by someone charged with assessing a design. The measures are selected with design in mind and measure the sort of things that a designer would be likely to wish to know about, albeit with a lack of clarity of intention in the case of certain descriptors. Similarly, the variables listed by Canter and Hill are intended to be used separately as independent components and are all related to directly measurable and controllable physical measures. They do, however, have a desirability value attached to them and, in environmental issues, this is considerably less contentious than in the case of design and aesthetics. Schafer's measures, in contrast, are almost entirely neutral in quality and, while measurable, have little bearing upon the physical construction of the scene in question. The components which make up the overall preference score are in themselves not particularly useful, and the fact that they are buried in a complicated formula is no loss to the use which Schafer makes of his method.

Guldmann's work [1979, 1980] is interesting in that he does not take the measures he uses directly from the real world (or nearly directly by using photographs) but from a computer model of the world. This is very close to Aylward and Turnbull's intentions with regard to descriptors, that they should become part of their CAD suite. The use of a computer simulation places a heavy reliance on there being a good match between the computer's simulation and the realities of human vision. Guldmann, himself, expresses some reservations about this. (Interestingly, neither Schafer nor Dearinger seems to be in the least worried about the match between photographs and reality.) The incompleteness inherent in any such model is probably not a serious problem, as Schafer has been able to obtain apparently valid results with an admittedly incomplete model despite the complex inter-relation of measures inherent in his method.

7.6 Conclusion to Chapter 7

Aylward and Turnbull's concept of descriptors appears to be basically sound. The question of adapting them to computer synthesis is more complex. Guldmann's approach is promising, but the inherent coarseness of the model used by him makes it unsuitable for use in modelling the environment in fine enough detail for deriving the type of data required. In order to synthesise descriptors, it is necessary that finite algorithms exist for all of them. Also such descriptors as are chosen must be clear and measurable physical quantities, whose values are beyond question and are verifiable. As the values of any set of descriptors are dependent on the position of the observer, some means of extending these into a design tool which describes the overall impact of a development is also required. Given that these criteria are met, the visual descriptor would seem to be a potentially very powerful design aid.

Chapter 8

Modelling Visual Descriptors

8.1 Introduction to Chapter 8

This chapter takes the concept of the visual descriptor, introduced in the previous chapter, and develops a consistent framework within which visual descriptors may be defined and unambiguously evaluated.

A performance specification for a set of visual descriptors is presented in this chapter. The performance specification re-defines and limits the concept of a visual descriptor to some extent but, by so doing, makes the concept more precise.

A possible model for the process of 'seeing' visual descriptors is also proposed in this chapter. This model establishes a means by which the re-defined descriptor may be evaluated or simulated in practice.

A possible set of visual descriptors which make use of the 'seeing' model and conform to the performance specification is presented and discussed.

Throughout this chapter, the concern is to present a consistent basis for the algorithmic development of the visual descriptor concept which will be presented in the next chapter.

8.2 A Performance Specification for Visual Descriptors

If a descriptor is to have any basis in reality it must represent some visual phenomenon unambiguously (but not necessarily uniquely). That is, the definition of a descriptor must be capable of only one interpretation, resulting in only one possible value, no matter who does the measurement, in a given set of circumstances. It is not necessary, however, that the descriptor be the only measure possible to describe a given phenomenon: other measures may be equally valid, as will be seen later in this chapter. If a visual descriptor is to be a repeatable and reproducible measure, it must have some definite, finite algorithm. Furthermore, if descriptors are to be used within the context of a computer-generated model of a landscape, the algorithms used must take cognisance of the limitations inherent in the model. The practicalities of using visual descriptors also demand that the values for descriptors be derived rapidly and efficiently, and, to this extent, the range of practical computer representations of the visual scene conditions the set of descriptors chosen. The validity of the concept of descriptors as a means of computer-aided visual analysis is wholly dependent upon the provision of algorithms which are efficient in computational terms while being capable of encompassing the subtleties of information required.

Aylward and Turnbull's descriptors [1978] vary as to the terms of reference for each measure. Some are directly properties of the object under scrutiny, others are properties of the image received by a distant observer, either static or moving. Some are numeric values defined by the object or its received image, others are the presence or absence of a phenomenon or simply the phenomenon itself. In order to render this problem capable of being analysed computationally, it is proposed that the approach adopted by Schafer [1969], Guldmann [1979, 1980] and Canter and Hill [1979] should be used, that is, all of the selected set of descriptors should be capable of being represented as numerical variables derived by direct measurement from the visual environment, or alternatively, by direct measurement of a simulation of the visual environment. This direct measurement ensures that the values obtained are wholly objective. While the measures themselves, the algorithms used to evaluate them or the conclusions drawn from the values obtained may all be open to question in a real visual impact analysis exercise, the actual measurement process must be repeatable at any time and by any observer.

The values of such a set of descriptors vary depending on the position of the observer, and the position of the potentially intrusive object under consideration, within the landscape. The landscape is best understood holistically as a map: while a perspective view shows aspects of the landscape (relief, in particular) that a map cannot, it shows only one view out of an infinity of possible views. It is, therefore, desirable that the descriptors be capable of being represented on a map of the terrain, in order to present the visual performance of an object in landscape holistically and in context. This requirement imposes a further limitation on the descriptor definition, in that each descriptor must then be a single-valued function of position, defined for all points on the landscape surface from which the object under consideration may be seen.

The revised definition for visual descriptors is threefold. Firstly, the chosen set of descriptors must provide a reasonably complete understanding of the visual performance of the object under consideration. Secondly, each descriptor must be an unambiguous direct measurement from the visual environment or from a simulation thereof. Thirdly, the descriptor values obtained must be single-valued and continuous for all locations from which the object is visible.

8.3 A Physiological and Psychophysical Model for Visual Descriptors

8.3.1 Introduction to 8.3

The actual properties of the object under consideration do not impinge directly on the observer, but are subject to a number of modifying factors. This provides an effective means of modelling the visual stimulus experienced by the observer.

It is proposed to model these modifying factors as the following four groups of properties:

Object properties:	dimensions form colour texture reflectivity luminance
Contextual modifiers:	relative position rotation intervening landform vegetation geology
Conditional modifiers:	weather visual range season of year time of day position of sun cloud cover
Observer characteristics:	visual acuity perception of colour Purkinje effect field of vision social and cultural variations

The properties listed above for each group should be taken as examples rather than as an exhaustive list. The properties important in one situation may not necessarily be relevant in another.

8.3.2 Object Properties

This group contains those properties which are directly measurable. These are the properties over which the designer has the most control and are the physical properties which are set out in the design drawings and associated documents. These properties are not, however, all constant, even without deliberate alteration taking place. For example, the colour and texture of many building materials change with age. Some temporary changes also occur, the reflectivity and colour of walls and roofs may be changed slightly by rain or quite radically by snow.

8.3.3 Contextual Modifiers

This group deals largely with the physical properties of the surroundings of the object under consideration. The more fundamental of these such as the physical form of the terrain, its geology and the relative position of object and observer, remain largely constant (but could possibly be affected by a gross change such as one involving engineering construction or mineral extraction). Other properties change with time, such as the height of trees, or are cyclical, such as the presence or absence of leaves on trees, the colour of vegetation or the presence or absence of snow on the ground.

8.3.4 Conditional Modifiers

This group deals with variations in the prevailing conditions under which the object is observed. These are all varying quantities, either randomly over a known range, such as atmospheric or meteorological effects, or predictably and cyclically, such as the position of the sun and the length of the day.

8.3.5 Observer Characteristics

This group deals with the physiological and, to some extent, the psychological characteristics of the observer. These include those physiological properties of the individual which determine the detection of external visual stimuli. These properties are so fundamental to the construction of any model of visual perception that they are probably best considered as part of the methodology of the modelling process rather than as a separate filter to be applied to the modelled stimulus. The social and cultural considerations which determine the response of the individual to a set of visual stimuli are outwith the scope of visual descriptors and of this study, lying in Rappoport's terms [1977] in the *'cognition'* and *'evaluation'* stages of visual perception.

8.3.6 Conclusion to 8.3

It is proposed, therefore, that, in addition to the definition set out in section 8.2, 'visual descriptors' will be considered as measures which describe the visual properties of an object as received by an observer after being filtered by the three stages of modification set out above but before being interpreted or evaluated.

8.4 Possible Visual Descriptors for Visual Synthesis

8.4.1 Introduction to 8.4

'Completeness' in a set of visual descriptors is a relative term. A set of descriptors may be considered 'incomplete' if it does not encompass the full range of visual phenomena which are regarded as critical in any situation. This range will vary with different types of object under consideration. Glass-houses, for example, fit fairly snugly to the terrain, and it is therefore likely that descriptors concerned with matters of form and bulk would be relatively unimportant in contrast with those concerned with the reflection of light, contrast of colour and orientation of surfaces. Similarly, in the case of very tall structures, such as industrial chimneys, descriptors concerned with outline, shape and form are likely to be more important than those of colour or shadow. There is thus no single, unique or universal set of descriptors to be found as any sort of absolute visual property. Many sets may be defined which might be suitable for different purposes or suitable in varying degrees for any given purpose.

In choosing a set of descriptors, consideration must be given to the practical aspects outlined above. Equally, the intended purpose of those descriptors has a bearing on the measures which are chosen [Aylward and Turnbull 1978]. For the purposes of analysing visual impact as a design tool, the measures most desirable are those which have the most direct bearing upon the designerly aspects of physical form.

A range of possible descriptors is described in detail in this section following. All are numerically-defined measures and yield results consistent with the psychophysical model for descriptors outlined above. They form neither a complete nor a unique or exclusive set of descriptors. Further investigation, including actual day-to-day experience in practice, will be required to identify more descriptors to complement these. Some will also prove to be be superfluous as there is a degree of conceptual overlap between some definitions, while others provide alternative measures for identical phenomena.

The range of possible visual descriptors discussed in the following sub-sections is as follows:

1	Solid angle subtended	(8.4.2)
2	Solid angle subtended by backclothed area	(8.4.3)
3	Solid angle subtended by skylined area	(8.4.4)
4	Angular length of visible edge	(8.4.5)
5	Angular length of skylined edge	(8.4.6)
6	Compactness of visible profile	(8.4.7)
7	Compactness of skylined profile	(8.4.8)
8	Dispersion of visible profile	(8.4.9)
9	Dispersion of skylined profile	(8.4.10)
10	Apparent hue	(8.4.11.2)
11	Apparent luminance	(8.4.11.3)
12	Apparent greyness	(8.4.11.4)
13	Contrast with sky	(8.4.11.5)
14	Contrast with background	(8.4.11.6)

8.4.2 Solid Angle Subtended

This descriptor is a measured counterpart of Aylward and Turnbull's *'size'* and is defined as the solid angle subtended by the visible part or parts of an object in the visual field (figure 8.1) or as some function which serves as a measure of the solid angle subtended.

The SI unit for measuring solid angle is the steradian which is actually rather too big for most practical purposes (there are only 4π steradians in a complete sphere). The millisteradian is a more useful measure in this context and is the one usually adopted in visual field measurement [Lassière 1976]. Possible numerical values for this descriptor could be the solid angle itself or the solid angle normalised to the normal human field of view (approximately 4000 millisteradians [Pirenne 1970]) or to the normal threshold of acuity (approximately 6×10^{-5} millisteradians).

The derivation of this data from a conventional perspective projection is potentially complex. Owing to the geometry of the transformation, the angle spanned by any individual picture element depends upon its position in the frame. Those nearer the edge of the frame represent a smaller angle than those nearer the centre.

8.4.3 Solid Angle Subtended by Backclothed Area

This descriptor is a refinement of 'solid angle subtended' and is defined as the solid angle subtended by the visible part or parts of an object which are also 'backclothed' by the terrain (i.e. they are seen against some part of the landscape, not the sky) (figure 8.2).

It is a common practice to attempt to maximise the extent to which an object is seen against parts of the landscape rather than the sky in order to minimise its intrusion into the scene [Evans and Turnbull 1984]. This descriptor is concerned solely with quantifying this phenomenon. The value of this descriptor is not constant but is subject to variations in visibility. If visibility is reduced through adverse weather conditions, then the effect of this may be to make some parts of a 'backcloth' invisible. The visual effect of this is that the sky appears to move 'closer' to the observer. In this way reduced visibility may actually make an object more prominent by robbing it of some or all of its backcloth.

The same considerations of units and their derivation apply to this descriptor as to 'solid angle subtended'. There is, however, a boundary condition in this case, in that the visible backclothed part of an object may in fact completely fill the field of view, thereby obscuring the background which nominally backcloths it. In this case it is irrelevant whether the object is backclothed or not. This would appear to correspond (on an intuitive level) with actual experience of the visual world, in which the relationship between object and surroundings is more important in the distant view and the nature of the object itself more important in the near view.

8.4.4 Solid Angle Subtended by Skylined Area

This descriptor is the converse of 'solid angle subtended by backclothed area'. It is defined as the solid angle subtended by the visible part or parts of an object which are also seen against the sky and not against the landscape (figure 8.3).

This descriptor is subject to exactly the same considerations as its counterpart, but with its numerical value acting in the opposite sense. Which of these is the more useful is a matter to be determined through experience or experiment.

8.4.5 Angular Length of Visible Edge

This descriptor is a measured counterpart of Aylward and Turnbull's [1978] *'edge'* descriptor. It is defined as the sum of all the angles subtended by the line segments making up the observed profile of the object in the visual field (i.e. the total length of the edge expressed in units of angle) (figure 8.4).

This descriptor attempts to quantify Gibson's [1950] phenomenon of *'edge'*. Gibson identifies edge, the extreme profile of an object, as being important in identifying an object. This is handled quite simply by measuring how much edge can be seen. It is debatable whether the whole edge of the visible profile should be taken or whether the ground line should be excluded. If the whole scene is considered as a series of overlapped shapes from foreground to background, then the ground-line of any one object actually belongs to whatever is immediately in front of it.

In the case of a partially masked object, this is clearly the case. Defining *'edge'* then as excluding the base-line of the profile enables all cases and all elements of the scene to be handled consistently. This latter point is an important element of Aylward and Turnbull's concept of descriptors [1978].

Sensible units for this measure, as in the case of the area measures, are not obvious. As in the case of solid angle, the SI unit for angle, the radian, is actually rather too big for this purpose (only 2π in a complete circle). Possible numerical values for this descriptor could be the angle itself, measured in milliradians, or the angle normalised to the normal human field of view (approximately 3500 millisteradians [Pirenne 1970]) or to the normal threshold of acuity (approximately 0.3 milliradians).

The definition of 'visible edge' is not a clear-cut issue. It can be defined most simply as the edge which can be seen under ideal conditions (i.e. all the edge not actually masked by any intervening visual obstructions). If more factors are taken into consideration, however, this becomes less obvious. A section of edge may, for example, be considered to be 'invisible' if the colour and tonal contrast is less than some threshold value or if the image is so complex that the edge is lost in visual 'noise'. This is an application of Gibson's [1950] principle of *'visual gradients'*. The simple definition will be taken as the fundamental measure. The other considerations may be added to the model subsequently, appearing in the definitions of other descriptors.

The derivation of this data from the perspective frame is subject to non-linearities similar to those encountered in the case of solid-angle measurement.

8.4.6 Angular Length of Skylined Edge

This descriptor is a specialisation of 'angular length of visible edge'. It is defined as the length of the object's profile which forms a visual edge with the sky (figure 8.5).

This descriptor is concerned with the influence of object and skyline, as is the case with the related descriptors 'solid angle subtended by backclothed area' and 'solid angle subtended by skylined area'.

The numerical measure for this descriptor is identical to that used for 'angular length of visible edge'. The issue of contrast in this case is a purely weather-related one, the colour of the sky being independent of surroundings but varying with conditions. The blurring of edge due to visual complexity probably does not arise in this context.

8.4.7 Compactness of Visible Profile

This descriptor is defined as being the compactness of profile of an object as received by an observer.

'Shape' is essentially a quality, not a quantity. No attempt is therefore made to address it directly. Gibson [1950] identifies the visual compactness of form as being a principal element in determining the perceived *'shape'* of an object.

The 'compactness' of a 2-dimensional shape (the projection of the 3-dimensional solid) may be defined in terms of the ratio of its area to its perimeter. The minimum possible ratio is found in the case of a circular profile. If, however, the ground line is excluded as not being part of the profile of the object, as in the case of the 'angular length of edge' descriptors, then the minimum ratio is found in the case of a semi-circle. A quantitative measure for compactness may then be defined as the ratio of the area of the received profile to the area of a semi-circle of equal perimeter (excluding the ground-line in each case). This will give a range of values from 0 (finite perimeter, zero area) to 1 (a semi-circle).

8.4.8 Compactness of Skylined Profile

This descriptor is a specialisation of 'compactness of visible profile' and is measured in exactly the same way as that descriptor but applies only to the portion of the visible profile seen above the skyline.

8.4.9 Dispersion of Visible Profile

As an alternative to 'compactness', the shape of a profile may be measured as 'dispersion'. Whereas maximum compactness occurs when the ratio of perimeter to area is a minimum, maximum dispersion occurs when the converse ratio of area to perimeter is a minimum. As compactness ranges from 0 to 1, so dispersion ranges form 1 to 0.

8.4.10 Dispersion of Skylined Profile

This descriptor is simply the 'dispersion' measure equivalent to 'compactness of skylined profile'.

8.4.11 Colour

8.4.11.1 Introduction to 8.4.11

'Colour' is a quality which cannot be measured directly using a single numeric quantity. There are three principal methods used for describing a colour numerically [Newman and Sproull 1979, Foley and Van Dam 1982].

RGB (red, green, blue) defines colour directly as the proportions of the three primaries (figure 8.6). This is the system used in all television or video applications. It works by imitating the colour response of the eye, which also works in terms of the primaries. There are a number of competing standards for the actual values of the primaries with no one standard agreed internationally.

HSV (hue, saturation, value) defines colour in terms more related to a painter's view [CAD Centre 1984a] (figure 8.7). 'Hue' is defined as a notional angle in degrees with the visible spectrum treated as being wrapped round on itself end-to-end so that an angle of 0° represents red, 120° represents green and 240° represents blue. 'Saturation' defines the departure of the colour from a point on a grey-scale. 'Value' represents brightness as a departure from black.

HLS (hue, lightness, saturation) also defines colour in painterly terms and is implicit in the Munsell colour coding system (also used to define British Standard colours) [NBS 1955, BSI 1972] (figure 8.8). 'Hue' is defined in exactly the same way as that described for HSV. 'Lightness' is the grey-scale equivalent of the colour, a measure of the light reflected. 'Saturation' defines the colour content and describes the intensity of the colour as a departure from the grey-scale (if this component is zero, hue is, of course, irrelevant).

Of these three, HLS is the most useful in the current context as it neatly separates colour into the three components which are closest to the way that colours are described verbally: 'hue' is simply the spectral colour under consideration; 'lightness' is the luminance of the colour; 'saturation' is its greyness. The fact that the components of HLS can easily be described verbally reflects the way that they may also be understood easily as three independent measurable quantities: in contrast, 'value', in the HSV system, is difficult either to describe in ordinary language or to understand intuitively; the three components of the RGB system are impossible to experience separately under normal circumstances. It may, however, prove necessary to define certain colour operations (extinction of contrast with distance, for example) in terms of RGB while maintaining HLS for user interaction. The necessary transfer functions are implicit in the definitions of the systems [Foley and Van Dam 1982].

8.4.11.2 <u>Apparent Hue</u>

This descriptor is defined as the hue of an object or part of an object as received by an observer.

Colour is subject to a number of influences. The underlying colorimetric hue of an object may be modified by the colour of the light illuminating it, for example, appearing redder at sunset, or may be modified by artificial light at night. The apparent hue is also modified by being seen through air, so that distant objects appear bluer than closer ones which are also of the same colorimetric hue. These colour changes may be predicted [Duntley 1948, Middleton 1968], and modelled quite accurately under most viewing conditions.

This descriptor may prove difficult to use in practice, as its value is a largely arbitrary number based on the 'colour-angle' of hue in the HLS model.

8.4.11.3 Apparent Luminance

This descriptor is defined as the brightness of an object as received by an observer (i.e. the grey-scale value of its apparent colour).

This descriptor is a compound of many factors contributing to the overall brightness seen. The actual colorimetric reflectivity of the object is a major contributor, but is modified by the brightness of the light falling on it and on the attenuating effects of the intervening atmosphere [Duntley 1948, Middleton 1968]. The object may also itself be a light source and this too will contribute.

8.4.11.4 Apparent Greyness

This descriptor is defined as the HLS saturation component of the object's colour as received by the observer.

The greyness of a colour seen at a distance is again principally determined by the actual colorimetric saturation of the colour concerned, but modified by being made greyer by the effects of the atmosphere [Duntley 1948, Middleton 1968].

8.4.11.5 Contrast with Sky

This descriptor is an alternative measure to 'apparent luminance'. It is defined as the contrast between the apparent luminance of the object, as defined in 8.4.11.3 above, and the luminance of the sky against which it is seen. The measure ranges from 0 (no contrast) to 1 (maximum contrast).

8.4.11.6 Contrast with Background

This descriptor is also an alternative measure to 'apparent luminance' and is complementary to 'contrast with background'. It is defined as the contrast between the apparent luminance of the object, as defined in 8.4.11.3 above, and the apparent luminance of the terrain (or other objects) which form its immediate backcloth. As is the case with 'contrast with sky', the measure ranges form 0 to 1.

8.4.11.7 Conclusion to 8.4.11

These proposed descriptors of colour are relatively easy to synthesise but extremely difficult to present in any simple manner. 'Apparent luminance', 'apparent greyness', 'contrast with sky' and 'contrast with background' are probably all usefully mappable. 'Apparent hue' is theoretically mappable as it is a continuous well-behaved function. Its numeric value, however, is arbitrary in the extreme. Hue is also the least useful of the three measures when taken in isolation, because of its relative insignificance at long range. The composite colour could, however, conceivably be presented visually as a coloured map using either a colour video display or a hard-copy device capable of full-colour continuous-tone colour representation.

8.5 Conclusion to Chapter 8

The definition of the visual descriptor has now been established fully. It has four elements. Firstly, visual descriptors are measures which describe the visual properties of an object as received by a viewer at some specified point in space, after being filtered by contextual modifiers, conditional modifiers and known observer characteristics. Secondly, each descriptor must be an unambiguous direct measurement from the visual environment or from a simulation thereof. Thirdly, the descriptor values obtained must be single-valued and continuous for all locations from which the object is visible. Fourthly, the chosen set of descriptors must provide a reasonably complete understanding of the visual performance of the object under consideration.

The model for visual descriptors presented in this chapter provides a consistent representation of the process by which a notional observer experiences the visual environment. This model also provides the basis from which the initial set of potential descriptors are derived. The proposed descriptors also form a consistent set as all are based upon measurements taken from either a photograph of the real visual world or from a computer-generated image simulating the real world. The process by which the values of these descriptors are to be derived and the precise nature of the computer-based model will be considered further in the next chapter.

Chapter 9

Software Implementation of Visual Descriptors

Software Implementation of Visual Descriptors

9.1 Introduction to Chapter 9

The majority of the proposed set of descriptors are based upon measurements from the field of vision of a notional observer. In order to implement such a set of descriptors in software, the approach adopted must model not only the various components of the 3-dimensional scene but must also include some means of adequately modelling human vision. The constraints which bear on this are numerous and ultimately incompatible. The resolution of the method adopted must approach that of the human eye, while making reasonable demands upon available computing resources in terms of speed of execution and demands on space in memory and filestore. This chapter examines the issues involved in selecting a suitable strategy and describes the approach chosen for this study.

9.2 Representation of Data

9.2.1 Introduction to 9.2

In order to evaluate visual descriptors modelled in the manner described in the previous chapter, it is necessary either to take measurements directly from the real visual world (possibly using a theodolite), from a photograph of the real world (essentially photogrammetry) or from a computer-generated image simulating the real world (a computer-generated perspective).

The problems involved in modelling a view in order to evaluate a set of visual descriptors are essentially identical to the problems encountered in 3-dimensional computer graphics. Known approaches to 3-dimensional modelling will, therefore, be examined for suitability in the context of visual descriptor modelling.

There are two fundamentally distinct approaches which may be made to the problem of representing a 3-dimensional scene. A one-dimensional data structure may be devised, holding all visible objects making up the scene as one or more lists of vectors. Alternatively, a purely graphical method may be used, with a frame-buffer being used both for visual representation and for analysis.

9.2.2 Vector-List Approach

A number of data structures for computer-graphics applications have been devised which are essentially of the one-dimensional, vector-list type. Most hidden-line elimination algorithms [Montanari and Galimberti 1969, Warnock 1969, Hedgely 1982] use some version of this approach. More general data structures of this type have been devised for graphical data representation such as LEAP [Feldman and Rovner 1969].

The principal advantage of such a structure is that there is no redundant space in it. Because of the general nature of the data storage, very little extra working space may be required in order to process information. The numerical precision is also guaranteed: it will be that of the underlying operating system of the host computer.

The disadvantages are more subtle. There is no relationship between the relative positions of objects in space, or on the picture plane of an observer, and their relative positions in the data structure. This can, in an extreme case, result in the entire data structure being traversed in order to establish one relationship between two lines. Because of this, the analysis time tends to increase dramatically with increasing data volume or complexity, although various methods have been devised to ameliorate this [Hedgley 1982]. On the other hand, there may well be economies where only part of the data structure is required.

9.2.3 Frame-Buffering Approach

The frame-buffering approach has become more popular in a number of applications with the advent of cheap semiconductor memory, particularly where rapid display updating is required, for example, in flight simulators and video processing systems [Smith 1983]. It was a common approach in the early days of computer graphics, using raster-scan refresh displays but suffered a loss of popularity with the advent of the cheap direct-view electrostatic storage display which allowed graphics to be used in a time-sharing environment [Newman and Sproull 1979].

This method has considerable advantages in terms of access to the raw data describing the objects which make up the scene under investigation. In principle, no more than one pass through the data is required. All questions of depth and overlap may be resolved automatically in the transformation from 3-dimensional to 2-dimensional geometry.

The disadvantages are principally those of scale, rather than theoretical considerations. The frame buffer is a 2-dimensional structure (or 2-dimensional by a few bit-planes deep) and as such may be used for working on a particular image but cannot store the original 3-dimensional data. There is also a fundamental and unavoidable overhead involved in loading the raw data into the frame buffer, when the position of each point (pixel) on each line-segment must be calculated, not just the end points. This is likely to be incurred to some degree even if only a part of the data set is to be used, as part of a clipping operation. The memory size, address space and processing speed of the underlying computer used has a bearing upon how serious this overhead is in practice. The frame buffer will typically occupy a large area of memory (of the order of hundreds or possibly thousands of kilobytes) and the ultimate size supportable will depend upon the machine. This also determines the final accuracy or resolution obtainable in any implementation as there is a definite pixel size associated with the frame buffer and, therefore, a lower limit to the ultimate resolution possible or practical in any situation.

9.2.4 Conclusion to 9.2

From the foregoing considerations the following strategy has been adopted as a means of implementing visual descriptors in computer software.

The frame-buffering approach to modelling and quantifying descriptors has been selected for the following reasons:

1 Directness of application. Image measurement operations may be carried out directly from the frame buffer by pixel-counting procedures, incorporating whatever weighting functions may be required.

2 Availability of techniques. All the methods required for the implementation of a frame-buffer are already well described and tested [Newman and Sproull 1979]. Image processing methods are also well documented and many are directly applicable to the present study or are capable of adaptation.

3 Ease of monitoring. Being essentially a graphically-based method, much testing may be carried out on a 'look-and-see' basis by dumping the frame buffer to a suitable hard-copy device.

9.3 Frame Buffer Resolution

Because of the threshold effect due to the pixels limiting the fineness of detail obtainable in the notional image, consideration must be given to the size of the frame-buffer required, and the consequent resolution of the system.

The field of view and resolution of the human eye were discussed in detail in Chapter 4. As was pointed out in that chapter, a 12000 × 8100 pixel raster would be capable of representing the entire human field of view to a resolution of 0° 1′ or better. In practice, as discussed previously, it is probably possible to reduce considerably the required size of the frame buffer. For example, by limiting the field of view to 60°, a 4096 × 4096 raster has a pixel resolution of 0° 0′ 58″ at the centre.

9.4 Frame Buffer Geometry

The geometry by which the scene is projected onto the frame buffer must also be considered. As was discussed previously, the perspective-viewing projection preserves the straightness of lines but distorts angles, shapes and, particularly, areas towards the edges of the picture, as does photography or classical perspective-casting. In the above example of a 4096 × 4096 raster representing a field of view of 60°, while the pixel resolution is 0° 0′ 58″ at the centre, it improves to 0° 0′ 44″ at the edge of the frame.

Angular and solid-angular measurements taken from the frame buffer should be independent of the position in the frame of the feature being measured. In order to achieve this, appropriate functions must be implemented to apply the necessary weighting factors to simple area and length measurements obtained by pixel-counting.

9.5 Frame Buffer Implementation

The GINO-F subroutine library [Woodford 1971, CAD Centre 1984a-c] provides all the necessary front-end (user level) routines to handle drawing and perspective transformation without having to handle the mechanics of the process directly. This library is used for all graphical output in the suite of programs presented in this study. Each graphical output device used requires a software interface (code-generator) between GINO and the graphics hardware. A GINO-F code-generator [CAD Centre 1984b] has been developed, as part of this research project, for operating the frame buffer, treating it as if it were a hardware device (such as a raster display). This code-generator provides the necessary bit-array in each of several bit-planes, together with the necessary support routines to do the required vector-to-raster conversions, bit-plane selections, 'pen' selections and frame-clear operations [Newman and Sproull 1979, Foley and van Dam 1982]. Extra front-end routines have also been developed as part of this project, supplementing the GINO library, to access the frame-buffer directly and provide the necessary image-processing routines to carry out the boundary-extraction, area-fill and boundary-fill functions which are required to separate elements of the scene. These routines are not, of course, truly device-independent, but may be considered as generic to a possible family of pseudo-hardware devices, such as the frame buffer.

The size of the frame buffer has been set (for development and testing purposes) at 512 × 512 pixels by 4 bit-planes deep. (This is equivalent to about the lowest acceptable resolution from a graphics display terminal for pictorial graphics.) The whole structure is thus 1 048 576 bits or 128k bytes in size. This reflects the size of a memory segment on the PRIME 50-series machine on which the system was first implemented, an economy of processing time being obtained by not exceeding this limit.

The resolution obtained by this prototype frame buffer is poor but acceptable for testing purposes. The pixel resolution at the centre of the raster is 0° 7′ 45″; the resolution at the edge is 0° 5′ 49″.

9.6 Frame Buffer Procedures

9.6.1 Introduction to 9.6

This section describes the manipulative procedures which are carried out upon the contents of the frame buffer in order to extract the required elements of the scene for the evaluation of visual descriptors. The algorithms involved in performing these procedures are derived from two main sources.

The basic line-drawing algorithm used to introduce the raw vector-based information into the raster of the frame buffer is based on Bresenham's line algorithm, commonly used in raster-scan graphics applications [Newman and Sproull 1979, Foley and Van Dam 1982]. This function is implemented as an integral part of the GINO-F code-generator for the frame buffer and is not discussed further.

The extraction of the relevant parts of the image for measurement by pixel-counting are more closely related to image-processing methods. Most image processing methods are more comprehensive than is actually needed for this purpose. Adaptations of methods for pattern recognition have been described in Nagao [1978] and Cugini *et al* [1978] and have been further adapted for use in this context.

The algorithms used are most easily defined as set operations, where the universal set **E** represents the full extent of the raster thus:

$$\mathbf{E} = \{\text{all pixels in raster}\}$$

All other sets discussed in the description of the algorithms used are, therefore, sets of pixels.

9.6.2 Extraction of Profile

A process has been devised for this purpose which has been dubbed a 'scan-fill'. A scan-fill may proceed across the frame buffer either upwards, downwards, left or right. Its effect is to carry out a set union of all the pixels in each row (or column) with those in the immediately preceding row (or column) thus:

$$\mathbf{R}_n := \mathbf{R}_n \cup \mathbf{R}_{n-1}$$

This fills in the profile of any object in the frame buffer and casts a 2-dimensional shadow of it in the direction of the fill (figures 9.1 and 9.2). A downward scan-fill will, for example, extract the solid profile of a terrain image with no further work being required. With an object on the landscape, whose outlines may contain re-entrants in any direction, this will not work. Instead, it is necessary to carry out scan-fills in all four directions (into separate pixel-planes) and then to carry out a set intersection of all four scan-filled images to leave only the profile and exclude the 'shadows' (figure 9.3). Thus the profile **P** is derived from the four scan fills $S_{L,R,U,D}$ by:

$$P := S_L \cap S_R \cap S_U \cap S_D$$

9.6.3 <u>Visible, Skylined and Back-Clothed Profiles</u>

In order to determine visibility and backcloth, it is necessary to treat the ground surface as being made up of two distinct zones, that lying between the observer and the object (figure 9.4) and that lying behind the object (figure 9.5). The visible portion of a profile obtained as described above may be extracted by the set intersection of the whole profile with the set complement of the scan-filled foreground profile (figure 9.6). If the profile is **P** and the foreground **F** the visible profile is given by:

$$P_V := P \cap F'$$

This operation may also be expressed as a relative difference:

$$P_V := P \Delta F$$

The skylined portion may be obtained by carrying out the same operation on the profile and the scan-filled background profile **B** (figure 9.7):

$$P_S := P \cap B'$$

or $$P_S := P \Delta B$$

The backclothed portion of the profile may be extracted by taking the set intersection of the visible profile with the scan-filled background profile or alternatively with the complement of the skylined profile (figure 9.8):

$$P_B := P_V \cap B$$

or $$P_B := P_V \cap P_S'$$

or $$P_B := P_V \Delta P_S$$

9.6.4 Edges

Edges may be extracted quite simply by producing a 'differential image'. This is obtained by carrying out the symmetric difference set operation (analogous to the Boolean exclusive-or) between the pixel-plane containing a profile and the same image shifted one pixel in any direction (figure 9.9):

$$E := P \nabla P_s$$

The resulting image contains only the boundaries of the original image but excludes those boundaries or elements of boundaries running parallel to the direction of the one-pixel offset. In order to capture all boundaries, it is necessary to take the set union of all four possible differential images, each shifted in a different direction:

$$E := E_L \cup E_R \cup E_U \cup E_D$$

This actually produces an edge outline two pixels thick, with one thickness of pixels immediately inside the original outline of the profile and one outside. This may then be reduced to a single thickness by its set intersection with the original profile to leave just the outermost layer of pixels (figure 9.10):

$$\mathbf{E} := \mathbf{E} \cap \mathbf{P}$$

9.6.5 Visible and Skylined Edges

The extraction of visible edge from complete edge is carried out in exactly the same way as the extraction of visible profile from complete profile. The set intersection of the edge with the complement of the foreground profile yields the visible edge:

$$\mathbf{E_v} := \mathbf{E} \cap \mathbf{F'}$$

or $$\mathbf{E_v} := \mathbf{E} \Delta \mathbf{F}$$

The set intersection of the edge with the complement of the background profile yields the skylined edge:

$$\mathbf{E_s} := \mathbf{E} \cap \mathbf{B'}$$

or $$\mathbf{E_s} := \mathbf{E} \Delta \mathbf{B}$$

9.6.6 Conclusion to 9.6

These operations described in the above sub-sections provide the basis for the calculation of those descriptor values which are derived from the numbers of pixels in the frame buffer. Although most readily presented in terms of set algebra, in the interests of efficiency, the operations are actually implemented as the equivalent bitwise Boolean functions. The formal algorithms for the pixel-based descriptors, which use these operations, are presented later in this chapter.

Other descriptors have non-pixel-based calculations, strictly independent of the frame buffer, and the algorithms for these are described separately.

This set of fundamental operations enables the majority of the proposed set of descriptors to be based on a common model of the scene. Their actual implementation in software is critical to the performance of the whole package and is described in greater detail later in this chapter.

9.7 Formal Algorithms for a Set of Visual Descriptors

9.7.1 Introduction to 9.7

This section defines the algorithms used to evaluate the eight visual descriptors to be used in the prototype version of the ADE program. All but one utilise the frame buffer procedures described in the previous section.

9.7.2 Choice of Descriptors

It was desired to implement a small, but representative, group of descriptors in the first instance. The descriptors chosen are as follows:

1. Area of visible profile
2. Area of skylined visible profile
3. Length of visible edge
4. Length of skylined edge
5. Dispersion of visible profile
6. Dispersion of skylined profile
7. Proportion of visible profile seen above skyline
8. Contrast with sky

The names adopted have been changed slightly from those used hitherto, partly to make them less cumbersome, partly in acceptance of the use of area and length measurements to obtain solid angular and angular quantities.

Where a choice existed between two descriptors which measure essentially the same phenomenon, the choice has favoured the measure which might intuitively be expected to yield higher numerical values in instances of higher visual impact. Thus, 'area of skylined visible profile' has been selected in preference to the complementary 'area of backclothed visible profile'. Similarly, 'dispersion' has been chosen in preference to 'compactness'.

The major omission from this list is colour, which is not addressed in any way. This reflects the comparative complexity of colour as an issue, compared with the geometrical problems involved in the first seven descriptors in the list. The problems are those of data representation, modelling of the conditional modifiers present in the model of vision adopted for this study and, finally, display of the resulting descriptors. It was decided, in the first instance, to simplify matters by examining a monochromatic measure which is, nevertheless, analogous in its behaviour to colour. The modelling of the contrast of object with sky involves the representation of object reflectivity, sky luminance and illuminance and the modelling of the effects of these phenomena over distance through the atmosphere. The omissions are the representation of colour, in object, landscape and sky, and the identification of background features. While the descriptor chosen is unlikely to be an intrinsically useful one, it will serve to explore the problems of modelling the effects of light.

9.7.3 Area of Visible Profile

This descriptor is a measure of the solid angle subtended by the visible profile of the study object.

The raster image is derived in the manner explained in section 9.6.3 above. The descriptor value is then evaluated according to the following formula:

$$A = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{i,j} \; W_a(i, j)$$

The width of the raster is m pixels, and the height n; $P_{i,j}$ is the value of the pixel at (i,j); W_a is the area-weighting function for (i,j).

The result of this formula is in millisteradians. The value is then normalised against the nominal threshold of visual acuity (a), expressed as a solid angle in millisteradians, and expressed in decibels thus:

$$A_n = 10 \log_{10} (A/a)$$

The reason for the use of this decibel scaling will be explained in section 9.7.12.

9.7.4 <u>Area of Skylined Visible Profile</u>

This descriptor is a measure of the solid angle subtended by that portion of the visible profile of the study object which is seen above the skyline.

The raster image used contains just the visible skylined profile derived as described in section 9.6.3. The formulae used to evaluate the descriptor value in millisteradians and then normalise it into decibels are exactly as described for 'area of visible profile' above.

9.7.5 Length of Visible Edge

This descriptor is a measure of the total angle subtended by the visible edge of the study object.

The raster image is derived in the manner explained in section 9.6.5 above. The descriptor value is then evaluated according to the following formula:

$$E = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{i,j} \; W_e(i,j)$$

The width of the raster is m pixels, and the height n; $P_{i,j}$ is the value of the pixel at (i,j); W_e is the length-weighting function for (i,j).

The result of this formula is in milliradians. The value is then normalised against the nominal threshold of visual acuity (e), expressed as a solid angle in milliradians, and expressed in decibels thus:

$$E_n = 10 \log_{10} (E/e)$$

9.7.6 Length of Skylined Visible Edge

This descriptor is a measure of the total angle subtended by that portion of the visible edge of the study object which is seen above the skyline.

The raster image used contains just the visible skylined edge derived as described in section 9.6.5. The formulae used to evaluate the descriptor value in millisteradians and then normalise it into decibels are exactly as described for 'length of visible edge' above.

9.7.7 Dispersion of Visible Profile

This descriptor is a measure of the dispersion of the visible profile of the design object. There are two alternative approaches, both using the comparison of the actual profile with an equivalent semi-circular profile, as described in the previous chapter.

If the actual edge is taken as a starting point, an equivalent semi-circle may be derived with the same perimeter. The comparison of the area of this semi-circle with the actual (solid-angular) area of the profile gives this formula for dispersion:

$$D_A = 1 - \frac{2\pi A}{E^2}$$

Alternatively, the actual area may be taken as a starting point. An equivalent semi-circle may be derived with the same (solid-angular) area. The comparison of the perimeter of this semi-circle with the actual edge length of the profile gives this alternative formula for dispersion:

$$D_B = 1 - \frac{\sqrt{(2\pi A)}}{E}$$

A and E are the area and edge values, evaluated according to the formulae described previously. The resulting descriptor values are dimensionless in both cases, being ratios normalised into the range 0 (semi-circle) to 1 (finite perimeter, no area). The comparison of these alternative formulae will be discussed further in the case studies.

9.7.8 Dispersion of Skylined Visible Profile

This descriptor is a measure of the dispersion of the skylined portion of the visible profile of the design object. As in the case of the previous descriptor, there are two alternative formulae, identical to those above, but using the skylined area and edge values.

9.7.9 Proportion of Visible Profile Seen Above Skyline

This descriptor simply expresses the proportion of the visible profile which is seen above the skyline. The value of the descriptor is the ratio of the skylined to visible (solid-angular) areas, expressed in millisteradians. The resulting descriptor value is dimensionless, being a ratio normalised into the range 0 (wholly back-clothed) to 1 (wholly skylined).

9.7.10 Contrast of Object with Sky

This descriptor is a measure of the contrast in luminance between the design object and the sky.

This descriptor, alone, makes no use of the frame buffer. It is evaluated from the sky luminance and illuminance, the reflectance of the object, the visual range and the distance of the object from the observer.

The visual range (v) gives the extinction co-efficient (σ) for contrast by the following formula (which assumes 2% as the limiting transmission contrast at distance v):

$$\sigma = 3.91202/v \qquad \text{[Duntley 1948, Purdie 1983]}$$

The sky luminance (B) and illuminance (E), and object reflectance (ρ) give absolute contrast (k) of object with sky by the following formula:

$$k = \frac{(E\rho/\pi)-B}{B} \qquad \text{[Middleton 1968]}$$

The apparent contrast (k_a) at distance (d) is given by:

$$k_a = \frac{k}{e^{\sigma d}} \qquad \text{[Middleton 1968]}$$

The resulting value is dimensionless and ranges from 0 (no contrast) to 1 (black:white contrast).

9.7.11 Order of Evaluation of Descriptors

The descriptors may be evaluated in such an order as to establish invisibility as early as possible in the process, and thus eliminate unnecessary calculation. The order may also make full use of intermediate values to eliminate repetition of calculations. Four bit-planes are required in the frame buffer to achieve this.

The order of evaluation is as follows:

1. Pre-set all descriptor values to zero.
2. Test distance of object against visual range: abort if out of range.
3. Plot foreground in plane 4 and downwards scan-fill it.
4. Plot the building in plane 3.
5. Check for total invisibility of the building. Copy plane 3 to plane 2. Make plane 2 the relative difference between plane 2 and plane 4. Abort if plane 2 is empty. (The silhouette extraction is expensive to carry out if unnecessary.)

6 Extract the building silhouette: the building starts in plane 3; plane 2 is for temporary storage; the silhouette ends up in plane 1.

7 Extract the outline of the solid profile in plane 1 to plane 2.

8 Mask plane 1 against plane 4 by making it the relative difference between the two.

9 Evaluate 'area of visible profile' from plane 1: abort if it is zero. Store the unscaled area for use later on.

10 Evaluate contrast against sky.

11 Mask plane 2 against plane 4 by making it the relative difference between the two.

12 Evaluate 'length of visible edge' from plane 2: abort if it is zero.

13 Evaluate 'dispersion of visible profile' from planes 1 and 2.

14 Plot background in plane 3 and downwards scan-fill it.

15 Mask plane 1 against plane 3 by making it the relative difference between the two.

16 Evaluate 'area of skylined visible profile' from plane 1: abort if it is zero.

17 Evaluate 'proportion of profile seen against sky' from plane 1 and stored visible profile area.

17 Mask plane 2 against plane 3 by making it the relative difference between the two.

18 Evaluate 'length of skylined visible edge' from plane 2: abort if it is zero.

19 Evaluate 'dispersion of skylined visible profile' from planes 1 and 2.

9.7.12 <u>Decibel Scaling of Descriptors</u>

Part of the definition of the algorithms for the 'area' and 'edge' descriptors, described above, is presented somewhat prematurely. The decibel measures were, in fact, introduced after preliminary performance tests had been undertaken, but before the formal verification study was begun. It had originally been intended to normalise the 'area' and 'edge' descriptors to run from 0 at the threshold of acuity to 1 at the full visual field. It was immediately obvious that, measured in this way, these descriptors have near-zero values almost everywhere, except in the immediate vicinity of the design object. The decibel measures were introduced to re-scale these descriptors into a range which would be readily readable in map form. This method of scaling physical quantities is commonly used in psychophysical studies [Stevens 1975, Snodgrass 1975].

9.7.13 Conclusion to 9.7

The algorithms described in this section provide measures which meet the performance specification set out in the previous chapter. They will be tested in action in the verification study and case study in the later chapters of this thesis.

9.8 Conclusion to Chapter 9

The frame-buffer, creating as it does a software image of the scene being analysed, provides a high degree of consistency in the derivation of the descriptor values as all become direct measurements from a single source. In the form proposed in this chapter, the frame buffer is somewhat rudimentary but is extendable. As pointed out above, the limitations are those of scale but are limitations which are becoming less important as computer hardware develops. The specialist hardware required to implement a high-speed frame buffer for this purpose already exists in the form of microprocessors capable of addressing very large contiguous memory arrays and graphics engines implementing the necessary transformations and projections in hardware. Alternatively, the high degree of parallelism in frame buffer operations makes this application suitable for implementation using transputer technology. In either case, present trends in computer technology make this approach an increasingly attractive one with a clear development path possible to full-colour high-resolution frame-buffers while still retaining reasonable performance.

Chapter 10

A Software Package Incorporating Visual Descriptors

10.1 Introduction to Chapter 10

This chapter presents a software package which incorporates the implementation of visual descriptors which was described in the previous chapter. The package contains all of the elements required to carry out the case studies which are presented in the chapters following this one.

The overall structure of the package, the approach to design of the user interface and the strategy for data handling will be described. A brief description of each element of the package follows, outlining its scope and function, and its place in the package.

10.2 The Structure of the Package

The software package, dubbed CAVIA by Purdie [1983] as an acronym for Computer-Aided Visual Impact Analysis, consists of a suite of linked but separate computer programs. Each program carries out some specific task or group of tasks upon the data representing any analysis problem.

The package is separated into individual programs for three principal reasons. Firstly, the package was developed in an environment where some software carrying out related tasks already existed. The adoption of an incremental approach allowed the package to grow stage by stage, while still allowing individual programs to be developed as complete entities.

Secondly, the programs are intended to perform well-defined tasks and are therefore conceived as modules in a larger system. The functionality of the whole package may be extended by adding further modules.

Thirdly, it is anticipated that the package will evolve in terms of efficiency and functionality over time. The modular approach makes it possible to upgrade individual modules, and to test them, without disturbing the whole working system. Similarly, modules may, in time, be replaced by different, but more effective, modules performing an equivalent task. This approach allows such replacement modules to co-exist with those they replace, allowing thorough testing and eliminating the need for an immediate change in operating practices.

10.3 The User Interface

The user interfaces for the various programs in the package have been devised with a designer in mind as the end user. The intention, throughout, has been to make the user interfaces as easy to learn as possible and as consistent as possible.

In order to minimise the number of new skills demanded of a user, the number of different types of user interface has been limited to as few as possible.

Textual menus are the simplest form of interface presented to the user. Almost all of the programs in the suite have at least one of these. The user's actions are restricted to reading the menu, choosing a numbered option and typing in the number. A variant of this also exists where the menu is not displayed but only the prompt for the user to enter a selection. In this case, however, the prompt will also accept the word 'menu' as a response to display the full menu. By use of this variation of the menu, it is possible to allow selection direct from a graphics display without either disrupting the display or waiting for a text screen to be output. An example of a textual menu is shown in figure 10.7.

Parameter selection menus are specialised textual menus. They are used for the setting of parameter values for subsequent (usually graphical) operations. An example is the viewpoint and target positions for perspective drawing. The current settings of parameters are displayed on the screen. The user is then prompted for new values for each parameter, with a null input leaving the value unchanged. An example of this type of menu is shown in figure 10.8.

Graphical interaction menus are more complex and only occur as subsidiary menus within an option selected from a textual main menu, as described above. In this type of menu, a narrow textual menu is presented at the top of a column occupying the left-hand quarter of the screen. This column is used for all textual dialogue. The rest of the screen is given over to graphics. Typically, the user selects a function from the menu by typing in a number and is then prompted either for alphanumeric input via the keyboard and the dialogue column, or for graphical input via the terminal's graphical (usually cross-hair) cursor. Option 1 on the menu is always the command to exit to the next higher level of menu. The graphical display area of the screen is usually a single plan view, but in some applications is divided horizontally into separate perspective and plan windows. An example of a graphical interaction menu is shown in figure 10.9.

Digitizer input also uses a mixed graphics and text display. The screen is divided into a series of boxes (figures 10.2 and 10.4) displaying the current status of various parameters. There is also a large graphics display box, occupying about three-quarters of the screen. A two-line box across the top of the screen is used for messages to the user and for keyboard-entered input. Almost all input is via an active menu on the digitizer surface (figures 10.3 and 10.5). Digitizing software recognises an input from the menu as being a command and input from any other part of the digitizer surface as being data. The graphical display (either perspective or plan) reflects the current status of the data digitized so far. The status boxes are kept up to date as the program parameters are changed by commands entered via the menu.

Command input is used by programs which may be considered to be editors of data files. These are intrinsically more difficult to use than other forms of input: the user is presented with a prompt and is expected to know the command set. One acceptable command is, however, always 'HELP', which displays a list of available commands and their arguments. Programs using this form of interaction are always textual in nature but may use some form of semi-graphical display made up of standard alphanumeric characters (figure 10.6).

There are also programs, or options in programs, which do not strictly follow any of these rules. These are either situations where none of the standard forms of display and interaction were appropriate, or where the interaction was so limited or simple that a prompt-and-response dialogue was sufficient.

10.4 The Organisation of Data

To date, no form of integrated database structure has been introduced into the package. Instead, each program is able to read or write files of a number of standard types. Any further organisation of data, for example by the use of sub-directories or file-naming conventions, is left to the the user to manage.

Two fundamental types of data file are used in the package: raster and vector. Raster-type files cover any data which is represented as a grid of values. These values may be fundamental data describing the landscape, such as topographical elevation, land use classes or soil types. They may, alternatively, be derived data such as slope or aspect analysis; viewsheds, visibility polls or dead-ground maps, or visual descriptors. Raster-type files divide further into two basic varieties: those where the numeric values are integers and those where they may be any real numbers.

Vector-type files cover any non-gridded data. This type of data generally describes some physical element of the problem under consideration (not an abstract value). These elements may be buildings, shorelines, roads, boundaries of tree-blocks, administrative boundaries, contour lines or any other feature which may be defined as a series of 3-dimensional polylines.

A distinction is drawn between fundamental and derived data. Fundamental data describes the physical world in some way and represents the input to a study. Examples of fundamental data are topographic elevation, buildings and land use. Derived data is the product of some processing carried out on fundamental data. It may also represent the physical world but is always an output from some module of the system. Examples of derived data are slope analysis maps, viewsheds and visual descriptors.

All software elements of the package create, gather or interact with one or more data files. Some elements provide direct input from or output to the outside world; other elements process fundamental data into derived data or derived data into other derived data. Some elements are very specific in their operation; others are generic to a type of data file.

10.5 The Components of the Package

A schematic layout of the CAVIA package is shown in figure 10.1. This diagram represents the package as it stood at the end of the present study in the Autumn of 1985. Elements added to the package since that time and elements unconnected with visual impact analysis have been omitted and will not be mentioned in this thesis.

10.5.1 INTERP

INTERP is an interactive, digitizer-based program for the input of contours from maps for the eventual creation of a DTM (figures 10.2 and 10.3).

The user digitizes the map by tracing the printed contours with the digitizer cursor using the digitizer's hardware time- or distance-based sampling mechanism (if available) to achieve a representative sampling of the contour data. The contours are displayed on plan as a map which builds up on the user's terminal screen as the digitizing progresses. The screen display enables the user to detect wrongly-entered contours visually. Limited editing facilities are provided in INTERP, allowing erroneous input to be erased immediately it has been entered.

INTERP interpolates the DTM grid from the raw contour data (hence its name) by creating a Delaunay triangulation [McCullagh and Ross 1980, McCullagh 1983a] and interpolating bilinearly within the triangular patches. Optional facilities are provided to monitor the triangulation process as it takes place and to limit the range of search used to generate triangles. The triangulation process is not infallible. It is possible for there to be too little raw data available for a valid triangle to be formed around any given grid cell. There are also some circumstances in which the interpolation results in an erroneous height being generated. For example, where the triangulated surface used in interpolation conforms poorly to the true ground surface, as it may at summits or ridge-lines, the interpolated heights may be too low. It is also possible for a near-vertical triangle to be generated, leading to instabilities in the interpolation process.

INTERP creates two types of data file. The raw contours are stored as a vector file. The DTM is stored as a raster of real values. Both may be plotted in plan with PLOT2D or displayed in perspective with LANDVU.

10.5.2 ADVENT

ADVENT is an interactive program for digitizing buildings [McAulay and Warbrick 1984] (figures 10.4 and 10.5). It is also adaptable to other related digitizing tasks.

The user digitizes from a plan of the building to be modelled. The program capitalises on the observation that the majority of buildings are wholly, or in part, upward projections of their plans, with vertical walls. ADVENT interprets lines on plan as walls in space according to a number of pre-defined modes, also offering a single-line mode for elements which do not conform to the above observation. A selection of pre-defined primitives are also provided for the rapid digitizing of common but complex forms such as pitched roofs.

The user digitizes the building by tracing the walls which make up the 3-dimensional form on plan, digitizing a single point at each change in direction. A screen display is maintained, building up a perspective view of the 3-dimensional form as it is digitized. Simple editing facilities are provided, allowing deletion of the last point entered or deletion back to the beginning of the current element being digitized.

Two files are output by ADVENT. One is in a format private to ADVENT and is a journal file which stores all commands and data input by the user during a run of ADVENT. This file may be re-loaded into ADVENT for further data to be added at a later time. The second file is a standard vector file, which may be displayed as a building in perspective by LANDVU, plotted in plan by PLOT2D or used by ADE to calculate visual descriptors.

10.5.3 <u>LANDED</u>

LANDED (the LANDscape EDitor) is an interactive program for adjusting the height values in a DTM. LANDED is used principally for correcting any interpolation errors or failures brought about by INTERP (figure 10.6).

The user may use LANDED either to alter an existing elevation file or to create one from scratch (a legacy of pre-digitizer days). The program allows individual grid cells and their neighbours to be examined, heights of grid cells to be changed and cells with specific height values, or values falling in a specified range, to be located.

LANDED both reads and writes elevation data as standard raster-type files. Because of this, it also has a rarely-used secondary function as an editor of other types of real-valued raster-files.

10.5.4 VISIBL

VISIBL is the first of the two main analysis tools in the CAVIA package. This program is concerned with intervisibility analysis (hence the name).

VISIBL is a stop-gap program with a limited projected life-span. It duplicates the more heavily-used features of Turnbull's VIEW1 and VIEW2 programs [Aylward and Turnbull 1977], but uses the same data file formats as the rest of the CAVIA package and offers an interactive menu-driven user interface. It is anticipated that this program will eventually be superseded by later versions of the VIEW programs.

VISIBL takes one or more viewpoints and a DTM as input. The processing actually carried out is at the discretion of the user. For each viewpoint, the program offers calculation of viewshed, depth of dead ground and height of available back-cloth. For a series of viewpoints, the program additionally offers calculation of aggregate viewshed, cumulative visibility poll, aggregate minimum depth of dead ground and aggregate minimum height of available back-cloth.

VISIBL reads in DTM data as standard raster-type files. Viewpoints are either entered at the terminal or, optionally, as a standard vector-type file. Output may be either direct to the lineprinter (or a lineprinter file) or as real- or integer-valued raster-type files.

10.5.5 ADE

ADE (the Automatic Descriptor Engine) is the second of the two main analysis tools in the CAVIA package. It generates visual descriptor values.

ADE must be regarded as being at the experimental stage of development. It is more a vehicle for a feasibility study than a production program. All eight of the visual descriptors listed in the previous chapter are implemented:

1 Area of visible profile
2 Length of visible edge
3 Area of skylined visible profile
4 Length of skylined visible edge
5 Dispersion of visible profile
6 Dispersion of skylined visible profile
7 Proportion of visible profile seen above skyline
8 Contrast of building with sky

The program takes as its input a DTM and one or more closely grouped buildings. The visual descriptor values are calculated for all grid cells in the DTM. The values are obtained in such an order that invisibility can be detected almost immediately, limiting unnecessary processing. The order also allows full use of all intermediate values obtained, eliminating unnecessary repetition of calculations.

Output from ADE is in the form of a series of eight files, one for each descriptor. No other information is output by the program in actual use. In the early stages of development, however, numerical values for the descriptors at specific viewpoints were available for verification purposes, as was a dot-matrix printer dump of the frame-buffer at various stages in the derivation of the descriptor values.

ADE reads in the DTM as a standard real-valued raster-type file and the building as a standard vector-type file. The descriptor values are output as real-valued raster-type files with the same grid parameters as the underlying DTM.

10.5.6 LANDVU

LANDVU is one of the two principal output modules of the CAVIA package. It is basically an interactive 3-dimensional perspective-drawing program, designed specifically to be optimal for landscape visualisation (hence the name) (figures 10.7-10.11).

LANDVU is capable of displaying a DTM in perspective as a warped mesh, as contours or as the visible edges of the landform. Full hidden-line elimination of the DTM is provided, as is simulation of earth-curvature and the refraction of light. Buildings and other vector-represented surface features may also be displayed. Surface features are correctly masked by the DTM but are otherwise drawn as wire frames.

Full freedom of view is provided: any combination of viewpoint and target may be specified. The viewcone angle may also be specified as any angle up to 150°.

Output from LANDVU is to any output device available, generally the user's terminal and plotters. Plotted output may be scaled to provide an accurate match to photographs.

On a suitable colour terminal, LANDVU also offers the option to display an attribute file, which may be any form of fundamental or derived rasterised data relating to the DTM. The attribute data may be displayed on plan as a grid of coloured blocks of varying intensities, according to the varying attribute values. It is possible to select a viewpoint and target for a perspective view directly from this display, in order to see immediately the 3-dimensional meaning of the 2-dimensional attribute pattern. This facility was devised specifically for the display of visual descriptor data.

10.5.7 PLOT2D

PLOT2D is the second of the two principal output modules of the package. It is a 2-dimensional plotting program (hence the name), producing accurately scaled plans or maps of CAVIA data (figure 10.12-10.15).

PLOT2D is capable of representing integer- or real-valued raster-type files and vector files to a specified scale and framed by specified limits of northing and easting. Legend-plotting facilities are also provided.

Real-valued raster data may be displayed as contour lines, as hatched symbols with density varying according to the data value or to the first derivative of the data value or as arrows indicating direction and magnitude of slope. The choice of which of these to use depends upon the actual meaning of the data: not all forms of representation are appropriate to any given data type.

Integer-valued raster data may be displayed only as various densities of hatching.

Vector-type files are simply plotted as the 2-dimensional projection of the 3-dimensional polylines they define.

Output is to any available plotter with preview facilities available on a suitable graphics display terminal.

10.5.8 Supplemetary Programs

In addition to the main components of the suite, which have been described above, there are a number of supplementary programs, usually referred to as the 'LANDVU tools'. These tools carry out particular specific operations on data files. For example, there are programs to interpolate one DTM grid from another; to carry out geometrical transformations on building files; and to translate file formats for import or export of data to or from other packages. The tools are often crude, compared with the main programs in the suite; frequently written on a 'one-off' basis for specific tasks on specific occasions. It is proposed that a basic toolkit of fundamental utilities will be identified and presented as one or more file manipulation programs.

10.6 Data Manipulation

The file format specifications have deliberately been kept as general as possible so that the same tools may be used for many different purposes in data preparation and manipulation. New classes of data may also be introduced and tested without requiring wholly new software to be developed for manipulation and display purposes.

Different classes of data are thus often stored in identical data formats. The semantic differences between different classes is simply a matter of usage. For example, the software is capable of contouring a land-use map, but the result is meaningless. On the other hand, it is of positive benefit to be able to load both elevation files and land-use files into the 'attribute file' slot of LANDVU or to be able to plot both of them with similar symbols using PLOT2D.

As stated previously, the user has the responsibility of managing and organising his data. This can be confusing for naïve users, but enables the suite to be used much more flexibly and creatively than would otherwise be the case.

10.7 Conclusion to Chapter 10

The suite of programs described in the foregoing sections provides an adequate range of facilities for a visual impact study within the limitations of the terms of reference of this study. Further tools are, however, required for more broadly-based studies to provide facilities such as cross-section plotting, cut and fill calculation for earthworks, analysis of drainage, calculation of effective latitude or prediction of forestry yield. Some of these tools have, in fact, since been added to the CAVIA package or already existed in the VIEW suite and have been used in conjunction with file conversion utilities.

While the computer graphics presented to the user are highly accurate geometrically, they are nevertheless crude in their rendering of the image. This is in keeping with the declared purpose of the package as a set of design tools. The graphical product is always of the minimum quality required to achieve the task in hand. Performance is thus kept to the maximum possible. While the performance, particularly in the case of visual descriptor calculation, is often still too poor to permit true interactive use, the turn-around time for an iteration of the design cycle is kept to a minimum.

Chapter 11

Performance and Verification Studies

Performance and Verification Studies

11.1 Introduction to Chapter 11

This chapter describes the tests carried out to verify the correct operation of the ADE program and to determine its inherent limitations and shortcomings.

This verification study has two main objectives. The first is to check that the program as implemented does, in fact, correctly embody the algorithms described in previous chapters. The second is to evaluate the performance of those algorithms against the expected performance of the purely mathematical conceptual models from which they were derived.

In order to carry out these tests, four special trial data sets were created. These data sets were designed to be geometrically simple in order to be able to predict the mathematically correct results and to compare these with the results actually obtained by running ADE. Similarly, the test data sets were designed to provide enough variation to distinguish between errors of implementation and fundamental shortcomings of the algorithms used.

A secondary objective of these tests was to prove the utility of the output produced by ADE and by LANDVU. This test is necessarily a much more subjective one which rests on the ability of the graphical information presented to a prospective user to be read.

11.2 Test Data

The output from ADE is a series of grids of visual descriptor values each of which provides a form of map describing the visual interaction of building (or other object) with landscape. In order to test these interactions, two simple buildings and two simple landscapes were modelled. In all cases the geometry was deliberately kept simple in order that the interaction should be comprehensible on an intuitive level.

The two buildings modelled are shown in figures 11.1 and 11.2. The first of these (figure 11.1) is a simple cylinder. This should exhibit isotropic patterns for all descriptors (ignoring landscape effects for the moment). The second building (figure 11.2) is a slab with width, length and height in the ratios 1:5:5. This should exhibit a marked anisotropy but strict symmetry in the patterns formed owing to its varying profile from different angles but inherent bilateral symmetry.

The two landscape models are shown in figures 11.3 and 11.4. The first of these (figure 11.3) is a perfectly flat 51 × 51 square grid DTM. This should not affect the patterns produced by the two buildings in any way. The second landscape (figure 11.4) is also a 51 × 51 square grid DTM but with a single hill placed centrally. The hill is a solid of rotation based on a full cycle of a sine wave from minimum to minimum. The height of the hill greatly exceeds the heights of the two buildings and its overall diameter is equal to half the width of the DTM. This hill should produce simple but marked perturbations in the patterns produced by the descriptor measures of the two buildings.

All four combinations of building and landscape were modelled. In the case of the flat landscape, the buildings were placed centrally. In the case of the hill, the buildings were placed South-West of centre on the flat portion of the DTM at the foot of the hill.

The experiments thus combine the uniform pattern of the cylinder and the non-uniform pattern of the slab with the neutral effects of the flat landscape and the perturbation to one quadrant of each pattern by the hill on the second test landscape.

11.3 Processing

For each of the four combinations of test data, the full set of eight descriptors implemented in ADE to date was run. These are as follows:

1 Area of visible profile
2 Length of visible edge
3 Area of skylined visible profile
4 Length of skylined visible edge
5 Dispersion of visible profile
6 Dispersion of skylined visible profile
7 Proportion of visible profile seen above skyline
8 Contrast of building with sky

11.4 Display and Reproduction

LANDVU was used as the presentation tool in all cases. LANDVU offers an option to draw the values in a landscape attribute file as an array of coloured blocks whose brightness reflects the numeric values of the cells of the attribute file. This may optionally be overlaid by the contours of a DTM and the plan outlines of one or more buildings.

The choice of colours used in these tests was largely dictated by their reproducibility in colour photographs. Some of the more effective colours on the screen are reproduced very poorly by the limited range of contrast possible in a colour print (only about 10:1 lightest:darkest) compared with the CRT display (over 100:1). The basic hues selected for each descriptor are as follows:

1	Cyan	(Area of visible profile)
2	Yellow	(Length of visible edge)
3	Cyan	(Area of skylined visible profile)
4	Yellow	(Length of skylined visible edge)
5	Green	(Dispersion of visible profile)
6	Green	(Dispersion of skylined visible profile)
7	White	(Proportion of visible profile seen above skyline)
8	White	(Contrast of building with sky)

In all cases the saturation of colour used is 100% (except white which has 0% saturation) with the range of values present mapped onto the range 0-100% lightness. These colours are used consistently throughout this and succeeding chapters.

In the case of the second test DTM (the one with the hill), the terrain contours (perfectly circular in this case) are superimposed on the coloured blocks representing the descriptor values. The plans of the two buildings are also superimposed on the coloured blocks

The graphics were displayed on a Sigma colour terminal capable of displaying 256 simultaneous colours to a resolution of 768 × 512. The photographs were taken using a 35mm single-lens reflex camera with a 50mm lens on a tripod. Some distortion is visible in the photographs due to the curvature of the terminal screen.

11.5 Evaluation of Results

11.5.1 Cylindrical Building on Flat Landscape

11.5.1.1 Area of Visible Profile

This descriptor should exhibit a square-law decrease in value outwards from the building and this decrease should be uniform in all directions. The pattern actually obtained (plate 11.1) reflects this property correctly. The circular edge to the pattern is produced by the fairly small radius of visibility used for these test runs.

The apparently stray block of colour visible at the top of the pattern is an artefact of a rounding error in calculating the radius of visibility. The centre of that block should actually be exactly on the threshold of visibility.

The clear steps in colour visible within the coloured pattern are artefacts of the quantisation that has to take place to map a continuous function onto a finite range of colours. The colour within each annular zone visible is, in fact, uniform. The apparent shading is due to contrast with the black background and to Mach Band Effect [Gregory 1969].

11.5.1.2 Length of Visible Edge

This descriptor should exhibit a linear decrease in value outwards from the building and this decrease should be uniform in all directions. The pattern actually obtained (plate 11.2) reflects this property accurately. As before, the circular edge to the pattern is produced by the fairly small radius of visibility used for these test runs. Although the pattern is superficially similar to the preceding descriptor, the steps in colour change occur at approximately equal intervals (only approximately equal because of rounding and quantisation effects) as compared with the increasing intervals going outwards from the building in the case of the area-based descriptors.

All remarks regarding rounding and quantisation effects are equally applicable to this and all succeeding descriptors.

11.5.1.3 <u>Area of Skylined Visible Profile</u>

In the case of this test data set, with no terrain relief, the resulting pattern should be almost identical to the 'area of visible profile' descriptor. The only part of the profile not seen against the sky should be a narrow strip along the base of the visible profile. The pattern actually obtained (plate 11.3) reflects these properties. The patterns for this descriptor and the previous one turn out to be almost identical in the case of this test data. The small differences in value between the two are almost entirely lost in the quantisation effects of allocating the different ranges of colour.

11.5.1.4 <u>Length of Skylined Visible Edge</u>

As was the case with the area-based descriptors, the pattern should be almost identical to the related 'length of visible edge' descriptor because of the flat landscape. The only part of the edge not seen against the sky should be a small piece at either side of the base of the visible edge. The pattern actually obtained (plate 11.4) reflects these properties. The patterns for this descriptor and 'length of visible edge' turn out to be almost identical in the case of this test data. Also, as was the case with the area-based descriptors, the small differences in value between the two are almost entirely lost in the quantisation effects of allocating the different ranges of colour.

11.5.1.5 Dispersion of Visible Profile

This descriptor should produce a nearly-uniform value throughout the area where the building is visible as the descriptor is defined as a measure of the relationship between the visible edge-length and visible profile-area of the building. Two different algorithms have been tested for this descriptor and the following one. The rationale for this change of algorithm will be explained later in this chapter.

The patterns produced by the two algorithms do not actually produce as uniform a pattern as would be expected (plates 11.5 and 11.6).

The centre of the pattern appears too bright. This is due to the building falling partly outside the boundaries of the cone of vision as seen from very close viewpoints. The area is duly reduced by clipping to the edge of the frame and this is reflected in the area-based descriptors. The algorithms used for the edge-based descriptors, however, cannot distinguish between the real profile of the building and that clipped by the edge of the frame. The length of edge therefore also includes elements of outline which are not truly part of the exterior edge of the visible profile. This discrepancy between the clipping effects for areas and edges results in spuriously high values for the dispersion descriptors in the case of very close viewpoints.

There are also several unduly bright cells in the pattern together with a general noisiness to the function as represented by the coloured blocks (this is only really visible in plate 11.6). The underlying cause for this is aliasing brought about by the finite pixel size and the binary nature of the pixels in the frame buffer. The setting of pixels in the routines which draw lines in the frame buffer is done on the basis that any data falling into a pixel will cause it to become set. This policy does not recognise the fact that many pixels should only be partly filled, thereby introducing aliasing into all line segments and the edges of all areas drawn. This is particularly critical in the case of the buildings used in these tests which have rectangular or near-rectangular profiles. As the viewpoint moves away from the building, the profile should diminish uniformly, but is only able to diminish by decrements of a whole row or column of pixels in its profile (or by both). The length of edge, on the other hand, is not so constrained and will typically vary by a single pixel between adjacent values. Singly, these effects only produce varying quantisation effects. Combined, however, their disparity produces considerable fluctuation in value. The background noise in the pattern and the few spuriously bright cells are brought about by these aliasing effects.

11.5.1.6 Dispersion of Skylined Visible Profile

As was the case with the previous descriptor, this descriptor does not produce as uniform a result as would be expected (plates 11.7 and 11.8).

The same considerations apply to this descriptor as to the previous one. The bright centre to the pattern is an artefact of the clipping effects experienced with very close viewpoints. The generally noisy background colour to the pattern (with some annular elements visible in this case in plate 11.8) is due to aliasing effects as before, although in this case there are no particularly bright spikes of noise as there were in plates 11.5 and 11.6.

11.5.1.7 Proportion of Visible Profile seen above Skyline

This descriptor in this situation should present a nearly uniform value with a small increase in proportion seen above the skyline as distance from the building increases (the horizon appears lower down in relation to the building with increasing distance). In practice, the pattern shows distinct perturbations (plate 11.9) due to the differences in the aliasing effects experienced by the two underlying area measures.

11.5.1.8 Contrast of Building with Sky

This descriptor displays the pattern which would be expected (plate 11.10), exhibiting an exponential decay in value with increasing distance from the building.

11.5.2 Slab Building on Flat Landscape

11.5.2.1 Area of Visible Profile

The pattern produced by this descriptor is much as would be expected (plate 11.11), displaying similar characteristics to that produced by the cylindrical building with this descriptor. The only difference is the expected one whereby the value of the descriptor varies with the aspect of the building seen from any particular viewpoint. The minimum values are very pronounced, reflecting the narrow ends of the slab; the maximum values rather less pronounced, reflecting the broad side-on views.

All the foregoing remarks regarding rounding, quantisation and aliasing effects are equally applicable to this test data set.

11.5.2.2 Length of Visible Edge

The pattern produced by the edge-based descriptors (plate 11.12) displays much less pronounced minima owing to the lesser variation in length of edge than area of profile between side and end aspects.

11.5.2.3 Area of Skylined Visible Profile

The pattern produced by this descriptor is also as would be expected (plate 11.13), differing from the pattern produced by the cylindrical building only in displaying the deep minima in values at the end-aspects of the building as was the case with the previous descriptor.

11.5.2.4 Length of Skylined Visible Edge

The pattern produced by this descriptor also displays the expected less pronounced minima described above (plate 11.14).

11.5.2.5 Dispersion of Visible Profile

This descriptor suffers from the problems of noise induced by aliasing effects and by close-in clipping effects (plates 11.15 and 11.16) as described in the case of the cylindrical building. This example displays more marked noise than was the case previously. The symmetry of the noise patterns reflect the symmetry of the aliasing effects brought about in a symmetrical data set. In addition to this spurious variation, clear maxima are visible radiating from the narrow ends of the slab. These correctly reflect the increased dispersion of the end profiles compared with the side-on case.

11.5.2.6 Dispersion of Skylined Visible Profile

This descriptor also correctly shows the maxima radiating from the ends of the slab (plate 11.17 and 11.18) but suffers from less noise in the general value of the descriptor.

11.5.2.7 Proportion of Visible Profile seen above Skyline

This descriptor suffers from the same aliasing effects as were visible in the case of the cylindrical building (plate 11.19). There are no noticeable maxima or minima in the pattern as the proportion of profile which is skylined is largely independent of the aspect of the building seen on a flat landscape.

11.5.2.8 Contrast of Building with Sky

As before, this descriptor simply reflects the correct exponential decay of contrast with distance (plate 11.20).

11.5.3 Cylindrical Building on Landscape with Hill

11.5.3.1 Area of Visible Profile

This pattern produced by this descriptor with this test data shows clearly the perturbation of the pattern produced by the hill in the centre of the DTM (plate 11.21). Other than this effect, the pattern is exactly that produced by the cylindrical building on the flat landscape. The pattern also correctly shows a diminution of visible profile at the edges of the visible zone reflecting the case where the building is partially masked by the hill. This is not the case at the summit of the hill, where the transition from visible to invisible is much faster, occurring within the span of a single cell.

11.5.3.2 Length of Visible Edge

The pattern produced by this descriptor in this case also shows the masking effect of the hill clearly (plate 11.22). A transition from visible to invisible is apparent in the pattern in this instance as was the case with the previous descriptor.

11.5.3.3 Area of Skylined Visible Profile

The pattern produced by this descriptor (plate 11.23) shows two elements of perturbation as compared with the equivalent case on the flat DTM.

The hill itself masks the building, producing a diminution of the value of the descriptor as was the case with the 'area of visible profile' descriptor. The hill also provides back-cloth to the building, so that to the South-West of the building there is a significant area where the building has no skylined profile. For viewpoints very close to the building, the building appears taller than the hill so that there is some skylined profile.

The value of this descriptor on the slope of the hill adjacent to the building is zero. This reflects the fact that from an elevated viewpoint on the hill, the building is seen against the ground, not against the sky.

11.5.3.4 Length of Skylined Visible Edge

This descriptor exhibits similar properties to the previous one, producing much the same pattern (although with linearly not quadratically diminishing values with distance) for the same reasons (plate 11.24).

11.5.3.5 Dispersion of Visible Profile

Predictably, this descriptor has non-zero values only where the 'area of visible profile' and 'length of visible edge' descriptors have non-zero values (plate 11.25). The descriptor exhibits the noisiness found in previous examples of the dispersion descriptors for the usual reason of aliasing.

The cells at the edges of the pattern exhibit noticeably higher values than their immediate neighbours. This correctly reflects the increased dispersion of a partially-masked profile.

The increased values on the slope of the hill adjacent to the building are correct but specific to the particular shape of the building used in this test. The proportion of width to height of the building happens to result in an increased dispersion of profile at elevated angles of view.

11.5.3.6 Dispersion of Skylined Visible Profile

This descriptor's pattern follows that of the 'area of skylined profile' and 'length of skylined edge' descriptors (plate 11.26). The increased values at the edges of the pattern are noticeable and present for the same reason as they appear with the previous descriptor.

11.5.3.7 Proportion of Visible Profile seen above Skyline

This descriptor's pattern (plate 11.27) is basically the same as that for the same building on a flat DTM but with two distinct perturbations due to the hill.

The areas masked by the hill exhibit a clean cut-off at the transition from visible to invisible. This is to be expected as masking has little or no effect on the proportion of skylined area.

The areas where there is no skylined area, on the other hand, exhibit a transition zone from (in this case) almost wholly skylined to not skylined at all. The extent of this transition zone will vary according to the particular geometry of building and DTM.

11.5.3.8 Contrast of Building with Sky

This descriptor exhibits no variation in value from the usual exponential decay function, the only change being the area masked by the hill (plate 11.28).

11.5.4 Slab Building on Landscape with Hill

11.5.4.1 Area of Visible Profile

The pattern in this case (plate 11.29) differs from the case of the cylindrical building only in exhibiting the minima in area of profile at the end aspects of the slab.

11.5.4.2 Length of Visible Edge

The pattern in this case (plate 11.30) also exhibits the expected variation due to the varying profile of the slab.

11.5.4.3 Area of Skylined Visible Profile

The pattern in this case (plate 11.31) exhibits the expected variation due to the varying profile of the slab and the interaction of this pattern with the pattern produced by the masking and back-clothing effects of the hill.

11.5.4.4 Length of Skylined Visible Edge

The pattern in this case (plate 11.32) similarly exhibits the expected interaction of patterns due to the varying profile of the slab and the effects of the hill.

11.5.4.5 Dispersion of Visible Profile

The pattern in this case (plate 11.33) clearly exhibits the effects of the transition to the area masked by the hill, the effects of elevated viewpoints on the hill and the effects of the varying profile of the building despite the noise present in the background colour of the pattern.

11.5.4.6 Dispersion of Skylined Visible Profile

In addition to the effects noted for the previous case, the pattern in this case (plate 11.34) also shows the effects of the transition into the back-clothed area.

11.5.4.7 Proportion of Visible Profile seen above Skyline

In this case, this descriptor displays the same pattern as in the case of the cylindrical building (plate 11.35)

11.5.4.8 Contrast of Building with Sky

As in the case of the cylindrical building, this descriptor exhibits no variation in value from the usual exponential decay function, the only change being the area masked by the hill (plate 11.36).

11.6 Modifications to Algorithms

Following these tests two changes have been made to the algorithms in use in the generation and display of visual descriptors. These are additional to the adoption of decibel scaling for the 'area' and 'edge' descriptors, which was mentioned in the previous chapter. Of the two alternative algorithms for the calculation of dispersion values in ADE, one has been selected and the other discarded. The algorithm for allocating colours to descriptor values for display in LANDVU has also been altered.

11.6.1 Decibel Scaling

As was mentioned in Chapter 9, the 'area' and 'edge' descriptors were originally intended to be scaled from zero at the threshold of acuity to unity at the full visual field. The initial testing of the ADE program (to test whether it worked), however, showed that the descriptors produced unreadable patterns when scaled in this way: the entire pattern, except for the few cells immediately surrounding the design object, was uniform in tone. Many psychophysical measurements suffer from the same problem and the commonly adopted solution is the use of decibel scaling [Stevens 1975].

The use of decibel scaling is effective in this application. This is for two related, but distinct, reasons. Firstly, the variation in values for the descriptors are spread more evenly through their range, and the huge ratio between highest and lowest values reduced. This simply moves the steps in colour in the display outwards from the design object and distributes them throughout the pattern, revealing the internal structure of the pattern. Secondly, the decibel scaling has much the same effect as the use of log-scaled graph paper: the underlying functions which contribute to the descriptor patterns are rendered near-linear. This linearity makes perturbations to the underlying patterns much clearer and more easily detectable by eye.

11.6.2 Dispersion Algorithms

Two alternative formulae for evaluating the dispersion descriptors were originally proposed. These were referred to as the A and B formulae, applying both to the dispersion of the visible profile and the dispersion of the skylined profile. The two formulae are as follows:

$$D_A = 1-\frac{2\pi A}{E^2}$$

$$D_B = 1-\frac{\sqrt{(2\pi A)}}{E}$$

Where A is the area of profile and E is the length of edge, as solid angular and angular measurements respectively.

As may be seen from the colour plates of the dispersion descriptors from the test runs on the flat DTM (plates 11.5 - 11.8 and 11.15 - 11.18), the results from formula A for dispersion (11.5, 11.7, 11.15 and 11.17) are less easily read than those using formula B. This is simply due to the relative distribution of values and the non-linearity of the A and B formulae.

The B formula also reduces the intrusiveness of the aliasing effects found in the patterns of the 'dispersion' descriptors, due to the implicit re-scaling introduced by the square root in the second term of the formula.

As the two formulae both describe the same conceptual phenomenon, the B formula has been selected for future use on the basis of its improved readability.

11.6.3 Display Algorithms

The colours used by LANDVU to display visual descriptor data are produced as steps along a scale of colours having constant hue and saturation. At the time of carrying out the verification studies and the subsequent case study, the colours were produced as steps of equal difference in lightness. This has proved not to be ideal in practice as the colours at the bright end of the scale are difficult to distinguish from one another.

The equal-step scale is defined as follows where L_i is the lightness of the i^{th} step in a scale of n steps:

$$L_i = \frac{i}{n}$$

A more easily read scale is one where there are equal ratios between the steps. If L_1 is defined as $1/n$ as before, the following formula defines the lightness of the i^{th} step in such a scale of n steps:

$$L_i = \frac{\left(e^{\frac{\log_e n}{n-1}}\right)^{i-1}}{n}$$

This formula has now been adopted as standard.

11.7 Conclusion to Chapter 11

In the test examples, the eight descriptors so far implemented in ADE produce values which are consistent with the values which would be expected, within the known tolerances of the underlying pixel size and the consequent quantisation effects.

The patterns produced, when the descriptors are displayed with LANDVU, agree closely with the anticipated patterns. All features visible in the patterns are either expected elements which describe some element of the interaction of building and landscape or are artefacts of the algorithms adopted with explainable causes and behaviour.

While undesirable, the quantisation and aliasing effects visible in some of the patterns are not serious enough to mask the genuine features of the patterns. The aliasing effects could be reduced either by the adoption of a larger frame buffer with comparatively smaller pixels or by the use of an anti-aliasing strategy to resolve sub-pixel structures, such as that used in the A-buffer [Carpenter 1984]. An anti-aliasing approach would be worth investigating: for example, by pairing all the bit-planes in the frame buffer, it would be possible to represent each pixel as a 2-bit binary number in the range 0-3, giving the illusion of a quadrupled frame resolution. The most serious aliasing, apparent in the dispersion descriptors, has, however, been alleviated to some extent by the adoption of the B formula for evaluating the descriptor values. The quantisation effects compressing the higher values of the descriptors are less serious but are effectively lessened by the adoption of the improved colour-allocation strategy in LANDVU. The use of more colours than the 64 currently used is not worthwhile and would also serve to diminish the visibility of the quantisation steps which serve as useful contours of equal descriptor value.

In general, the visual descriptor patterns appear to provide an effective, easily interpreted and understood overall picture of the visual performance of the test buildings and landscapes.

Chapter 12

Case Study:
Visual Descriptors as Design Tool

12.1 Introduction to Chapter 12

This chapter presents a case study of the use of visual descriptors as a part of the visual analysis of a large building in rural landscape. The case study is as full as is practical in the context of the present study. Some of the underlying assumptions in the design problem and the attitudes adopted to various design constraints have been simplified where they are not directly relevant to the issue of visual impact analysis.

The design vehicle chosen for this case study is a nuclear power station. The locality of a real power station will be examined to identify a range of alternative sites, including that actually used. The visual properties and performance of these sites will be examined both in terms of the patterns produced by the visual descriptors and as perspective views.

The criteria for judging the effectiveness of visual descriptors as a design tool will be twofold. Firstly, as described in the previous chapter, the utility of the descriptors depends upon the readability of the patterns produced by them. In this case study, a real, complex landscape is used together with a complex group of buildings, and a critical element of the study is to ensure that the patterns produced by the descriptors in this situation are both explainable and understandable. Secondly, the visual descriptors are intended to be used as one element in a set of design tools. For such a set of tools to be used together, the individual tools complement each other in the information they present to the user and enable a clear, holistic understanding of the visual environment to be reached. This case study will also assess the degree to which visual descriptors and more established design tools complement each other.

12.2 The Test Problem

The test site chosen is Hinkley Point Nuclear Power station in North Somerset.

The rationale for the choice of building type is that a nuclear power station is a large building in rural, often remote, landscape. The rural character of the surrounding landscape ensures that the Power Station is one building (or a closely grouped complex) well away from any other of comparable scale rather than one building among many, thus providing a clearer test example for visual descriptors. The large scale of the building compared with its surroundings also ensures that vegetation will have a minimal effect on its actual visibility and minimal distortion of the patterns of interaction between building and landform.

The Hinkley Point site provides a particularly varied landscape. The power station site is coastal, as are all British civil nuclear plants. In addition to offering views from both land and sea, Hinkley Point enjoys a range of types of local landform. the power station site (figure 12.1) stands on a north-facing Bristol Channel coastline at the foot of rolling hills which form the eastern foothills to the Quantock ridge, rising to 1175 feet. The Quantock Hills reach the Bristol Channel some five miles west of the power station site and form the skyline from west round to south-south-east. To the east of the site is the mouth of the River Parrett and beyond that, to the south-east and east, the Somerset Levels, stretching out flat some fifteen miles to Glastonbury.

A range of local viewpoints are to be considered, intervisibility studies carried out and their individual and combined viewsheds determined. From the resulting intervisibility patterns, a number of potential alternative sites for the Power Station will be identified (in addition to the actual site). Each of these sites will then be used for the generation of a full set of eight visual descriptor patterns. In addition to the visual descriptor patterns, a range of perspective views will be generated, showing the Power Station on its alternative sites in context.

The relative merits of the alternative sites will be discussed (within the limited range of design parameters considered in this case study). The performance of the visual descriptor patterns in providing the necessary information will be discussed and the overall effectiveness of the range of design tools used will be evaluated.

The effects of vegetation and built-up areas will be ignored for the purposes of this case study. This policy ensures that the findings of the study will relate to a 'worst case' situation. It also caters for the fundamental shortcoming of the use of a gridded model that the fine detail of woodland and urban areas cannot be represented adequately. The use of a 'bare ground' model ensures that 'glimpse' views through trees or between buildings are allowed for.

12.3 Data Capture

12.3.1 The digital terrain model

The study area selected for this case study is bounded by the following Ordnance Survey National Grid references:

North west:	ST 100 500
North east:	ST 340 500
South west:	ST 100 400
South east:	ST 340 400

This defines a rectangle 24km × 10km: a total area of $240km^2$ (figure 12.1). The study area contains the northern end of the Quantock ridge, the mouth of the River Parrett, part of the Somerset Levels, the western end of the Polden Hills and the towns of Highbridge and Burnham-on-Sea.

Owing to the then-current limitations in the software, the digital terrain model was constructed as a grid of 121 × 51 points with a grid increment of 200m. (The performance of the current versions of the software would, for example, allow a 481 × 201 × 50m grid to be contemplated or a larger study area to be used.)

The DTM was based on the contour information on the Ordnance Survey 1:25000 scale maps of the area. All contours falling inside the study area were digitized using the program INTERP. In order to allow the interpolation process to operate correctly, contours immediately outside the study area were also digitized up to a distance of 1km from the study area boundary. All spot-heights shown on the maps were also digitized. The study area contains a large proportion of sea. The sea was digitized as many spot-heights of zero altitude.

The interpolation of contours to grid was also carried out using INTERP. In situations where there is insufficient contour data to interpolate, INTERP leaves an unset height in the grid (actually a rogue value recognised as representing an absence of data).

The DTM was checked by plotting the contour map of the DTM over the input contours. Some minor discrepancies between the two patterns are inevitable, but major mismatches imply either a problem with the interpolation process or an error in digitizing (a contour height entered wrongly, for example).

The few errors that did occur were all in the Somerset Levels and were interpolation errors brought about by the paucity of data in that area.

The program LANDED was used to correct the errors in the grid, by manually substituting the correct heights (read from the Ordnance Survey map) for those left unset by INTERP. The checking of the DTM by contouring was repeated to verify that the DTM was indeed correct after modification.

A perspective view of the completed DTM is shown in figure 12.2.

12.3.2 The Coastline

To provide a reference feature for both plan and perspective views, the coastline was also modelled. The source for the data was the 1:25000 scale Ordnance Survey maps, as was the case with the contours.

The high and low water marks, including the banks of the River Parrett to the highest tide point and all off-shore sand banks, were digitized using the program ADVENT (actually intended for buildings but equally applicable to coastlines). The coastline model is shown with the DTM in figure 12.2.

12.3.3 The Power Station

Hinkley Point Nuclear Power Station was modelled as an outline model (figure 12.3). The form of the buildings but not the fine detail was included as only distant viewpoints were contemplated and surface details have no effect on the visual descriptors.

No detailed drawings of the Power Station are available to the general public (for security reasons) so it was necessary to resort to a range of secondary sources in order to build the model.

The plan of the power station complex, consisting of the Magnox 'A' Station and the AGR 'B' Station is shown in reasonable detail on the 1:2500 scale Ordnance Survey map. This was used as the source for the plan of the station. The elevational details were taken from photographs. On-site photographs were taken from the road to the Power Station and from the Somerset Coast Path. An aerial view of another nuclear power station was found in CEGB promotional material. This station (believed to be Sizewell) appears to have identical buildings to those found at Hinkley Point 'A' Station. The highest part of the Power Station is about 52m above ground level at the top of the reactor building of the 'A' Station.

From the information collected, a sketch plan and elevation of the Power Station were prepared. These were then digitized using the program ADVENT.

12.4 Intervisibility Studies of Critical Viewpoints

12.4.1 Introduction to 12.4

The object of carrying out intervisibility studies is to arrive at a small selection of possible coastal sites for the Power Station. The studies will take a number of viewpoints and determine the properties of the surrounding landform with regard to visibility and to depth of dead ground both on an individual, per-viewpoint basis and aggregated for all viewpoints. The viewpoints are selected by the user as those being critical. This judgment is necessarily subjective and, to a degree, intuitive, based on known locations whose visual environments are to be preserved or are known to be sensitive and on locations where many people are likely to be affected.

A total of 22 viewpoints will be considered. They will be divided into four groups as follows:

1. Views from the M5 motorway
2. Views from the shoreline near Burnham-on-Sea
3. Views from the A39 trunk road
4. Views from the Somerset coastal route

The viewshed and dead ground patterns relative to each viewpoint, to each group and to all viewpoints will be studied.

The viewshed is the area which can be seen from a given viewpoint (for the purpose of this study an unlimited radius of visibility was assumed). It is represented as a lineprinter-drawn map of symbols. An aggregate viewshed for each group of viewpoints and for all viewpoints will also be derived. This is represented as a lineprinter map of symbols of varying density showing the 'number of times seen' for each grid node on the DTM relative to the viewpoints under consideration.

Dead ground is ground which cannot be seen from the viewpoint. Its depth may be measured by considering the maximum height of building which could be hidden from the viewpoint at any position on the DTM. It is also represented by a line-printer map of symbols of various densities. An aggregate dead-ground map for each group of viewpoints and for all viewpoints will also be derived. The aggregate dead-ground depth of any point relative to a set of viewpoints is the minimum of all the individual dead-ground depths for that point.

All intervisibility analysis will be carried out using the program VISIBL which basically mimics the operation of Turnbull's program VIEW1 but expresses itself to the user and expects input from the user more consistent with the method of operation of the programs developed during the course of this programme of study.

12.4.2 <u>Views from the M5 Motorway</u>

The M5 is the most heavily used road through the study area. Clear views to the Hinkley Point Power Station site are obtainable from the motorway. The views are interrupted by motorway bridges, individual buildings and the towns of Highbridge and Burnham-on-Sea.

The following five viewpoints were used to represent the whole of the motorway between junctions 22 and 23 (figure 12.4):

ST 31500 41000
ST 31900 43000
ST 32450 45000
ST 32100 47000
ST 34000 49000

The viewshed patterns from each of these viewpoints are shown in figures 12.5 - 12.9 respectively. The dead-ground patterns are shown in figures

12.10 - 12.14. The aggregate viewshed, visibility poll and dead-ground pattern for this group of viewpoints are shown in figures 12.15 - 12.17.

As the viewpoints progress from south to north along the motorway, narrow glimpses of the coast seen between hills (figures 12.5 and 12.6) change to a very restricted view at the gap in the Polden Hills (figure 12.7) then give way to a broad view across the coast at Burnham-on-Sea towards Hinkley Point and beyond (figures 12.8 and 12.9). These changes in visibility may clearly be seen in the viewshed patterns. The strips of invisible cells along the coastlines are due to the difference in level between land (about 5m) and sea (zero), resulting in a strip of dead ground (of very limited depth).

The aggregate visibility map (figure 12.15) shows almost complete coverage of the study area, only the area screened by the hills to the west remaining completely invisible (other than the small and shallow areas of dead ground produced by the coastline and the channel of the River Parrett and three small patches screened by the Polden Hills).

The visibility poll map (figure 12.16) shows a more complete picture. The most-seen areas are the low lying areas to the east, through which the motorway runs, and, to a lesser extent, the remaining coastal areas to the east of Hinkley Point. (The tops of the Quantock hills also appear in the most-seen category but are not really relevant to the question of siting a power station.)

The aggregate dead-ground map (figure 12.17) shows that nowhere (except the far slope of the Quantock Hills) is there more than about 33m depth of dead ground. It is apparent immediately from this information that the

Power Station will not be completely hidden on any coastal site in the study area.

12.4.3 Views from Shoreline near Burnham-on-Sea

Burnham-on-Sea is a popular holiday resort, busy with visitors in the summer months. It also has a large retired population. Its beach and promenade are therefore one of the town's chief assets. The promenade enjoys views to the Quantock Hills, to Exmoor, to Brean Down (near Weston-super-Mare) and to the South Glamorgan coast.

The following three viewpoints were used to represent Burnham beach (figure 12.18):

ST 30100 48000
ST 30350 49000
ST 30200 50000

The viewshed patterns from each of these viewpoints are shown in figures 12.19 - 12.21 respectively. The dead-ground patterns are shown in figures 12.22 - 12.24. The aggregate viewshed, visibility poll and dead-ground pattern for this group of viewpoints are shown in figures 12.25 - 12.27.

There is little difference apparent between the viewshed patterns of the three viewpoints in this group (figures 12.19 - 12.21). All have good views to the west, seeing all of the coastline as far as Hinkley Point. Other than that, the near slopes of the hills are seen and little else. The variation from viewpoint to viewpoint in the visibility of the shore between Hinkley Point and the mouth of the River Parrett and eastward from the coast at Burnham-on-Sea is a function of the small differences in height between the three viewpoints: the northernmost of the viewpoints is on a level with the Somerset Levels; the other two are slightly lower.

The aggregate visibility map (figure 12.25) shows complete visibility of the shoreline east of Hinkley Point. The few gaps in the pattern are due to the usual small areas of dead ground hidden behind the slope of the beaches and in the channel of the river.

The visibility poll map (figure 12.26) clearly shows the almost exact match between the seaward viewshed patterns of the three viewpoints: almost all grid cells to the west of the viewpoints have a visibility poll of 3.

The aggregate dead-ground map (figure 12.27) tells much the same story as that for the M5 viewpoints: there is no dead ground deeper than about 33m anywhere on the coast to the east of Hinkley Point. All other significant dead ground is on the far slope of the Quantock Hills.

12.4.4 Views from the A39 Trunk Road

The A39 is the main road serving North Somerset and North Devon from Bridgwater. From Bridgwater, it runs westward through the Quantock foothills, crossing the Quantock ridge at West Quantoxhead, then follows the coast through Minehead and Lynton. The road enjoys clear views over the sea and back up the coast towards Weston-super-Mare.

The following seven viewpoints were used to represent the whole of the A39 from Nether Stowey to West Quantoxhead (figure 12.28):

ST 11000 41800
ST 13000 42700
ST 15000 42900
ST 15850 42000
ST 15800 41000
ST 17000 40100
ST 19000 40050

The viewshed patterns from each of these viewpoints are shown in figures 12.29 - 12.35 respectively. The dead-ground patterns are shown in figures 12.35 - 12.42. The aggregate viewshed, visibility poll and dead-ground pattern for this group of viewpoints are shown in figures 12.43 - 12.45.

The convoluted terrain ensures that the pattern of viewsheds (figures 12.29 - 12.35) varies radically from viewpoint to viewpoint. No clear pattern to successive patterns is apparent. The dead-ground map for the second viewpoint (figure 12.37) shows contours of depth of dead-ground particularly clearly.

The aggregate viewshed pattern (figure 12.43) shows a high proportion of the study area visible from these viewpoints. The various inland gaps in the pattern are due to the hills surrounding the viewpoints themselves. The sea is almost completely visible, although inspection of the individual viewsheds shows that this is largely due to only two out of the seven viewpoints. There is, however, a pronounced shadow of dead ground visible as along the shoreline to the west of Hinkley Point.

The visibility poll (figure 12.44) clarifies the situation. The entire shoreline to the west of Hinkley Point is either invisible or has a low visibility poll.

The aggregate dead-ground map (figure 12.45), however, shows that none of the dead ground is deeper than about 26m.

12.4.5 Views from the Somerset Coastal Route

This road is signposted as a scenic route and forms a loop of unclassified road, paralleling the A39 but at a lower level and nearer the coast. The inclusion of this route as a series of critical viewpoints for the supposed siting of a power station is somewhat artificial: it largely owes its existence to the presence of the actual power station, without which the road would never have been improved to its present standard.

The following seven viewpoints were used to represent the whole of this route (figure 12.46):

ST 16500 44000
ST 18000 43500
ST 20000 44300
ST 22000 43950
ST 23000 42600
ST 25000 42400
ST 25500 41000

The viewshed patterns from each of these viewpoints are shown in figures 12.47 - 12.53 respectively. The dead-ground patterns are shown in figures 12.54 - 12.60. The aggregate viewshed, visibility poll and dead-ground pattern for this group of viewpoints are shown in figures 12.61 - 12.63.

As with the views from the A39, the pattern of viewsheds (figures 12.47 - 12.53) varies radically from viewpoint to viewpoint. No clear relationship between successive patterns is, however, apparent in this case.

The aggregate viewshed (figure 12.61) shows a similar pattern to that produced by the A39 viewpoints. The inland patches of dead ground are due to the hills in the immediate vicinity of the viewpoints. The coastal strip of dead ground is, however, much more pronounced and much wider due to the lower elevation of the viewpoints compared with the A39.

The visibility poll (figure 12.62) also shows either complete invisibility or a low visibility poll for the whole of the coastline west of Hinkley Point.

The aggregate dead-ground map (figure 12.63), however, shows no coastal dead ground deeper than 38m.

12.4.6 Aggregate Patterns for all Viewpoints

The aggregate viewshed, visibility poll and dead-ground map for all 22 viewpoints are shown in figures 12.64 - 12.66.

The aggregate viewshed pattern (figure 12.64) leaves no significant or useful areas of dead ground other than a strip of about 4km of coastline immediately west of Hinkley Point and another of about the same length near West Quantoxhead.

The cumulative visibility poll (figure 12.65) shows low visibility polls (7 or less) in the immediate vicinity of the strip of dead ground on the coast at Hinkley Point. There is an even larger area of low poll around the other area of dead ground mentioned above, but this may be artificially low owing to its position on the extreme edge of the study area: there are no viewpoints to the west of this area.

The aggregate dead-ground map (figure 12.66) is, however, less encouraging. The dead ground is all less than 26m deep.

12.4.7 Conclusion to 12.4

In the light of the intervisibility studies carried out above, the only sensible coastal sites available within the study area are those identified in the previous section: the 4km stretch of coastline immediately west of Hinkley Point and the 4km stretch at the extreme west of the study area.

As was mentioned previously, the findings regarding the latter stretch of coast are somewhat suspect owing to its immediate proximity to the boundary of the study area. This area is also unsuitable on amenity (and visual amenity) grounds as it lies within the Quantock Hills Designated Area of Outstanding Natural Beauty.

The stretch of coastline immediately west of Hinkley Point will be investigated further. A number of possible sites will be identified (including the actual power station site which is peripheral to this area). Outward-looking intervisibility studies will be carried out on the sites identified.

12.5 Intervisibility Study of Possible Sites

12.5.1 Introduction to 12.5

This section of the case study will further investigate the area identified in the previous section. Three possible sites, including the actual site of the real Hinkley Point Power Station, will be studied.

The same intervisibility software will be used in this part of the study as was used in the previous section. The difference in application is that, in this instance, the sites under investigation will be nominated as the viewpoints. The viewshed then becomes the zone of visual influence (ZVI) of the site. Dead ground has no useful meaning in this context: it defines the height above ground which an observer must attain in order to see the building.

For each of the three sites, nine viewsheds will be derived, all with the same viewpoint (site) position on plan but with height values from 10m to 90m in 10m increments. The individual viewsheds will then become indicators of how the ZVI increases in area with increasing height. The cumulative visibility poll will define contours indicating how much of the building can be seen from different locations.

The three sites to be studied are as follows (figure 12.67):

1	ST 21000 46100
2	ST 19500 45800
3	ST 17000 45300

Site 1 represents the actual site of Hinkley Point Power Station.

12.5.2 <u>Site 1 Zone of Visual Influence</u>

The viewshed patterns for this site (the real one) are shown in figures 12.68 - 12.76. The cumulative visibility poll is shown in figure 12.77.

As is to be expected, successively higher viewpoints produce successively larger viewshed patterns.

All viewsheds from the 10m level (figure 12.68) upwards show the ZVI covering the whole of the coastal and low-lying areas to the eastern side of the study area. Other than the small area masked by the Polden Hills, the viewshed cuts off quite cleanly to the south-east where the Power Station is masked by the low hills immediately to the south of the site.

To the west, the viewshed is cut off by the headland on which the Power Station stands up to a height of 40m (figure 12.71), above which the Power Station becomes visible to observers on the coast to the west of Hinkley Point.

The overall height of the building on this site is about 57m above datum. The above observations therefore indicate the building being entirely visible from all coastal views to the east and from all low-lying areas in the eastern half of the study area where the view is unobstructed by buildings or vegetation. From the west, on the other hand, only the top 20m of the highest building would be expected to be visible.

The cumulative visibility poll (figure 12.77) shows clearly the high levels of visibility to the east and south-east and the progressively increasing visibility along the coast to the west.

In the instance of this site (alone), it is possible to check the predictions of the intervisibility study against observed reality. The site photographs (plates 12.1 - 12.6) do indeed confirm the predictions.

12.5.3 <u>Site 2 Zone of Visual Influence</u>

The viewshed patterns for this site are shown in figures 12.78 - 12.86. The cumulative visibility poll is shown in figure 12.87.

This site is very close to Site 1, which occupies the eastern side of a blunt, north-facing headland (Hinkley Point, the geographical feature from which the Power Station takes its name). Site 2 is on the western side of the same headland.

The viewshed patterns are basically similar to those produced by Site 1, but slightly more screening is provided by the headland itself and the high ground immediately to the south. Comparing the 30m levels for Sites 1 and 2 (figures 12.71 and 12.80), the pattern to the west is only slightly different, varying only in the immediate vicinity of the sites, where the local topography has the major influence. To the east, the angle of cut-off to the south-east is noticeably different, Site 2 being less visible from more southerly locations by virtue of the more westerly location of Site 2. Higher level viewsheds show less difference as the viewpoints are seen above the high ground immediately south of Hinkley Point.

The cumulative visibility polls for Sites 1 and 2 show basically similar patterns except that the density of the pattern to the east of Hinkley Point is less dense in the case of Site 2. This indicates that the Power Station would not be completely visible on this site. From the east, it would be visible from about 5m above to the top. From the west, there would be very little difference in visibility except in the immediate vicinity of Site 2 where the building would be fully visible from the coast of the small bay to the west of Hinkley Point.

12.5.4 <u>Site 3 Zone of Visual Influence</u>

The viewshed patterns for this site are shown in figures 12.88 - 12.96. The cumulative visibility poll is shown in figure 12.97.

Site 3 is situated in the bay mentioned in the discussion of Site 2 above.

Despite the short separation from Site 2, the viewshed patterns for this site are radically changed. As may be expected, the sides of the bay act to limit views from both east and west. From the 40m level and above, however, the patterns revert to being very similar to those for Sites 1 and 2, with the exception of an area of dead ground to the east of the site, which is screened by the high ground immediately south of Hinkley Point. From this it may be concluded that about the top 20m of the Power Station would be visible from the coast at Burnham-on-Sea and also along the coast to the west of the site.

The cumulative visibility poll shows the same underlying pattern as was seen with Sites 1 and 2. This is to be expected with three sites as close together (relative to distant viewpoints) as these. The pattern is, in this case, much less dense, particularly from the valuable coastal views both east and west of the site. There is, however, a dense patch in the pattern, indicating complete visibility, to the south-west of the site. Inland views such as this were largely screened by the high ground immediately to the south of Hinkley Point in the case of Sites 1 and 2.

12.5.5 Conclusion to 12.5

The limitations of an intervisibility analysis as a tool to understand the visual impact of a building or group of buildings on a particular site are clear from the above discussion.

The building must essentially be represented as a point in space, adequate only for a single building or a compact group of buildings not spread widely across the observer's arc of vision. Representation as a single point can only reveal visibility or invisibility: no further understanding of the nature of that visibility may be gained.

To obtain any understanding of the degree of visibility by these methods, the approach used above must be adopted: the building must be represented as a column of points in space in order to identify the partial viewsheds which make up the viewshed of the whole building. This approach still provides no understanding of the nature of the visibility of the building: any building on the same site would yield the same patterns.

The study does, nevertheless, provide useful insight into the relationship between a building of the size of a nuclear power station and the surrounding landforms in the vicinity of Hinkley Point. Obviously poor sites may be rejected very quickly by this method. Distinguishing between sites of similar merit in terms of simple visibility is impossible without more information.

On the basis of the investigations carried out thus far, Site 3 would appear to be slightly better than Sites 1 and 2, which offer little to choose between them. All three sites will be investigated further by considering the visual descriptor patterns produced by the Power Station model on each of those sites and by considering the perspective views obtained from selected viewpoints.

12.6 Visual Descriptor and Perspective Study of Possible Sites

12.6.1 Introduction to 12.6

In this section, the three sites discussed above in terms of intervisibility will be investigated further.

The foregoing intervisibility studies establish the compass of visibility of a building on a given site in the form of the viewshed. Further, such studies may reveal the degree of visibility of the building by using the method of multiple viewpoints co-incident on plan as demonstrated above.

The visual descriptor patterns will be derived for the three test sites. For each site, the full set of eight visual descriptors currently available will be calculated and displayed. For these tests, a radius of visibility of 15km has been set: sufficiently short for the limit of visibility to appear in the patterns but also a reasonable approximation to average conditions in coastal North Somerset.

Parallel to the descriptor patterns, perspectives have been drawn (also by LANDVU) from the viewpoints featured in five of the site photographs (plates 12.1 - 12.5). The visual descriptor patterns will be considered in relation to these perspective views to ensure that the visual properties inferred from the descriptor patterns are, in fact, identifiable features in the perspectives.

The five photographs, mentioned above, were all taken with Hinkley Point Power Station appearing centrally in the frame. The computer-generated perspectives will be based upon the same viewpoints but in each case will be targeted upon the power station complex placed upon the site position under consideration. The perspectives for Site 1 will thus correspond with the photographs but those for the other two sites will correspond with the perspective views used in the calculation of the visual descriptor values. The sets of perspectives for Sites 2 and 3 will consequently each show degrees of mismatch with the photographs varying from viewpoint to viewpoint.

The descriptor patterns will be considered primarily as a design tool and assessed on the basis of the insight they allow into the visual properties of the test building on the three test sites.

12.6.2 Site 1

The location for the power station buildings for Site 1 is shown in figure 12.67 and is visible in plate 12.8. The buildings are arranged as they actually appear on the real site at Hinkley Point with the large building housing the magnox reactor (the 'A' Station) to the east of the two smaller buildings and with its long axis orientated north-south. The two smaller buildings housing the advanced gas-cooled reactors (the 'B' Station) are situated side by side to the west of the site.

12.6.2.1 Visual Descriptors

The visual descriptor patterns for Site 1 are reproduced in plates 12.8 - 12.15.

The 'area of visible profile' descriptor (plate 12.8) shows the viewshed of the building clearly as a pattern of cyan against a black background. It should be noted that this pattern is a true viewshed based upon the whole 3-dimensional form of the building, not solely upon a single point in space. In the area north of the actual site, the unobstructed pattern seen in the verification tests is repeated. This area shows the expected gradation of decreasing intensity with increasing distance from the building. The intensity of the pattern varies only slightly from different aspects of the building: the pattern is only very slightly less intense to east and west of the site compared with north and south; although the buildings are in line from east and west, this is offset by the 'A' Station being seen broadside-on instead of end-on. To the south of the study area are areas where the building on this site is invisible. These areas of invisibility are almost all surrounded by areas where the intensity of the pattern is noticeably diminished in comparison with neighbouring cells. The building is only partly visible from these areas.

The 'length of visible edge' descriptor (plate 12.9) shows much the same overall pattern as the previous descriptor. In particular, as is to be expected, this descriptor and the previous one share the same overall pattern of colour and black. The intensity of the pattern also exhibits broadly similar behaviour, diminishing with distance and also diminishing in areas of partial visibility. Close to the building, however, a much higher degree of anisotropy is apparent in the pattern. The change of the power station complex from three distinct units seen from north and south to a single mass seen from east and west appears to have a more profound effect on the length of edge visible than on the area visible.

The 'area of skylined profile' descriptor (plate 12.10) shares many features with the 'area of visible profile' descriptor. In particular, the behaviour with regard to diminution of intensity with distance and to the slight anisotropy apparent in the pattern are repeated. In the case of this combination of building and site, the majority of the area of the 'skylined' descriptor's pattern repeats that of the 'visible' pattern. It is only in two areas that a marked difference is apparent. From the very high parts of the Quantock Hills, in the south-west part of the study area, the building is seen against the sea instead of the sky. Conversely, from an area of sea to the north-east of the site, the building is seen against a back-cloth of hills. Accordingly both of these areas are black on the pattern. With a reduced radius of visibility, these patterns would change as the more distant areas of back-cloth became invisible.

The 'length of skylined profile' descriptor (plate 12.11) shares some features of both of the two preceding descriptors: 'length of visible edge' and 'area of skylined profile'. The extent of the pattern is identical to that for 'area of skylined profile'. The detail features, particularly at short range, repeat those of 'length of visible edge'. The reason for this latter observation is the point mentioned above that, in the case of this combination of building and topography, the majority of views of the building are seen wholly or largely against the sky.

The two 'dispersion' descriptors (plates 12.12 and 12.13) both show marked anisotropy of pattern. As expected, a much higher level of dispersion is seen from north and south, where the complex is seen as three distinct buildings, than is seen from east and west, where the individual profiles merge. Clear radial lines, demarking large changes in the intensity of the pattern, are visible. These radial lines denote the critical angles where the gaps between individual buildings in the complex disappear. In the case of the 'dispersion of skylined profile' descriptor, bright edges to some of the areas of invisibility may be observed. These bright edges were pointed out in some of the verification study patterns and indicate the skylined profile assuming an elongated form (of comparatively small area) as seen from these parts of the study area.

The 'proportion of profile seen above skyline' descriptor (plate 12.14) confirms that the majority of views of the building are either completely or almost completely skylined. The radial elements of shading in the pattern, particularly apparent in the views from north and north-east, indicate areas where the building is seen partially backclothed. The same is true of the hilly areas to the south and south-west of the site, except that here the radials are disrupted by the underlying convolutions of the topography. The circumferential elements visible in the pattern are due to the effects of the limited radius of visibility used for the study. Elements of back-cloth disappear beyond the selected radius of visibility. Changes in proportion of skylined profile thus tend to follow arcs centred on the building. These arcs are limited by the effective angle through which any given topographic feature is able to act as back-cloth to the site.

The 'contrast with sky' descriptor's pattern (plate 12.15) exhibits the usual exponential decay with increasing distance and with the usual black areas due to the presence of areas of invisibility.

12.6.2.2 Perspectives

The perspectives for Site 1 (figures 12.99 - 12.103) correspond to the site photographs which look towards Hinkley Point Power Station (plates 12.1 - 12.5).

Each of the five perspectives should match the corresponding photograph. In practice, this is not exactly the case.

The photographic parameters are those set by a 50mm focal length lens and 35mm film (negative format 36 × 24mm). The 6" × 4" prints have the correct aspect ratio for the negatives but are slightly cropped by the printing process. The viewcone angle for the photographs is about 40° (a metric camera with these camera parameters would have a viewcone angle of 39° 35′ 52″). The viewcone angle for the perspectives is 60° to correspond with the angle used by ADE to calculate the visual descriptors for this case study. The perspectives have the same aspect ratio as the photographs and are plotted to a size of 215 × 143.5mm to fit the A4 pages of this thesis.

The viewpoints used for the perspectives do not precisely match the positions of the camera stations. This is revealed by the slightly different aspects of the Power Station seen in figure 12.101 and plate 12.3. It was not practical to carry out a full survey for the camera station locations for this case study. The 1:10000 scale Ordnance Survey maps of the area were used to obtain the co-ordinates of the camera stations. The accuracy of these co-ordinates is about ±25m in both northing and easting. The height accuracy for the stated co-ordinates of the camera stations is about ±2m.

12.6.3 Site 2

The location for the power station buildings for Site 2 is shown in figure 12.67 and is visible in plate 12.16. The relationship between the three buildings on the site is the same as is the case with the buildings on the real site (see description of Site 1 above). The whole complex is, however, rotated anti-clockwise by 10° on its site relative to the orientation for Site 1 to allow it to lie parallel to the shoreline and, therefore, lower down the coastal slope.

12.6.3.1 Visual Descriptors

The visual descriptor patterns for Site 2 are reproduced in plates 12.16 - 12.23.

The 'area of visible profile' and 'length of visible edge' descriptors for Site 2 (plates 12.16 and 12.17) show very similar patterns to the same descriptors for Site 1. The patterns differ only slightly in the areas distant from the building, as is to be expected with two such sites so close together. The pattern is less intense in the coastal areas in the eastern part of the study area. This lessening is due both to increased distance reducing the apparent size of the building as seen from those areas and to partial masking, as predicted by the intervisibility study. Parts of the pattern closer to the site show a more marked difference. The anisotropy visible in the patterns for Site 1 (plates 12.8 and 12.9) are repeated in the equivalent patterns for Site 2. As is to be expected, the patterns differ in that those for Site 2 are re-centred on the new site and rotated by the 10° rotation of the complex on Site 2 relative to Site 1.

The 'area of skylined profile' and 'length of skylined edge' descriptors for Site 2 (plates 12.18 and 12.19) show similar differences from the equivalent descriptors for Site 1 (plates 12.10 and 12.11) to those described above. The effects of back-clothing are equally visible in the patterns for Site 2 as they were for Site 1.

The 'dispersion' descriptors (plates 12.20 and 12.21) show clearly the changed orientation of the complex relative to Site 1. The internal structures of the patterns are identical to those for Site 1 but the rotation of these structures relative to the topography alters the relationship between light and dark areas at the periphery of the pattern. The rotation of the pattern now places a higher value for the dispersion of the visible and skylined profiles on the coastline to both east and west: the complex must be seen as a more irregular outline than is the case with the actual building.

The 'proportion of profile seen above skyline' descriptor (plate 12.22) shows much the same overall pattern as that seen for Site 1. Site 2, however, although near to Site 1, has a quite different relationship to the hills to the south, as can be seen from the contour lines overlaying the descriptor displays. This difference in relative position to the hills also produces a radically different pattern of back-cloth, as may be seen from the different patterns of grey for this descriptor compared with the same descriptor for Site 1 (plate 12.14).

The 'contrast with sky' descriptor shows the expected pattern (plate 12.23), very little different, other than in the distribution of areas of invisibility from the equivalent pattern (plate 12.15) for Site 1.

12.6.3.2 <u>Perspectives</u>

The perspective views of the Hinkley Point complex on Site 2 are shown in figures 12.104 - 12.108.

The view from Viewpoint 1 (figure 12.104) is superficially very similar to the equivalent view for Site 1 (figure 12.99). The orientation of the component buildings in the complex is, however, different: the 'A' Station appears to the right of the 'B' Station in figure 12.104. The complex appears slightly more prominent in the case of Site 2 than Site 1. The area of the building as seen in the perspective is slightly less in the case of Site 2. The profile is much more dispersed, however, in the case of Site 2. In both cases, the building is seen entirely against the sky. These properties are correctly represented in the patterns for the descriptors 'area of visible profile' and 'dispersion of visible profile' shown in plates 12.16 and 12.20.

Viewpoint 2 (figure 12.105) looks in a more westerly direction than was the case with Site 1 (figure 12.101). The building complex is seen in a similar orientation in both perspectives. The building appears smaller on Site 2, because of increased distance from Viewpoint 2. It is also more masked by intervening high ground. The descriptor patterns accordingly show decreased values for the 'area' and 'length of edge' descriptors (plates 12.16 - 12.19). The 'dispersion' descriptors (plates 12.20 - 12.21) show increased values, due here to the partial masking of the building. The descriptor patterns suggest that these properties typify the inland views from the south.

Viewpoint 3 (figure 12.106) shows differences from the equivalent Site 1 view (figure 12.101) similar to those noted from Viewpoint 2, noted above. The profiles are larger in the case of this viewpoint, reflecting the shorter distances from the viewpoint to the building, compared with Viewpoint 2. The masking is greater in the case of Site 2, diminishing the 'area' and 'length of edge' descriptors. The 'dispersion' descriptors are slightly increased by the masking. These findings appear to confirm the hypothesis, proposed above, the Viewpoints 2 and 3 are typical of the possible viewpoints to the south of the sites.

Viewpoint 4 (figure 12.107), from the coastline to the west of Hinkley Point, shows a radical change from the equivalent Site 1 view (figure

12.101). The building is closer on Site 2, and much less masked by the intervening land, both factors increasing the value of the 'area' and 'length of edge' descriptors (plates 12.16 - 12.19). The different orientation relative to the viewpoint also separates the buildings out into two groups, greatly increasing the values of the 'dispersion' descriptors (plates 12.20 and 12.21). The change in site position makes a very large change to the visual impact of the building as seen from this viewpoint.

Viewpoint 5 (figure 12.108), also from the coastline, but to the east of Hinkley Point, shows a diminution in 'area' and 'length' descriptors (plates 12.16 - 12.19) corresponding to the increase seen in these descriptors in Viewpoint 4. The same high ground which partly screens Site 1 as seen from Viewpoint 4 also screens Site 2 from Viewpoint 5. The 'dispersion' descriptors (plates 12.20 and 12.21) show a much larger value for Site 2 than for Site 1 (plates 12.12 and 12.13) as seen from Viewpoint 5: the orientation breaks the building complex into two separate groups; the partial masking of the buildings by the intervening land also contributes to this. This dispersion effect and also that seen from Viewpoint 4 reflect the change in the value of the 'dispersion' descriptors brought about by the rotation of the patterns seen in plates 12.20 and 12.21 relative to those seen in plates 12.12 and 12.13.

12.6.4 <u>Site 3</u>

The location for the power station buildings for Site 3 is shown in figure 12.67 and is visible in plate 12.24. The relationship between the buildings in the complex is, again, the same as the relationship between the buildings on the real site (Site 1 above). The orientation is also maintained: the buildings lie in a line from east to west with the 'A' Station to the east of the 'B' Station.

12.6.4.1 <u>Visual Descriptors</u>

The visual descriptor patterns for Site 3 are reproduced in plates 12.24 - 12.31.

The pattern for the 'area of visible profile' descriptor (plate 12.24) shows all the features observed in the equivalent patterns for Sites 1 and 2, as described above. In addition to those features, distinct radial lines to the west and the east-north-east of the site may be seen in the pattern. These lines mark the transition from full visibility of the building from the seaward side to a partial visibility over the arms of the bay in which the site is situated.

The pattern for 'length of visible edge' (plate 12.25) shows the same features as were described for the previous descriptor, but shows the variation in degree of visibility even more distinctly.

The 'area of skylined profile' descriptor (plate 12.26) and 'length of skylined edge' (plate 12.27) show much diminished levels of visibility against the skyline compared with the equivalent patterns for Sites 1 and 2 described above. The closeness of Site 3 to the hills, compared with Sites 1 and 2, also ensures that the skylined portion of the building is much reduced as seen against the sea from the hills, and against the hills from the sea. The extent of the pattern is, therefore, also much reduced.

The 'dispersion' descriptor patterns (plates 12.28 and 12.29) show basically similar underlying structures to those found in the case of the equivalent descriptors for Sites 1 and 2. The orientation of the structure is the same as that for Site 1. The areas of lowest dispersion are thus aligned with the coastline both to east and west of the site. The lowest values of dispersion are, however, significantly higher than those found in Sites 1 and 2 due to the clipping of the profile to east and west as shown in the 'area of visible profile' descriptor.

The 'proportion of profile seen above skyline' descriptor (plate 12.30) shows a much reduced level of skylining across the study area compared with Sites 1 and 2. The areas which see the building most skylined, however, turn out to be precisely those coastal areas considered to be most critical earlier at the outset of this case study.

The 'contrast with sky' descriptor (plate 12.31) shows little change from the two previous sites. The pattern differs only in its centre and the extent and form of the areas of invisibility.

12.6.4.2 <u>Perspectives</u>

The perspective views of the Hinkley Point complex on Site 3 are shown in figures 12.109 - 12.113.

The perspective view of Site 3 from Viewpoint 1 (figure 12.109) is superficially almost identical to the equivalent view of Site 1 (figure 12.99). The size of the image on the perspective is much diminished in the case of Site 3, owing to the greater distance from the viewpoint. The shape of the profile is otherwise almost identical. The descriptor patterns accordingly show diminished 'area' and 'length of edge' values (plates 12.24 - 12.27) compared with Site 1, but approximately equally low 'dispersion' descriptor values (plates 12.28 and 12.29).

Viewpoint 2 shows a radical change from Site 1 (figure 12.110). The building is shifted far to the left compared with Site 1, as seen from this viewpoint. The building on Site 3 is very much diminished in size from this view compared with Site 1 (figure 12.100). The descriptor patterns accordingly show diminished 'area' and 'length of edge' values. The perspective, in this instance, demonstrates the visual effect corresponding to the diminished descriptor value to the south-east of Site 3 compared with Site 1: the building is in this case simply hidden in the relief of the landform surrounding the bay in which the site is located.

Viewpoint 3 (figure 12.111) shows the same effect of the coastal slope seen from a different angle and demonstrates the reason for the diminution of the descriptor values seen in the descriptor patterns for areas inland of Site 3, compared with Sites 1 and 2.

Viewpoint 4 (figure 12.112) is practically useless for the assessment of Site 3. It lies only a few hundred metres from the site and only serves to demonstrate the truism that large buildings dominate the view at very short viewing distances. The clipping of the built form by the edge of the perspective frame indicates that the frame buffer will also clip the profile of the building complex and produce unreliable descriptor values.

Viewpoint 5 (figure 12.113) shows the diminution of the visible area of profile of the building predicted by the 'area' descriptors as observed above. The 'dispersion' descriptors show a slight increase in value owing to the partial clipping of the profile.

12.6.5 <u>Conclusion to 12.6</u>

The descriptor patterns provide a good picture of the visual performance of the test buildings on the three different sites. This performance is further described by the perspective views which also give insight into the actual meaning of the descriptor patterns.

Site 3, which was slightly favoured in the conclusion to the previous section of this chapter, shows a markedly lesser impact than the other two sites in the light of the visual descriptor study. The perspectives show the reasons for this lesser impact.

In retrospect, although the layout of the power station complex was taken as being fixed in the scenario for this case study, a re-arrangement of its component parts would have been worth investigating. In particular, the 'A' Station has its axis running north-south (or nearly north-south) in all three test sites. A variation of Site 3, with the 'A' Station aligned east-west, would probably have produced markedly lower values for 'area', 'edge' and 'dispersion' descriptors, as seen from coastal sites, to the detriment only of views from the sea or from the top of the Quantock Hills.

12.7 <u>Conclusion to Chapter 12</u>

The case study shows an effective use of a combination of methods of analysis. It provides a good worked example in that the complexity of the scene involved is realistic. The problem has been simplified only in that no criteria are considered other than visual ones. The analysis has been simplified only in that a very small number of viewpoints have been used for intervisibility analysis and photography, and in that a coarse DTM grid has been used.

The use of intervisibility analysis to understand the potential of a landscape to diminish the visibility of objects placed within it is well understood and documented [Travis *et al* 1975, Tlusty 1980]. The combination of this information with perspective views to understand the intervisibility patterns as experienced from ground level has also been described [Tlusty 1980, Nickerson 1980]. As mentioned in the introduction to the previous section of this chapter, such a study only determines the visibility of one or more points in space which are judged by the user to be critical to the choice of a site.

The descriptor patterns presented above provide considerable information to supplement the simple intervisibility patterns described previously. The patterns produced are much more complex and less easily understood than those seen in the verification studies in the previous chapter. While still constituting a simplified test example, the case study provides a more realistic impression of the appearance of the descriptor patterns produced in a real visual impact study. The patterns are still comprehensible on an intuitive level by consideration of the interaction of the building geometry with the geometry of the underlying landforms.

The perspective views give 'snapshot' samples of the actual visual performance of the test building from specific viewpoints. In a real study, these would have to be much more numerous, in order to provide a more comprehensive sampling of the viewshed. The perspectives are essential in order to understand the detail seen in the descriptor patterns. For example, the 'dispersion' descriptors can show increased values due either to masking effects of the landscape or to the fundamental asymmetry of the building.

Whereas the intervisibility analysis gives a quantitative understanding of the visual properties of a building, the visual descriptor analysis gives a qualitative understanding. The nature of the visual impact of the building cannot be inferred directly from any one of the descriptors implemented to date. In particular, the patterns produced by the 'dispersion' descriptors cannot be interpreted in isolation, as noted above. Used in combination, the descriptor patterns, supplemented by the perspectives, enable the user to develop a detailed understanding of the visual impact of a building over the study area. The overall assessment of the magnitude of visual impact, however, remains in the realm of the judgement of the user and must rest upon his understanding of the finer details of the visual problem involved.

For the purposes of this case study, the configuration of the power station complex was taken as being fixed. However, as mentioned in the previous section, a study of the visual descriptor patterns suggests alternative arrangements that might usefully be examined. Similarly, consideration of the visual descriptor patterns, in conjunction with the patterns yielded by the intervisibility studies, indicates the likely effect of reducing the height of some of the buildings in the complex and suggests that, in this case, a maximum height in the range 30-40m for the buildings on Site 3 might well make a screening strategy, using tree planting, effective in diminishing the visual impact of the power station as seen from coastal viewpoints. It is in precisely this manner that visual descriptors are intended to be used iteratively as a design tool.

In this case study, the overall result, favouring Site 3, is one which could easily be arrived at by conventional means. The summary conclusion of the study is simply that moving the site into a convenient bay in the coastline will much reduce its visual impact. The study, however, demonstrates the manner in which the impact is reduced by re-siting the building and provides a check against any unexpected visual side-effects of re-siting.

Chapter 13

Assessment of Visual Descriptors as Design Tool

Assessment of Visual Descriptors as Design Tool

13.1 Introduction to Chapter 13

This chapter is an assessment of the performance of visual descriptors. Visual descriptors, as implemented in software, will be considered in the light of the verification and case studies presented in Chapters 11 and 12. The set of descriptors implemented in the course of this study will be considered both theoretically and as working design tools.

13.2 Criteria for Assessment

The concept of 'design tool' was introduced in Chapter 3. It is worth summarising the characteristics of a design tool again here:

1 A design tool is more concerned with making changes to the environment than with understanding it.

2 A design tool must give reliable and accurate information to the designer, framed in terms used by the designer.

3 A design tool must indicate the way in which a design must be changed to improve its performance.

The working definition of a set of 'visual descriptors' was established in Chapter 8:

1 Visual descriptors are measures which describe the visual properties of an object as received by a viewer at some specified point in space, after being filtered by contextual modifiers, conditional modifiers and known observer characteristics.

2 Each descriptor must be an unambiguous direct measurement from the visual environment or from a simulation thereof.

3 The descriptor values obtained must be single-valued and continuous for all locations from which the object is visible.

4 The chosen set of descriptors must provide a reasonably complete understanding of the visual performance of the object under consideration.

The definition of visual descriptors incorporates elements of the definition of design tools but both definitions form the effective assessment criteria for the set of descriptors presented in this study.

13.3 Theoretical Assessment of Visual Descriptors

To a degree, comparing the descriptors actually implemented with the definition set out above is pointless: the descriptors were initially selected with exactly that definition in mind. Some discussion of the descriptors as a set, is however worthwhile in the light of the case study.

The first point of the definition of visual descriptors really defines the properties of the model which is used to obtain the descriptor values. The structure used is basically a conventional approach borrowed from computer graphics. Its points of departure from the real world are known and have been described in previous chapters. This point will not be discussed further here.

The second point of the definition, the issue of ambiguity, is worth considering. The main thrust of that point of the definition has been met: each descriptor of the chosen set has a single value under any specified conditions and is entirely objective in its measurement (similar to the mathematical definition of a function). However, in use, the descriptor is interpreted by the designer as having some implications regarding the 3-dimensional form of his design object: an inverse function is implied. However, in the case of the 'dispersion' descriptors, no inverse function exists. High dispersion values naturally occur in situations where the profile is highly dispersed, but also occur where a profile is masked almost to visibility, typically leaving a highly dispersed sliver of visible profile. Descriptors such as these are impossible to interpret in isolation: they must be considered in relation to the other descriptors in the set. Descriptors which are capable of returning the same value under different conditions are valid but must be used with care. They also effectively prevent any purely numerical and mechanical assessment of visual impact from a set of descriptors: there is no ideal value to optimise towards.

The third point of the definition, that a descriptor should be a single-valued continuous function has not been met strictly. The reason for this element of the definition is that visual descriptors should be mappable. In fact, while all descriptors of the set implemented have true values for all visible points, some have severe discontinuities at the boundaries of the ZVI. The 'area' and 'edge' descriptors are well-behaved in this respect: they all diminish to zero at the ZVI boundary and, in effect, define that boundary by their zero values. The 'dispersion' descriptors, on the other hand, reach their maximum value (unity) at the boundary of the ZVI. They are, therefore, continuous only over the ZVI and not strictly over the whole of a study area. While such descriptors may be represented by coloured blocks (as in this study), they would not, for example, be contourable without taking steps to eliminate spurious contours around the edge of the ZVI.

The fourth point of the descriptor definition, completeness, has probably not quite been met in the set of visual descriptors presented. The most obvious omissions are any treatment of colour and treatment of contrast with the background of the design object. The methods by which these could be implemented have, however, been described in earlier chapters. In view of the comments about the 'dispersion' descriptors above, an alternative measure of shape, with different properties, might be useful as a complement to the existing set of descriptors.

In summary, with the exception of the issue of completeness, the set of visual descriptors conform to the spirit, if not the letter, of the definition set out in the introduction to this chapter. They perform quite effectively, in that they provide an otherwise unobtainable overview of the visual performance of a design object in a landscape.

13.4 Practical Assessment of Visual Descriptors

This section is concerned principally with the software used to present visual descriptors to the user and less with the software used to derive the descriptor values.

The nature of the design tool which has been presented in this thesis is quite complicated. It combines elements of both 2- and 3-dimensional conventional CAD and digital cartography.

The first point of the definition of a design tool, the issue of making changes to the environment rather than understanding it, lies in a method of using the visual descriptor package rather than being inherent in it. The visual performance of a design object is described by a set of descriptor patterns. Change must be measured by observing changes in the patterns, either by comparing existing with proposed, or by carrying out an iterative refinement of the design object.

The second point, accurate information in the designers own terms, is met by the adoption of well-defined algorithms for the descriptor measures themselves and by the presentation of the visual descriptor patterns to the user as a map. The plan is the traditional and, in many ways, the most flexible way to present holistic information about a site to a designer. It is, therefore, also the most 'natural' way to present it. Without context, the descriptor pattern would be useless. As was seen in the case study, the overlay of contours and topographic features on the descriptor pattern is essential to the understanding of the visual performance of the design object. The 3-dimensional nature of the design object and the landscape is also critical to the usability of visual descriptors. The ability to switch directly between 2-dimensional overview and 3-dimensional perspective is critical to the understanding of both the visual descriptor patterns and the perspectives. The visual descriptor software is also a much richer design tool when supported by more conventional design aids such as visibility analysis, perspective visualisation and analytical mapping; all facilities available in the software package presented in this study. The uniformity of the terms of reference of the various modules of the package and the uniformity of the user interface adopted make the whole system more easily used as a single entity.

The third point, indicating the manner of change to rectify poor visual performance, appears to be met. All descriptor measures have been chosen to be as individually simple as possible: they are intended to be components of a multi-dimensional tool; understood singly or together. The case study presented in the previous chapter demonstrated the use of the descriptors to gain an understanding of the visual behaviour of the test building on its site. There is, however, as yet, insufficient expertise in interpreting the descriptor patterns to be certain of how effective the present set of descriptors are in this respect.

13.5 Performance of the ADE Program

The ADE program, as implemented, appears to produce quite well-behaved visual descriptor patterns. A number of fundamental limitations have, however, become apparent during the testing stages:

1. The finite pixel size used in the frame buffer introduces aliasing effects which are manifest in minor disruptions to the patterns of the 'dispersion' descriptors, in particular.

2. The finite pixel size also introduces errors into the descriptor values for very distant objects. The vector-to-raster conversion routines cannot assign to less than a whole pixel: sub-pixel-sized objects are therefore over-represented.

3. The finite raster size, coupled with the shape-extracting procedures used, causes errors when the building profile overlaps the edges of the frame buffer.

4. The division of the ground surface into foreground and background can become inaccurate with buildings which are both large and complex in plan.

None of these constraints have caused particular problems in either the verification or case study but would cause problems with some other types of design object.

13.6 Limitations of the ADE Program

There are a number of intrinsic limitations in the ADE program as it has been implemented. They are as follows:

1 The division of the landscape into foreground and background assumes that the building is compact and can, effectively, be treated as a point. This simple division will not work for linear objects such as roads which may wind through the scene, dividing it in a complex way.

2 The division of landscape into foreground and background is, equally, inappropriate for multiple objects, such as electricity transmission lines.

3 The view for each frame in the descriptor evaluation process is directed automatically to the midpoint of the building. This is inappropriate for large or multiple objects which may surround the viewpoint.

4 Transparent objects, such as pylons, are not catered for correctly but are 'filled in' by the profile-extraction procedures.

5 Topographic features, other than the DTM, are not included in the foreground and background profiles and therefore

do not contribute to the screening or backclothing of the design object.

These limitations restrict the range of applications which ADE can, at present, address.

13.7 Conclusion to Chapter 13

Visual descriptors provide an effective design tool for use in visual impact analysis. Their effectiveness owes as much to the way in which they are presented to the user as in the descriptors themselves: presenting numerical data graphically enables it to be used effectively in a graphical environment by graphically-oriented designers.

The main problem with the use of visual descriptors is lack of experience. To date, the nearest approach to 'real' use that has been made of descriptors has been the case study presented in the previous chapter. More experience will expose both the strengths and the weaknesses of the set of descriptors, the algorithms used and the design of the programs used to present them to the user.

Experience will also enable a methodology to be built up around the use of visual descriptors for visual impact assessments. The demands imposed by commercial design or consultancy jobs will further refine all elements of the system.

Chapter 14

Conclusion

14.1 Contribution to Knowledge

The contribution to knowledge made by this study breaks down into four principal elements.

Firstly, a conceptual model has been developed which describes the way buildings are seen in the landscape. This model consists of three layers of filtering between object and observer: contextual modifiers, conditional modifiers and known observer characteristics. The concept of 'visual descriptors' has been developed from Aylward and Turnbull's initial idea into a system of measurement from the visual environment in the context of this model of seeing.

Secondly, a mathematical model has been developed, defining a series of possible visual descriptors and incorporating the above model of seeing. The mathematical model has been further developed into a practical approach for implementation of the visual descriptor measures as computer software.

Thirdly, a conceptual design tool has been devised to make use of visual descriptors in the context of a visual impact assessment.

Fourthly, a suite of computer programs has been written which incorporate eight of the proposed set of possible visual descriptors and present them to a user as a system of design tools. This suite has been verified and tested in a suitable case study.

14.2 Further Work

14.2.1 General

There are four main areas of obvious improvement required in the visual descriptor work presented in this thesis. They are:

1 Further descriptors
2 Resolution of frame buffer
3 Scope of system
4 Performance of system

14.2.2 Further descriptors

More of the possible descriptors which were described in Chapter 8 should be implemented and tested against those which have been implemented to date. In particular, the descriptors which deal with colour should be tested.

There are a number of other possible algorithms for certain descriptors, in particular, the 'dispersion' descriptors. Further alternative algorithms should be implemented and tested against those already implemented.

14.2.3 Resolution of Frame Buffer

All tests, to date, have been carried out on a 512 × 512 × 4 frame buffer. Comparative trials should be carried out with finer and coarser frame buffers, for example, 1024 × 1024 and 256 × 256, to determine the nature and magnitude of the changes brought about by the varying pixel size.

An alternative approach, which should also be explored, is to dimension the frame buffer dynamically. In this case the perspective view would no longer have a fixed arc of vision, but would effectively zoom in or out to fit the building to the frame buffer. The area and edge weighting functions would also have to adjust to accommodate these variations. This approach would maximise the ratio of subtended solid angle to pixel size in all cases. Effectively, the pixels would become finer, in terms of subtended angle, in the situations where resolution is most critical.

Anti-aliasing of the frame buffer by increasing all pixels to 2-bit representations is also worth exploring, either as an alternative to, or in addition to, the above approach.

14.2.4 Scope of System

A number of restrictions in the ADE program were mentioned in the previous chapter. If ADE is to be used on a wider range of applications, other than single large buildings in open rural landscapes, various parts of the program must be re-implemented.

14.2.5 Performance of System

While most of the software presented in this thesis is now quite mature and has been refined and improved several times, ADE must still be regarded as being in the alpha-test stage. An improvement of up to 5 times in execution speed is probably possible with refinements in the software. Coupled with the processing power of modern super-micros or graphics workstations, reasonably short execution times are in sight. Visual descriptor evaluation will always be slower than intervisibility analysis and, as yet, cannot be achieved on an interactive basis. Current processor architecture is expected to achieve processing speeds of up to 50 mips on super-micros within the next few years. This speed would allow interactive visual descriptor analysis.

14.3 Overall Assessment

The visual descriptor, both in theory and in practice, appears to be a promising approach to improving the quality of visual impact analysis studies. In spite of the case study carried out in this research project, the visual descriptor must still be regarded as an untried tool in practice. The next stage will be to apply visual descriptors to a live visual impact analysis project.

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Appendix A

Programming Languages

A.1 Choice of Programming Language

Three principal criteria were considered in the choice of a programming language for the implementation of the software presented in this thesis.

Firstly, the language had to be suitable for solving the programming problems which were expected to be encountered in the course of the project. This effectively constrained the choice to a procedural scientific language, with comprehensive mathematical facilities. Possible choices would have been BASIC, FORTRAN, Pascal, C, PL/I or Ada.

Secondly, the language had to be portable, thereby eliminating dependence on any one machine or operating system: no ideal target machine has been identified to date. The selected language, therefore, had to conform to some recognized standard. All of the above mentioned languages have BSI, ANSI or ISO standards (either agreed or draft) which define them. BASIC implementations, however, rarely conform to the ANSI standard, which, in any case, is too restrictive to be really useful. Prime V-mode compiled BASIC was, nevertheless, used for some test software during the early stages of the project. PL/I is standardised and available from many computer manufacturers (but rarely on systems running under Unix). It is, however, in practice, only popular on a few makes of machine.

Thirdly, the language had to be available on the machine used during the development of the software. The Plymouth Polytechnic Prime network was used as the host machine at this time and had only BASIC, FORTRAN, Pascal and PL/I available at the commencement of the project. C became available during the course of the project.

The above considerations effectively limited the choice of language to either FORTRAN or Pascal.

Pascal was considered seriously at one stage; indeed, it was used for the first version of ADVENT. Pascal, however, suffers from a number of shortcomings for large programming projects of this type. There is an intrinsic source-code management problem: Pascal provides no standard and portable means of developing subroutine libraries; it also does not provide any means of modularising code by hiding static local variables in subroutines. There is also a problem with writing programs which have to cope with the 'real world': no standardised exception- or error-handling facilities are provided in Pascal.

FORTRAN 77 has been selected as the programming language for all software connected with this project.

In retrospect, C, might have offered certain advantages, had it been available at the outset of the project: C provides dynamic memory allocation, indirection operators and structured data types, all of which are lacking in FORTRAN.

A.2 <u>Standard Programming Practice</u>

A standard code of practice has been adopted for software development connected with this project. The FORTRAN 77 standard [ANSI 1978] has been adhered to rigorously, with the exception of three commonly available extensions to the standard which have been permitted, to make software development simpler while losing very little portability. These are list-directed READ from an internal file, the INCLUDE statement and the $ editing descriptor (or equivalent) to suppress the newline following a WRITE to the terminal.

Whenever possible, commonly-used subroutines are made part of one of a series of subroutine libraries. All machine-dependent code is isolated in library subroutines which are re-implemented if the library has to be ported to another machine.

All machine- or site-dependent constants in any program, and all those which define the operating data storage capacity of the program are isolated as PARAMETER statements in a file to be INCLUDEd at compile-time.

To date, these policies have been very successful. After the overhead of any library changes is passed, a working program can often be installed on a new machine in a matter of minutes and normally requires no source-code changes.

Appendix B

Graphics Packages

Graphics Packages

Both interactive and off-line graphics are used heavily in the software presented in this thesis. The graphics package used to achieve this has to be both powerful and flexible to support the range of features demanded by the applications software. It was also desired that the software should be largely device-independent.

The choice of graphics package was actually constrained by the software available at Plymouth Polytechnic at the time of the study. The only suitable software available was the GINO-F library [CAD Centre 1984a-c]. All graphical input and most graphical output is, therefore, handled by calls to GINO. The exception to this rule is digitizer input, for which a separate subroutine library has been developed.

Attention has since been paid to alternatives such as PHIGS or GKS. While PHIGS supplies most of the functionality currently required, its inherent hierarchical structure is not easily applicable to the data structure requirements of the problems encountered in this study. GKS is now an international standard [Hopgood *et al* 1983, 1986, BSI 1985, 1986a] but only as a 2-dimensional library: the 3-dimensional version has only reached the draft standard stage [BSI 1986b, 1987]. The device code-generator modules for GKS also vary from implementation to implementation, making them non-portable; the proposed CGI (computer graphics interface) standard will rectify this. It is, however, probable that a later version of GKS, with 3-dimensional functionality and CGI, will be a better choice, in the long term, than a proprietary package such as GINO-F.

In the mean time, all software has been written in such a way as to isolate calls to GINO-F into small groups in subroutines wherever possible. Particular care has been taken to do this with calls which establish transformations, viewing parameters and graphical input. Calls which perform simple graphical output are spread more liberally through the code. In theory, this approach should enable a relatively simple substitution of another graphics package for GINO-F: in practice, it is untested.

Appendix C

Papers

Plymouth Polytechnic

ADVENT: an interactive digitizing program for three-dimensional architectural forms.

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September 1984

Abstract

A computer program for the graphical input and editing of 3-dimensional architectural forms is presented in this paper.

The data is input from a plan using a CalComp interactive digitizer, with all program control accomplished via an active menu on the surface of the digitizer. Conversion from 2-dimensional plan to 3-dimensional model is carried out in a number of user-selectable modes, interpreting lines on plan as lines, walls or certain pre-defined solids in space.

Visual feedback to the user, monitoring of the current status of the program and of the data and instructions entered, is provided by a continuously-updated display on a graphics terminal.

Introduction

The capture of data and the compilation of data structures for the visualisation of 3-dimensional scenes of any complexity is a daunting task, particularly if the required data structure is in itself complex. This is further compounded if the object of the exercise is to provide a design tool, when it is particularly important that the cycle of design-visualise-evaluate-alter should not be unduly prolonged or disrupted.

ADVENT was devised to provide a means of capturing data for architectural scenes of considerable complexity. The program seeks to provide a user interface sympathetic to the architect's design process at the sketch-design stage and sufficiently intuitive to be used by undergraduate architectural students both for the visualisation of their building design projects and as a learning tool for the use of computer-aided design methods.

2-dimensional input of 3-dimensional data

The fundamental problem to be overcome in any digitizing program is the introduction of the third dimension into the 2-dimensional data captured by the digitizer.

Various methods have been used to achieve this. Sutherland [1] described a method using a multi-pen digitizing tablet to work from several projections of the required 3-dimensional scene simultaneously. This allows any views to be used, including photographs, as no assumptions regarding the orthogonality of the object or input projections are made, and the necessary removal of the perspective projection is carried out by the program. Thornton [2] extended this concept to use a combination of tablet and graphical display terminal to allow direct interactive manipulation of the 3-dimensional object being entered, again through the use of multiple projections. A different approach using a single axonometric view as the input data was described by Liardet [3] again allowing full interaction with the object. Rogers [4] described a synthetic rather than descriptive approach, building up the required object from prismic elements first defined and then located in space using a digitizing tablet.

For an architectural application it was felt from the outset that the plan was the most appropriate projection to use for input. This is generally used as the principal design drawing in architecture and is normally available in some form, however crude, at the sketch design stage. The use of any drawings which would have to be drawn specially for the sole purpose of digitizing was seen as counter-productive. For the input of height data, hardware constraints prevented the use of multiple pens. The use of a single pen on multiple views was considered but rejected as being too error-prone and confusing for the user on all but the simplest of drawings. However, in architectural work, there is frequently comparatively little height data required to complement the plan, the majority of buildings being composed largely of vertical walls which may simply be treated as a vertical projection of part of the plan through a known height.

Background

ADVENT was designed to supersede earlier digitizing programs in use for architectural applications at Plymouth Polytechnic School of Architecture.

PERSPEC [5], a general-purpose wire-frame perspective drawing program, has been in use at the polytechnic since 1980. Initially, all data had to be prepared manually, by scaling dimensions from drawings and constructing data files using a text editor. This was a painfully slow and error-prone process even with the very simple data structure involved. Although PERSPEC is very good, this problem of data preparation rendered it virtually unusable as any kind of iterative design tool and effectively limited its role to one of illustration at the end of the design process.

In 1982, two CalComp interactive digitizers were acquired. First AD02 [6], and later AD99 were written as experimental programs using the digitizer to prepare data files for PERSPEC. These programs worked by interpreting lines on plan as walls in space (figure 1) as the user traced out the required plan corner-by-corner using the digitizer cursor. This introduced the concept of the 'facade', central to the operation of the ADVENT program. As many buildings may be broken down into a composition of walls which are simply a vertical projection of some part of the plan, a good deal of work could be done very simply and quickly. Other features allowed top and bottom levels for walls to be set and re-set, and for single-line drawing or non-drawing jumps to be selected. As all of these options had to be selected by keying in alphanumeric codes, the flow of the digitizing process was continually interrupted.

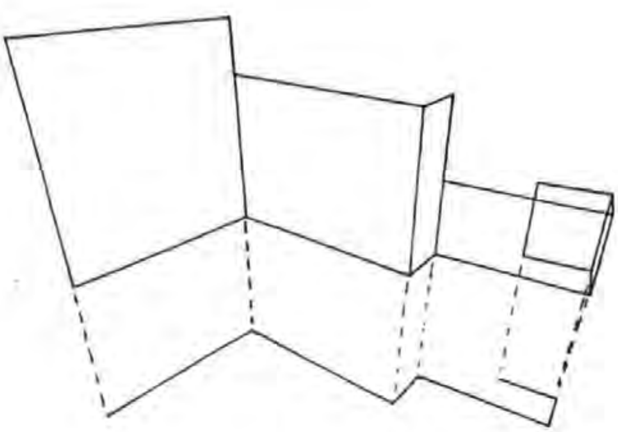

Figure 1. Lines on plan become walls in space.

While both these programs enjoyed almost continuous use by students, they proved to be both error-prone and counter-intuitive, with many quirks and tricks to be mastered before acceptable results could be obtained.

In parallel with AD99, AD101 [7] was developed for use with BIBLE [8], a hidden-line perspective drawing program. To provide hidden-line elimination, a more complex data structure was involved [9,10], containing much more information. For this reason, AD101 was originally limited in its scope to three pre-defined, but flexible, forms. These were a right prism with an arbitrary plan, a similarly arbitrary pyramid and a pitched roof (figures 5 - 7). In each case only the topology of the form was provided by the program, while the actual location and, in the case of the prism and pyramid, the number of vertices, was determined by the user, by tracing out the required plan on the digitizer.

In use, all of these digitizing programs proved to suffer from a common defect: they lacked any effective means of feedback to the user. AD02 provided the option of having the plan drawn on the terminal screen as it was traversed by the digitizer, but in practice this was rarely used as it tended to obscure other information on the screen. The other programs merely echoed the instructions sent to and from the digitizer. The effect of this shortcoming was to demand a very high level of concentration from the user as missed points or erroneous instructions were not easily detected once made. The usual strategy adopted to circumvent this was to digitize any scene in a series of very small units, verifying each immediately via the appropriate perspective program and discarding it if any errors were detected, a lengthy, slow and often frustrating process.

Environment

From the outset, it was realised that ADVENT would have to operate in a far from ideal machine environment.

The main computer installation at Plymouth Polytechnic is a small network of PR1ME machines, a 9950, an 850 and a 550. The School of Architecture is at a site remote from the computer installation. As a wide range of software is in use at the School, it was not possible to provide a special hardware configuration for this application. The actual requirement was that ADVENT should be able to operate on a Westward Micro Systems 2000 series graphics display terminal in series with the existing CalComp 600 series digitizer, and communicate with the host via a single land-line at 2400 baud, while still providing a reasonable response time for interactive graphics.

The digitizer is fitted with CalComp's SMART firmware. This outputs co-ordinate information to the host in centimetres, as a formatted string. A number of other features are also provided which allow the digitizer's co-ordinate system to be redefined. These features are not used in this application as previous experience has shown that users find the necessary local setup procedure confusing, and as the firmware provides neither a means of prompting from the host, nor for the host to monitor the process, it is frequently a source of error. Functions equivalent to SMART's co-ordinate system transformations are implemented in software within ADVENT.

The terminal specified for use with ADVENT was judged to be the minimum standard usable for this purpose. The Westward terminal is a raster-scan frame-buffered device, but its protocol emulates that of a Tektronix 4010 series storage terminal. However, it also includes a full ASCII character set and provides block and line erase features, essential in this application to allow the screen display to be updated in part without having to be erased and entirely redrawn.

Design considerations

For its intended role, the effectiveness of the user interface was regarded as being of paramount importance in the development of ADVENT, even at the expense of the scope and efficiency of the program.

The principal use of ADVENT is by undergraduate architectural students for digitizing their building design projects in order to provide accurate visualisation at an early stage in the design process. Frequently, ADVENT and PERSPEC are the first computer progams that students encounter. Because of this, it was important that intended users should be able to grasp the essence of ADVENT with the minimum of tuition, and thereafter, be able to master its use in a reasonably short space of time. However, extreme simplicity in the program was not acceptable as many design projects incorporate extremely complex forms and features, and the program would have to be able to cope with them. ADVENT was designed to be used even when only a small subset of its features are understood. Considerable thought has gone into making ADVENT sufficiently consistent and intuitive in use to make progress from this point possible on a trial-and-error basis.

The scope of ADVENT derives partly from the known strengths of the programs it supersedes and partly from their observed weaknesses.

No formal study of the performance of the predecessors of ADVENT was undertaken, but some 18 months of their use by undergraduate students rapidly revealed the strengths and weaknesses inherent in them. For the majority of architectural applications, the facade-following approach of AD02 and AD99 was clearly a good one, mimicking the normal graphical convention of the drawn plan. The majority of errors, however, were observed to stem from mistakes in the entry of supplementary commands to change the drawing parameters. The other principal source of error stemmed from the lack of any graphical feedback resulting in the user losing his place in the digitizing process. Largely because of these problems, irregular and non-prismic bodies proved to be extraordinarily difficult to digitize, owing to the need to enter numerous extra commands in order to over-ride the facade-following feature. As the majority of buildings incorporate at least a pitched roof, this proved to be a serious shortcoming. The pitched-roof primitive provided by AD101, on the other hand, proved to be extremely effective and adaptable in use, allowing quite complex roof-forms to be built up quickly and accurately. The specification for ADVENT, as finalised, incorporates both of these concepts.

It has already been mentioned that the plan was judged to be the ideal input medium for two of the three dimensions. Two classes of supplementary information are required. Firstly, analogue information defining the third dimension, height. Secondly, a series of logical switches to select the required operating mode. ADVENT uses an active menu fixed to the surface of the digitizer to do all this.

It was early decided that a menu was the most appropriate method of control. It never requires the user to direct his attention away from the digitizing surface, and it provides a continual reminder of the facilities at his disposal. Use of the terminal keyboard is therefore confined to the initial phases of the program, and to the very occasional entry of textual data (e.g. filenames) where use of the menu is wholly inappropriate.

Experience of AD02 showed that the plan is a far from ideal view for monitoring work in progress, as it contains none of the height data being entered. The perspective view was reckoned to be the easiest to interpret quickly, incorporating both the height dimension of the information being entered and a depth cue, reducing the ambiguity of a wire-frame image [11]. The view selected for monitoring is a perspective projection which approximates to the user's actual 3-dimensional view of the plan on the digitizer in front of him.

Implementation

The ADVENT program is implemented as some 3000 lines of PASCAL. The choice of language is somewhat unconventional, as most graphics work in the Polytechnic is in FORTRAN 77. The choice is partly because of the complexity of the internal logic of the program, partly because of the complexity of the internal data structures involved, but mainly out of a personal preference on the part of the authors. The compiler used is the University of Sheffield PASCAL compiler for PR1ME 50 series machines.

Graphical support is provided by the GINO-F subroutine library. Fortunately mixed language programming is particularly easy to achieve on PR1ME machines.

All working storage of input data is in memory, using the dynamic storage allocation facilities of PASCAL. Permanent storage of the data to file is carried out only on request, mainly to prevent disk access times from affecting the program's response time. (Disk accesses on all the Plymouth PR1MEs can be extremely slow with even a moderate number of logged-on users.)

Once created, the files may be used in one of two ways. They may either be post-processed to provide suitable input for the PERSPEC program, or they may be used to initialise ADVENT at the start of a run. This returns the program to the state it was in at the moment the file was stored, and allows a digitizing session to be suspended and continued after a break.

Operating modes

ADVENT operates in 3 main modes. Modes 1 and 2 are both facade-following modes, projecting lines on plan into vertical planes in space. In Mode 1, all changes in either the top or bottom levels of the facade are treated as slopes from one digitized point to the next (figure 2). In Mode 2 such changes are interpreted as steps (figure 3). Mode 3 complements these by providing a single-line drawing capability for the delineation of forms not pre-defined by the program and not composed of facades (figure 4).

In addition to the three main modes, ADVENT provides six pre-defined 3-dimensional primitives. These are defined in much the same way as those provided by AD101. The three original primitives from AD101 (right prism, pyramid and pitched roof) are provided by ADVENT (figures 5 - 7). As with AD101, the right prism and pyramid may have any number of vertices. The remaining primitives, however, are finite, like AD101's pitched roof, in that there is a fixed number of points to be digitized in order to define each body. These primitives are, in addition to the roof, a barrel-vault (figure 8), a hyperbolic-paraboloid shell (figure 9) and a frustrum of a regular polygonal-based pyramid (figure 10).

The menu (figure 11) is attached to the digitizer surface. It consists of a series of boxes, any of which may be selected by placing the digitizer's cross-hair cursor over a point within the box, and pressing one of the buttons. Height information is input from a pair of scales on the right-hand side of the menu. These scales, labelled 'Top' and 'Bottom', indicate the levels between which facades will be drawn. Heights are selected by digitizing a point within one of the boxes at the required level. For cases where only one height is required, an additional pair of boxes ('Mode 3 level is top', and 'Mode 3 level is bottom') are provided. Both scales initially run from -8 to +20 units, but it is possible to re-scale these up or down repeatedly by factors of 10.

For each object entered, the sequence Select mode - Enter points - Terminate mode is followed. The current mode is selected by digitizing one of the boxes 'Mode 1', 'Mode 2' or 'Mode 3', or one of the boxes corresponding to a pre-defined form. Points are then entered from the plan, and are interpreted according to the selected mode. If required, other features, for example top and bottom levels, may also be redefined while points are being entered. Current mode is normally terminated by digitizing the 'End current mode' box on the menu; however, four of the pre-defined shapes are defined by a fixed number of points, and once they have been entered the mode terminates automatically.

To add flexibility, it is possible to change between Mode 1, Mode 2 and Mode 3 at will, without first leaving the current mode. If one of the pre-defined forms is selected while some other mode is set, the program acts as though 'End current mode' had been entered first.

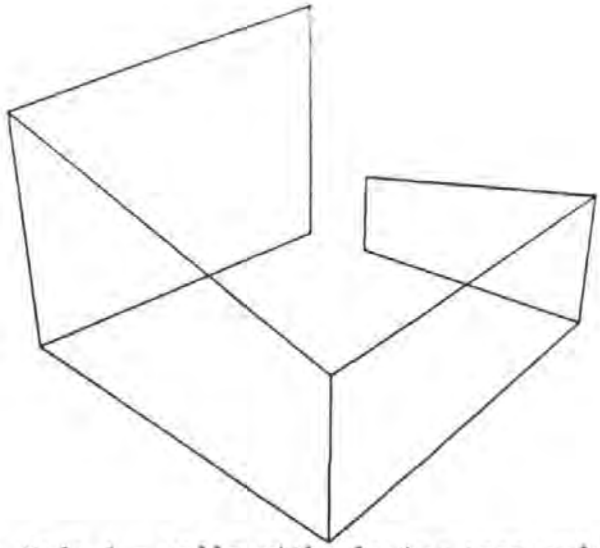

Figure 2. Mode 1 - walls with sloping tops and bottoms.

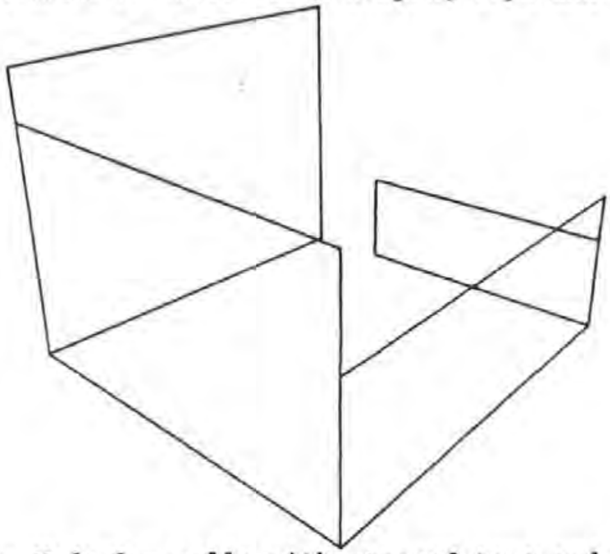

Figure 3. Mode 2 - walls with stepped tops and bottoms.

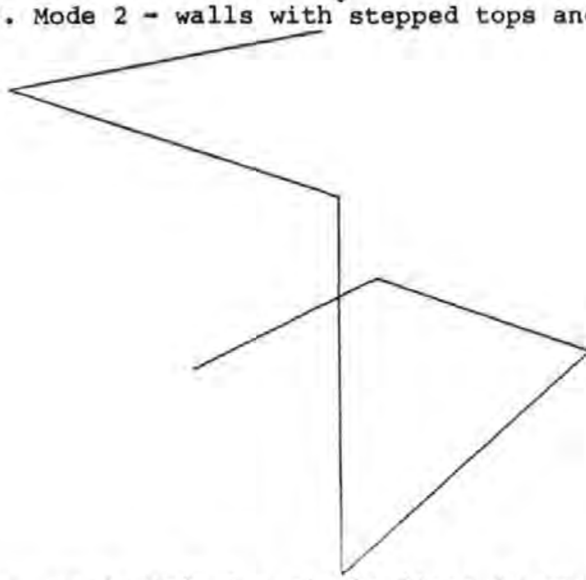

Figure 4. Mode 3 - single lines in space.

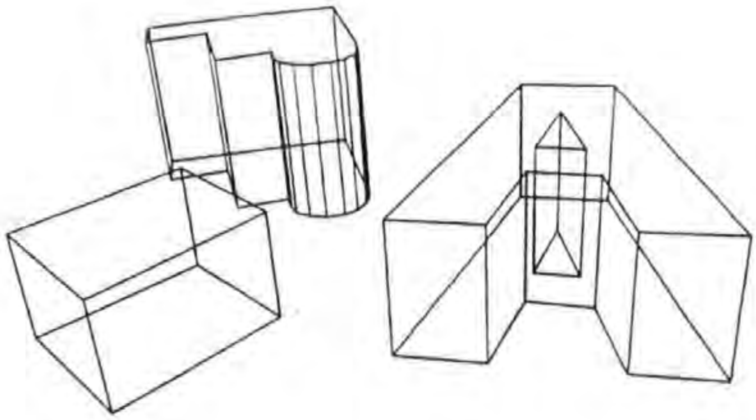

Figure 5. The prism primitive.

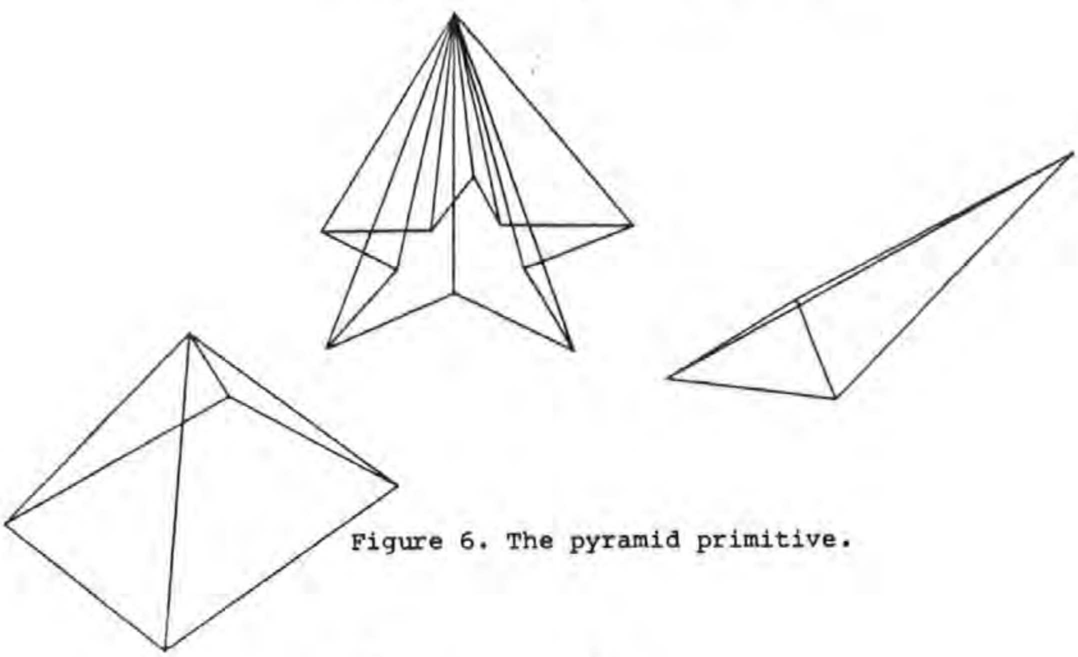

Figure 6. The pyramid primitive.

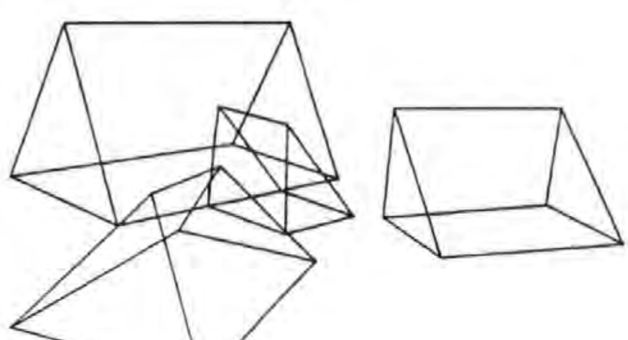

Figure 7. The pitched roof primitive.

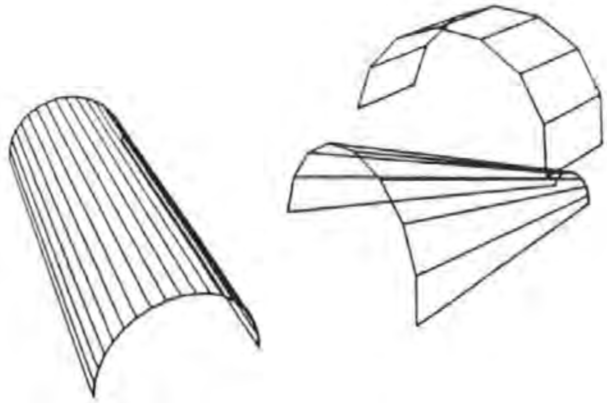

Figure 8. The barrel-vault primitive.

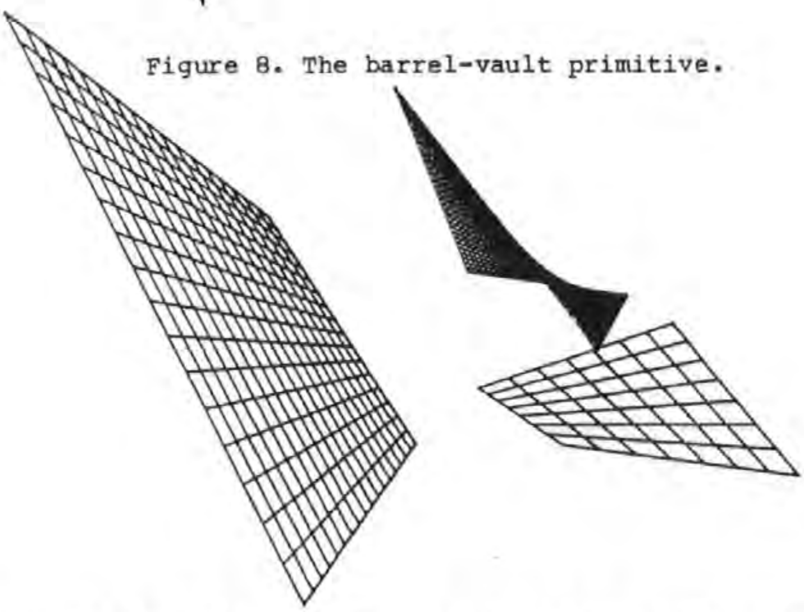

Figure 9. The hyperbolic paraboloid shell primitive.

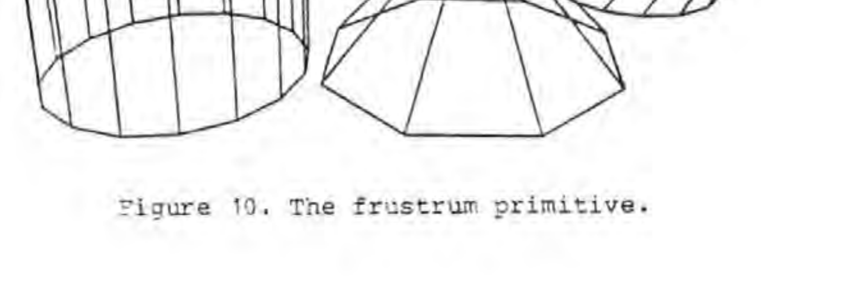

Figure 10. The frustrum primitive.

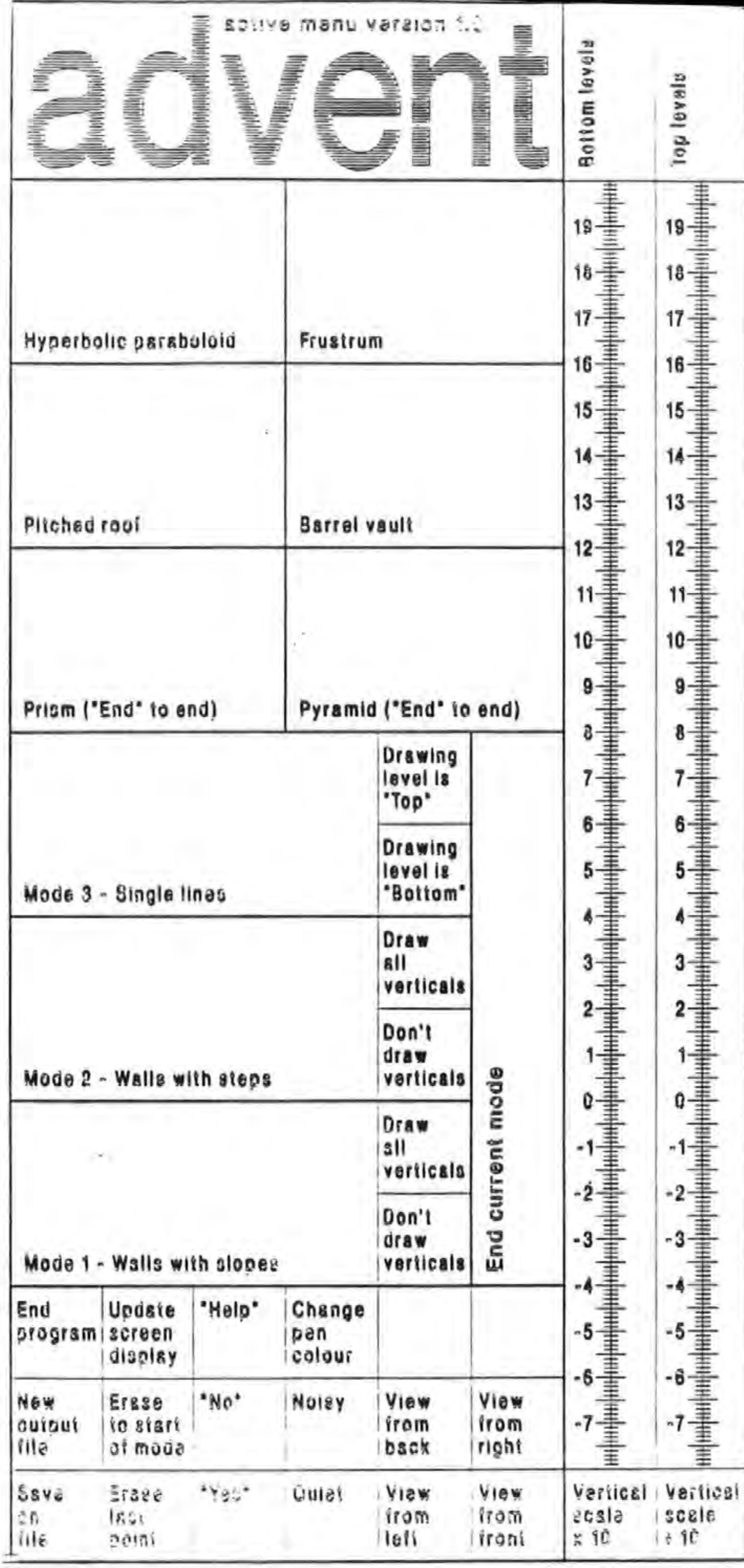

Figure 11. The active menu.

Objects entered in separate cycles around the above sequence are entirely separate, the first point of one object is never connected to the last point of the previous one. This provides one method of entering separate objects. However, for entering, for example, the windows in a building this method becomes cumbersome and an alternative is provided. The buttons on the digitizer's cross-hair cursor are arranged as a numeric keypad, and different actions are taken depending on the key used when a point is entered. When button 2 is used, the horizontal lines joining the point being entered to the previous point are suppressed, providing an easier way to enter discontinuous objects. Button 3 is used to suppress the vertical line that would be drawn at the point being entered, a feature that may also be switched on and off 'until further notice' by the 'Draw verticals' and 'Don't draw verticals' menu boxes.

Down the right hand side of the terminal screen (figure 12) is a continuous display of the state of the main program parameters: drawing mode, 'Top' and 'Bottom' levels, etc. With the exception of a small area at the top of the screen used to display messages to the user, the rest of the screen displays a perspective of the subject being digitized. The viewpoint chosen corresponds to the actual position of the user's head if he were viewing a model standing on the digitizing surface in place of his plan. As the foreground can easily obscure background detail, three alternative views are also available: from the back, and from the left- and right-hand sides.

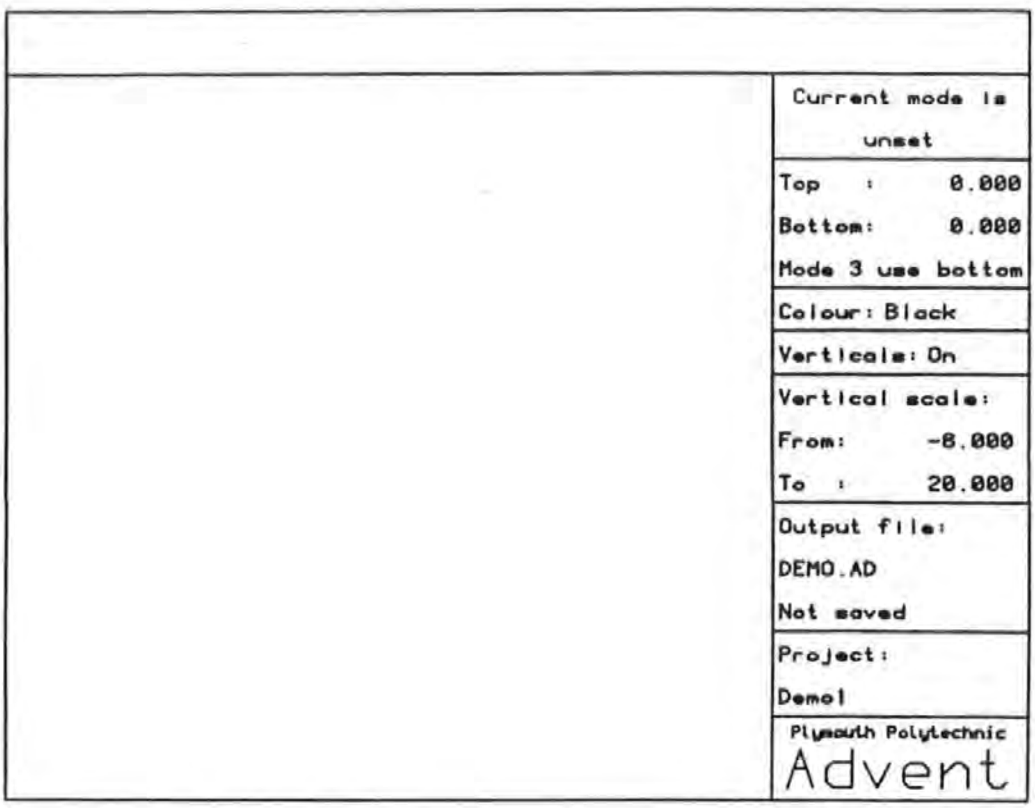

Figure 12. The screen layout.

Editing

It is inevitable that mistakes will be made at some stage while entering data. It was beyond the scope of the ADVENT project to implement a full scale 3-dimensional editor, allowing the identification and modification of random points within the data structure. However, with the aid of the perspective view, most mistakes are apparent almost as soon as they are made. The program therefore provides the ability to rub-out the last point entered.

This rubbing-out, or backstepping, has been made as general as possible. It is possible to repeat it, rubbing out as many points as required, and with each point removed the entire state of the program (drawing mode, 'Top' and 'Bottom' levels, etc.) reverts to how it was just before the point was entered. Using this facility it is possible to backstep past an error to remove it from both the stored data and the screen and then to continue the digitizing process. It is also possible for a user to experiment with the program, and to remove the results of his experiment if unsatisfactory. This provides a very effective self-teaching aid, greatly increasing the accessibility of ADVENT, reducing the time taken to master it and largely eliminating the need for a complicated handbook.

For simplicity two functions are provided: 'Erase last point' which backsteps to the moment just before the last point was entered, and 'Erase to last mode change' which backsteps to just before the first point entered in the current mode. Both of these may be repeated, if required, until the entire drawing has been erased.

Applications

Although designed for architectural applications, the methods used in ADVENT are applicable to many other fields where visualisation of 3-dimensional scenes is required.

ADVENT is designed for use with a wire-frame perspective program and therefore includes no tests for closure or intersection of bodies. The pre-defined primitives are clearly adaptable to hidden-line or hidden surface applications (as in the case of AD101), and the range of such primitives could certainly be extended to encompass other forms not included in ADVENT. However, such a program would also have to include a range of tests superfluous to those required by ADVENT, particularly non-closure, self and mutual intersection of bodies would have to be detected and trapped, as would ploughshare surfaces.

Conclusion

ADVENT, at the time of writing, had not entered every-day service in its intended role. Preliminary tests, with selected users using various prototype versions of the program, revealed a number of shortcomings in the conception or implementation of some features. The correction or avoidance of these led to the present form and scope of the program.

Experience of ADVENT's use to date has been very encouraging. The internal logic of its operation appears to be both sufficiently consistent and sufficiently evident to have allowed some users to work with it after little or no formal instruction. Other prospective users who have acted as 'guinea-pigs' have reported that ADVENT promoted a much greater level of confidence in their use of the digitizer by providing immediate feedback. The accessibility of features through their incorporation in the menu was also well received.

ADVENT promises to allow students at Plymouth much easier access to simple and rapid visual evaluation of their design projects, giving them genuine computer-aided design facilities by involving the machine at a much earlier stage than was previously the norm.

As ADVENT goes into first-line service some enhancements and modifications will no doubt be made, but the essence of the concept appears to be both sound and effective.

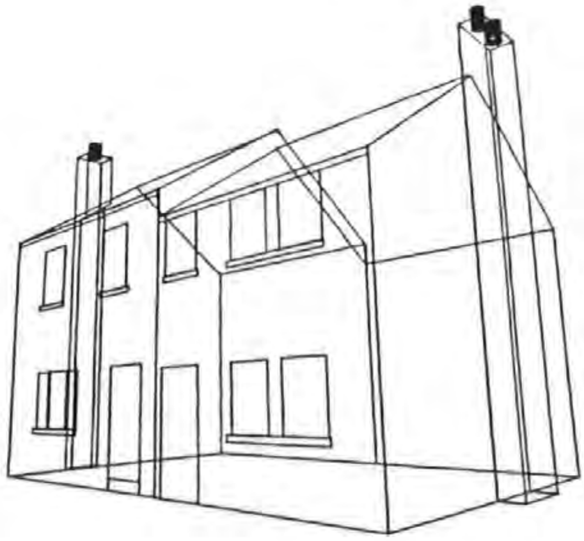

Figure 13. Perspective of sketch design digitised using modes 1, 2 and 3.

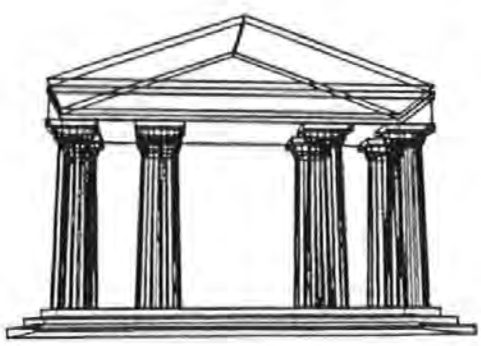

Figure 14. Perspective of sketch design digitised using primitives.

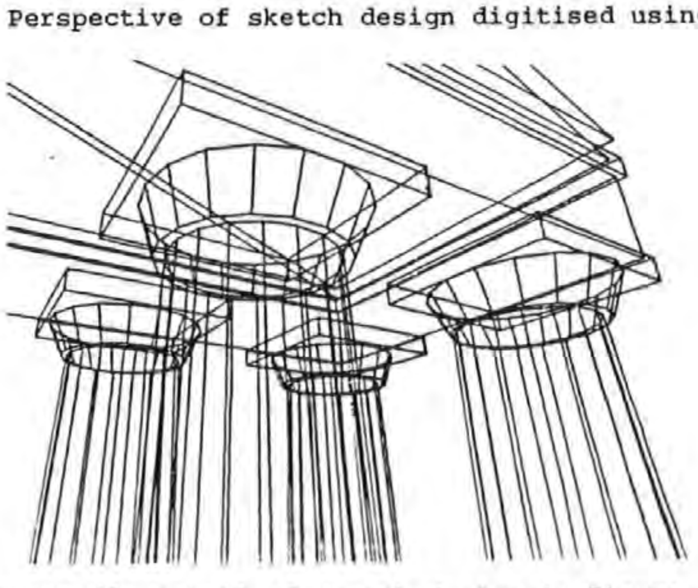

Figure 15. Detail of sketch design in figure 14.

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THE ROLE OF TERRAIN MODELLING IN COMPUTER AIDED LANDSCAPE DESIGN

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ABSTRACT

A system for Computer Aided Landscape Design has been developed to provide a more rigorous and efficient approach to the planning and design of proposed changes to or new objects in the landscape. Current applications in this area include the evaluation of the visual impact of alternate electricity transmission lines, forest design and urban design. A Major component of this approach addresses Computer Aided Visual Impact Analysis (CAVIA). The CAVIA component provides tools for the input of existing Landscape Data, input and manipulation of Man-Made Design Object Data, Visibility Analysis and the generation of high quality Visualisations. The need and the approach for the system as an aid to planning and design problems is explained through the description of a case study. Central to the technique is the Terrain Modelling component. The currently integrated Digital Terrain Model (DTM) package is described and its role within the design environment discussed.

GENERAL INTRODUCTION

Under pressure of growing public awareness of environmental issues, planning applications for the creation or modification of structures in the landscape are now being subjected to more stringent environmental impact analyses. This will be reinforeced in Spring 1988 when a new EEC directive governing environmental impact will become effective. The directive recognises landscape and, by implication, visual impact, as an issue within environmental impact analysis.

Traditional visual impact analysis techniques have employed artists impressions and physical scale models. However, this approach has tended to be inaccurate and subjective in analysis. In an attempt to improve the techniques, a more analytical approach involving computer aided analysis of digital landscape models has been developed.

The paper is divided into 2 complementary parts. The first part describes the computer aided approach to landscape design from the applications or designers perspective. The new design tools and their use are explained in the context of a recent case study. Finally, areas of research leading to the enhancement of these tools are detailed. In the second part, the supportive role of the DTM component of the design package is analysed. The workflow associated with the design process is outlined and the capture, generation and use of the DTM explained within this framework.

PART 1 - VISUAL IMPACT ANALYSIS : A CASE STUDY OF A COMPUTER BASED SYSTEM

INTRODUCTION

Over a number of years the Turnbull Jeffrey Partnership, a firm of Planners, Architects and Landscape Architects, have developed a system for Computer Aided Landscape Design. This system has recently been extended with the support of the Forestry Commission to include forestry planting, felling and replanting design. In collaberation with ABACUS, a research unit in the Department of Architecture and Building Science at the University of Strathclyde and supported by the Science and Engineering Research Council (SERC) the Central Electricity Board (CEGB) and the South of Scotland Electricity Board (SSEB) the Computer Aided Visual Impact Analysis (CAVIA) is being validated and further system is being developed This work builds on visual impact analysis commissions undertaken over a number of years by the Turnbull Jeffrey Partnership for the CEGB, SSEB and other clients. In particular it builds on the work undertaken on transmission line routing since data exists for a number of these routes from planning and design through to construction forming an excellent basis for validation of the computer techniques used for visual assessment and for presentation at public enquiry.

The software is written in Fortran 77 and uses GINO-F. It runs on the University of Strathclydes VAX cluster under VMS where the choice of computer ranges from a VAX 11/750 to an 8600 series. The system supports a number of graphics terminals, digitizers, and plotters. Data is transfered from the Vax Cluster to an IRIS 2400 workstation for animation. Frame grabbing and colour work is done using an IBM PC with a Pluto 2 imaging system.

CAVIA - DATA AND TOOLS

The system for Computer Aided Visual Impact Analysis (CAVIA) can be considered as having four main sub-systems.

Landscape Objects

Integration of digital terrain models with landuse, topographic features and satellite ground cover data to generate plans, cross sections and perspective views of the landscape.

Design Objects

Modelling, in plan, section and perspective and, if required in colour, of any man made objects such as electricity pylons, buildings, bridges, or natural objects such as trees, shrubs etc.

Visibility

Accurate measurement of the degree of visibility of design objects or topographic features in the landscape and the complementary measurement of 'dead ground'.

Visualisation

Generation of images of terrain and design objects, in line or colour form, suitable as visualisations on their own, as montages with black and white or colour photographs or as colour video by mixing with 'frame-grabbed' or live images.

Techniques used for Visibility and Visualisation

Six principal programs are involved in the process of determining the visibility of design objects or features (topographic) in the landscape and these are briefly described below. In addition, many other programs are needed in support for the purposes of data input, checking, modification, manipulation, analysis and display. All programs operate on the same landscape and design object data. The principle of intervisibility is fundamental to the program methodology in identifying the locations in the landscape where a person can or would see a design object or feature.

The program VIEW1, based on this principle considers only topography as defined by a DTM. The visibility of a design object established by the application of this program results in the worst possible case since no allowance is made for any screening which may result from trees, buildings or other such features in the landscape. In some landscapes these features may reduce visibility considerably. The height of the design object may be set as required, thus if the height of the design object is, for example, the top of a transmission tower, the visibility of the whole tower can be investigated. All the simulations take into account curvature of the earth and refraction of light which can be significant when view distances over one kilometre are involved. VIEW1 also allows the investigation of invisible areas, that is 'dead ground'. This is important in certain siting or routing considerations since the visibility or invisibility of a design object placed in an area of dead ground can be immediately determined.

The VIEW2 program can be used, for example, to analyse views of transmission tower route from specified viewpoints. This program can modify a DTM to allow for the screening effect of features such as trees or buildings, identify those towers visible from a specified viewpoint and detail the percentage visibility of each tower. It can also determine for each tower whether it is seen against a backcloth in which case the area acting as backcloth is identified or if seen above the horizon, the percentage of the tower seen in this way. This program can take into account whether a viewpoint, such as a road, is in a cutting or on an embankment. Additional programs VIEW3 and VIEW4 can identify the significance of features such as trees or hedges in controlling the visibility and screening of towers, and can identify the areas which would see the towers if existing screening such as trees were removed, thus identifying areas critical to achieving screening. The results of the VIEW1, VIEW2, VIEW3 and VIEW4 programs are represented in map form, either as computer print-outs, computer line drawings or as tables and diagrams. By using additional programs, VIEWER and LANDVU, it is possible to produce an accurate perspective drawing of the visible towers in the landscape from a given viewpoint. This is important in demonstrating the visibility of the towers and their scale in the landscape.

The VIEWER program is a three point perspective drawing procedure providing 'wireline' drawings with hidden lines removed of design objects for photomontaging. VIEWER processes a three dimensional geometrical description of a design object, for example the structural steelwork of a transmission tower and/or a DTM and outputs a three point perspective view of it. This view is fully corrected and adjusted to accurately depict the exact design object as viewed by an observer from any viewpoint location in the study area.

The LANDVU program produces a computer generated three point perspective of the DTM from a specified viewpoint in the form of a 'wireline' drawing with hidden lines removed.

Using this data and the appropriate viewing parameters recorded during the site photography, perspective views can be drawn by the computer replicating the photographs exactly. To prepare a photomontage, these perspectives are printed onto transparent sheets and overlaid on the enlarged colour site photographs. An exact registration between a photograph and the computer drawing is achieved by means of control points. These points are known and visible features in the photographs, and are modelled in the computer views to ensure an accurate match in the montage.

CASE STUDY : TORNESS TRANSMISSION LINES

The CAVIA system has been put to use on various projects as it has been developed and is to some extent project led. The Torness Transmission Lines Study is one of a considerable number of projects undertaken, but was the first in which the majority of the system has been used. The lines have been constructed for several years.

Transmission lines are constructed to transmit electrical power from the source of generation to load centres and carry power on conductors suspended at regular intervals from towers of lattice steel construction some forty-five to fifty metres high.
The Torness Transmission Lines Study involved the detailed visual assessment of two alternative transmission line routes in the south east of Scotland in the Berwickshire and Ettrick and Lauderdale Districts of Borders Region, centred on the Lammermuir Hills which rise up to 500 metres and separate the fertile and populous plains of East Lothian in the north and the Merse and Upper Tweed Valleys in the south. In scenic terms, the Lammermuirs have an open treeless appearance characteristic of much of the upland scenery of southern Scotland south of the fault line from Dunbar to Girvan. At a regional level the Hills are subject to environmental policies contained within the structure plans of Lothian and Borders Regional Councils, designed to protect the ecology and the scenic nature of the area.

Visibility : General Considerations

In conducting a study of the potential visibility of a transmission line, it is first of all necessary to make some judgement about the area from which the transmission towers will be visible. Distance is a very important factor when viewing a transmission line in the landscape. In general, apparent height in the landscape varies inversely with distance, the smaller the apparent size of the transmission tower, the less significant its visibility. In many instances, the overall visibility of a transmission line will be limited by surrounding topographic features. Where this is not so, experience has indicated that the most significant views are likely to be experienced within a distance of five kilometres from the transmission towers. Longer distance views can be significant, particularly where a transmission line is viewed above the horizon, that is, on the skyline. Accordingly, a study area extending beyond five kilometres from the routes was defined to accommodate such longer views to towers. This larger area was selected by examining the topography surrounding the immediate study area in Borders Region.

Use of a computer in visibility studies has distinct advantages over field studies:

1 to given levels of accuracy, the visibility of design objects in the landscape can be simulated and recorded by analytical techniques which could be impossibly long to undertake manually

2 after data acquisition different alternatives can be evaluated quickly and easily.

Data Collection

A 30km x 30km area of the Lammermuirs mainly within Borders Region was identified for analysis. Although a square study area was chosen, this is not a requirement of the techniques. The DTM was prepared from Ordnance Survey 1:25000 series maps by Laser-Scan Laboratories Limited of Cambridge, using specially developed equipment and computer programs. The process involved following the contours with a laser and recording in digital form the location of all points where the contour lines changed direction. The data was then transformed to National Grid co-ordinates, interpolated to the specific grid of 25 metre and verified using contoured drawings and three dimensional representations of the data. Before the DTM of the study area was prepared, four trial areas, typifying the different topographic features of the study area, were tested to determine the most appropriate grid interval for the DTM and the levels of accuracy required. Roads and woodlands were also digitised and the information converted for use at a 25 metre grid.

Application and Interpretation

Initially the entire area of 30km by 30km was studied using a DTM with a 200 metre grid generalised from the 25 metre grid to assess the overall visibility of alternative routes. The VIEW1 program produced visibility maps for each of forty transmission towers and amalgamated these to produce 'contours of visibility' for each route in total (Figure 1). This level of analysis was used to identify broad patterns of visibility and to highlight areas for further detailed study.

The results showed that both of the proposed routes exhibited a similar pattern of visibility. Both crossed a high upland section of the Lammermuir Hills at a height of approximately 400 metres. In the area, the local population resided in villages and farm steadings which for the most part lie in lowland areas along valley floors.

With the exception of one stretch of trunk road, the same conclusion applied to the major roads in the area. The results demonstrated that the resident and road using population were entirely screened by intervening topography from either of the transmission routes considered in the study.

Subsequently, a smaller area of 22km by 22km was analysed using a 100 metre grid to give a greater level of accuracy. The area chosen was based on the 'contours of visibility' map produced using the 200 metre grid. The analysis of information generated by the VIEW1 program when run using the smaller data set, validated the general conclusion and permitted certain more detailed conclusions to be drawn about the similarities and differences in visibility for each of the proposed lines.

Once the main areas of visibility had been defined a more accurate visual assessment was undertaken from selected viewpoints within these areas. Clearly not every potential viewpoint was of equal importance and a selected list of viewpoints was identified by field observation and from the results of the VIEW1 program.

The visibility from individual viewpoints was assessed using the VIEW2 program. This analysis generated a range of detailed information for each viewpoint. In this way, valuable data was obtained to assist with the assessment of the visibility, particularly in respect of the extent of visibility of particular towers above the skyline.

Whenever possible, the results of the computer studies were correlated with a parallel exercise of field observation recording the nature of the view, type of landscape and vegetation, important buildings, and recreational activities. The height of a transmission tower can be estimated roughly in the field by employing a yardstick device and estimates of visibility can be recorded by a simple method of classification. The computer results can then be combined to construct an analysis of visibility in the context of landscape setting and type. The VIEW3 program was used to define 'critical areas' where the existence of a feature, such as woodland or a building, of a stated size would make the difference between visibility and invisibility. It was then possible to examine maps and aerial photographs to establish if trees or buildings occurred at these critical locations.

Visualisation

The visualisation stage of the study was undertaken using VIEWER and LANDVU computer perspective programs. It was originally intended to prepare a photomontage from each of the viewpoints with a view of the alternative lines (Figure 4). However, bad weather precluded the possibility of obtaining photographs from all but one of the viewpoints and a perspective view of the landscape from these viewpoints was generated using the LANDVU program. The results of this program were correlated with the results of the VIEW2 program and from the photomentage process obtained for the one possible montage permitted by the weather.

Outcome of Case Study

A Public Inquiry proved to be necessary to resolve the issues associated with the transmission routes. The computer assisted techniques proved to have certain key advantages:

1 the quantification of the extent of visibility associated with the alternative routes and the exploration of the detailed pattern of change in the visibility was demonstrated by reference to maps with overlays. This directed debate away from speculation about what might or might not be seen, and instead focussed it on interprepation of patterns of visibility and the implications of these for the landscape of the area

2 the production of accurate photomontage and perspective views of the landscape from selected viewpoints showed the landscape before and after the transmission towers had been erected. In some cases these proved particularly interesting since the towers were screened entirely from view where field observation had indicated that some parts of some towers might be visible. Once again, debate was focussed on the interpretation of visual images rather than on their accuracy.

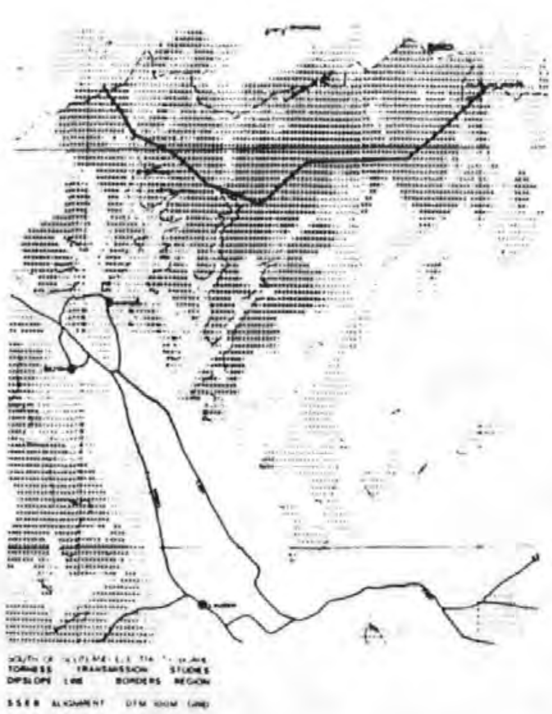

Figure 1 Contours of Visability

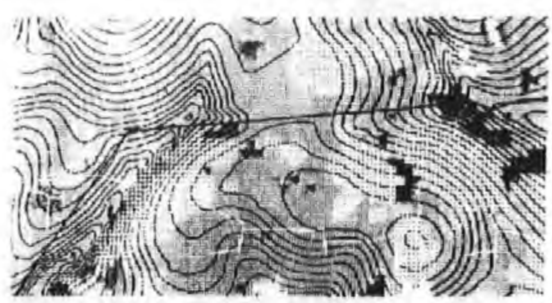

Figure 2 Ground Cover Map

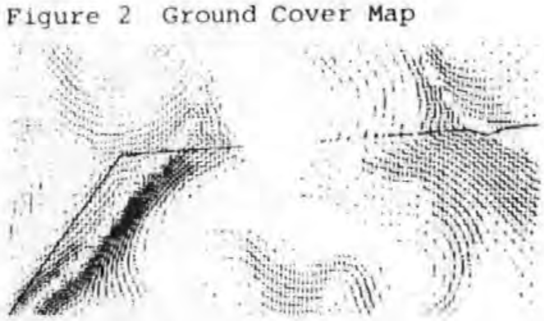

Figure 3 Slope Map

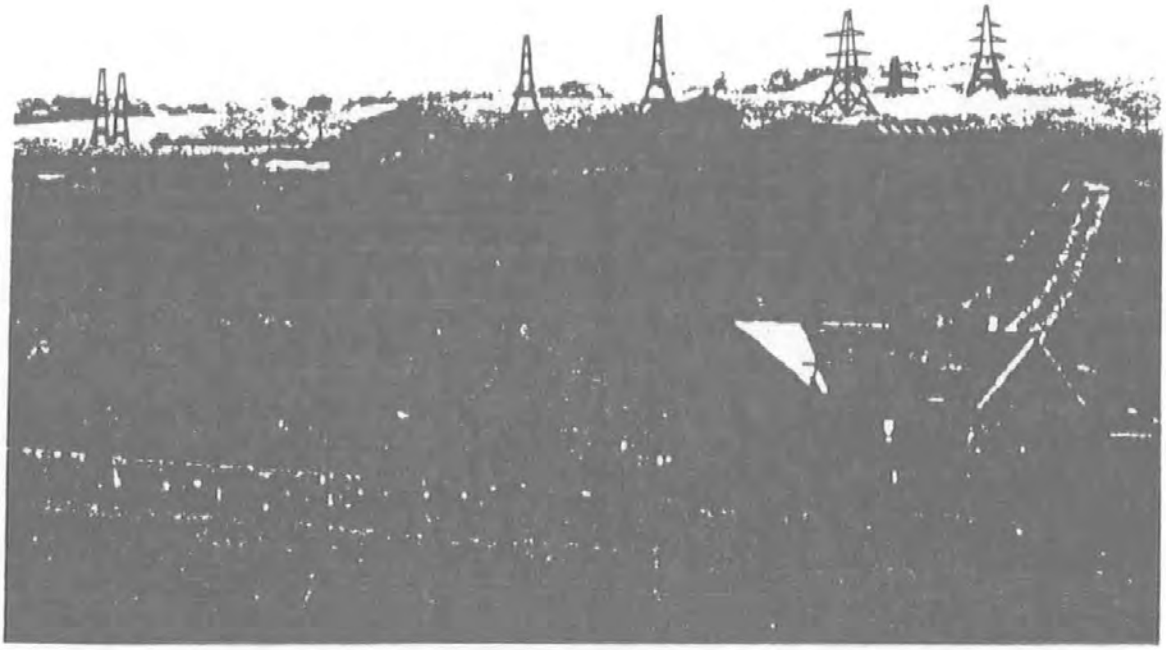

Figure 4 Photomontage of proposed transmission towers

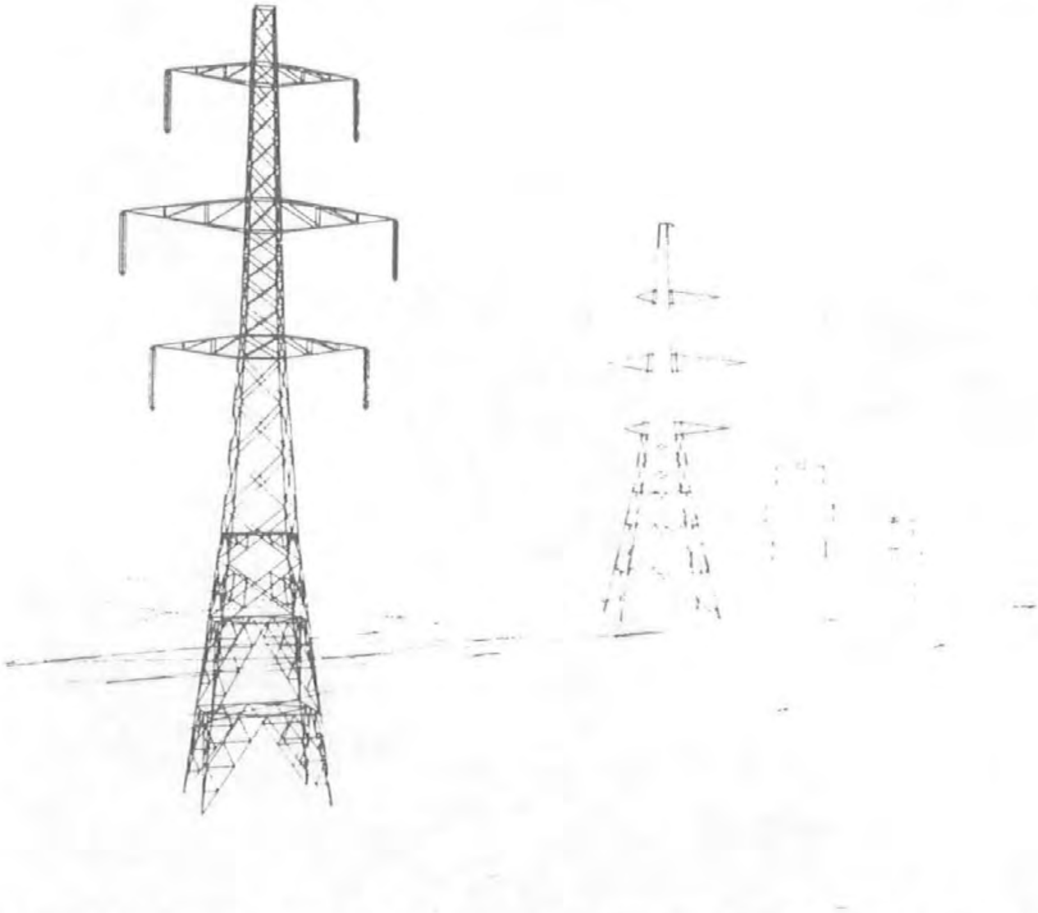

Figure 5 Perspective of towers using pen plotter to give distance effect

Access Tracks

Although the Public Inquiry found in favour of the SSEB's proposed route, the method of construction, the access tracks for construction and maintenace of the lines were subject to further planning submissions to ensure that their impact on the environment was minimised.

It was therefore decided to prepare detailed maps identifying ground cover habitats along 12 kilometres of the most sensitive terrain on the route and to advise on the most appropriate construction techniques and ground reinstatement.

The practical objective was to provide good quality ground cover data to ensure accurate and prompt drawings for Planning Permission outlining proposals for a proper and full landscape and ecological reinstatement and for subsequent contract documents. In addition to the planning submission, this information was used in design work and as an outline guide in construction planning, and in discussion with relevant conservation bodies to assure them of adequate landscape reinstatement. Finally, the maps with a distribution of ground cover habitats were linked to prescribed components of landscape advice detailed techniques of construction and reinstatement practice to be employed in association with particular habitats.

The distribution of ground cover habitats was prepared by remote sensing techniques based on LANDSAT satellite imagery. In this case the use of LANDSAT data was selected due to the short timescale before construction work began. Traditional methods using published maps of soil and land use classifications linked to a time consuming site survey would have limited the scope and extent of the study particularly in the ability to examine the distribution of ground cover habitats at a variety of scales.

The satellite interpretation work was carried out by the Environmental Remote Sensing Applications Centre (ERSAC) Limited using an image processing computer system. The interpretation was validated by on-site checking of selected areas. The ground cover data available at the end of this process was held in the form of a classification at 50 metre grid intervals for an area of 22km x 22km.

After the interpretation and field-checking process a final ground cover interpretation was prepared as follows: woodland, water, heather dominant, heather grass/burnt mix, upland grass, improved grass, bracken dominant, cropland.

The ground cover data derived from the satellite imagery was analysed and then combined with elevation data at a 25 metre grid and data on the location of woodlands and roads (Figure 2). Additional data was derived from the DTM: slope at specified gradients (Figure 3); drainage direction; aspect; elevation at specified contour intervals.

Output Display : Video

The main issue to be investigated is the cost-effectiveness of producing dynamic images of design/planning proposals. It is already possible to generate a 'walk-through' of buildings and of neighbourhoods but only by the expensive and time consuming process of frame-by-frame filming. The IRIS 2400 workstation offers the possibility of real time dynamic viewing, video recording and manipulation of a model, in either wire-line or fully coloured modelling. The remaining problem is then to ensure colour constancy from designer's materials to screen view to video record.

PART 2 - THE ROLE OF TERRAIN MODELLING WITHIN CAVIA

INTRODUCTION

The Computer Aided Landscape Design package developed by Turnbull Jeffrey Parternship has been described in the first part of this paper from an applications perspective, describing the design tools provided and how they have been used within the context of an example case study. Given this scenario, this part of the paper describes the underlying DTM component of the system, explaining its role within this design environment.

The paper has been structured to reflect the workflow associated with CAVIA design procedures. The high level workflow is shown in the figure below:

```
           PROJECT DEFINITION
                   |
                   V
          CAPTURE OF DTM DATA
                   |
                   V
           GENERATION OF DTM
                   |
                   V
      CAPTURE OF LANDSCAPE OBJECTS
                   |
                   V
        CAPTURE OF DESIGN OBJECTS
                   |
                   V
           ANALYSIS OF DESIGNS
                   |
                   V
       OUTPUT OF VISUALISATIONS
         AND DESIGN PARAMETERS
```

FIGURE 6: CAVIA Workflow

The system's use and the designer's interaction with the DTM at each of the phases are explained and possible areas of improvement and system extensions are described.

PROJECT DEFINITION

The preliminary stage of a project is to set up a series of 'soft' system parameters to customize the CAVIA system for the particular project characteristics. The parameters associated with the DTM are Feature Class to DTM Data Type Relationships.

The user can create a data model for the project through the facility of feature class definition. Having defined the data model, the user can then associate feature classes with DTM data input types to control the generation of the DTM. For example, ridge lines, rivers and roads could be allocated to break lines.

CAPTURE OF DTM DATA

Elevation Data Types to be Captured

The DTM package is designed to accept generalized forms of elevation data, including:

- Arbitrarily distributed spot heights
- Profile or grid measurements
- Contour lines
- Break lines

The most common and readily available form of elevation data used in projects have been contours and spot heights from topographic maps. Although their accuracy is relatively low, it has proven sufficient for projects where evaluating alternative locations of objects in the landscape or evaluting different size of objects in the landscape is the primary objectve. However, once the general location plan has been approved, an original survey is carried out to enable the design refinement and to derive engineering construction parameters. This approach minimizes the cost of surveying, particularly in projects involving route selection as it limits surveying to the corridor of the selected route.

One of the key landscape design analysis tools of the CAVIA system is the accurate measurement of the visibility of objects. This involves line of sight calculations using the DTM. The results of this analysis are extremely sensitive to the accuracy of modelling ridge features within the DTM. To meet this requirement, the DTM allows these features to be defined and integrated into the DTM through the mechanism of breaklines.

Methods of Capture

The spatial extent of project areas where this technique of landscape design is applied varies enormously from planning sub-regions, 30 x 30 kms, to street sites a hundred metres across. Therefore, the methods used to capture the terrain information reflect the quantity and quality of data to be collected. For projects involving route selection over large areas, the source of elevations is usually restricted to existing topographic maps. However, for projects whose final product is an engineering design, an original survey using photogrammetry or field surveying is performed.

In the case where the project encompasses a large spatial extent, the digitising of the contour information has been contracted out to service bureaux such as Laser-scan Laboratories Limited of Cambridge to automatically digitise on their FASTRAK system. Once the digital contours have been loaded into the system, they are then supplemented by manually digitised spot heights and breaklines.

For all smaller project areas, all the elevation information has been manually digitised. The contour digitising procedure involves a user definable filter based on an automatic, incremental, distance release that substantially reduces the data volume without jeopardizing the resulting DTM fidelity.

For large scale urban projects, an interface to the UK Ordnance Survey digital data has been comtemplated. However, apart from the current sparse coverage, the 1/1250 series has insufficient elevation information to support this application.

FORMING THE TRIANGULAR IRREGULAR NETWORK (TIN)

The generation of the DTM involves setting up a spatial, triangular irregular network including connection information about neighbouring triangles throughout the network.

Prior to the formation of the TIN, the elevation input data is filtered so that resulting segment lengths conform to a user defined constraint. This controls the length of triangle sides.

The construction of the triangles uses a constrained version of the procedure proposed by Delauney (explained in Gottschalk 1981 for example). As with the Delauney approach, the triangulation is unique, but the following constraints are imposed during the generation:

- Triangles must not cross breaklines (including contours since they are treated as breaklines in this application).

- Triangles must not be composed of more that 2 vertices from any one breakline.

The result of this process is a continuous triangular mesh that is stored in the associated project database. This is the definitive version of the terrain definition from which all other terrain characteristics are derived.

CAPTURE OF LANDSCAPE OBJECTS

As landscape objects such as roads are being digitised from map material, the system automatically forces the features to conform to the DTM.

In the case where landscape objects have no explicitly associated elevation information, the system automatically calculates and allocates the elevation to the X, Y points defining the features. This is achieved by floating the landscape object on to the DTM.

Instead of landscape objects being constrained to conform to the existing DTM, some may force modifications to the DTM during placement. This occurs when the landscape object either has explicit elevation information associated with it or is a 3-D object with inherent geometry that does not conform to the existing DTM. In both cases, the landscape object is providing extra elevation information and the DTM is locally modified to accommodate it.

CAPTURE OF DESIGN OBJECTS

The DTM is involved in two aspects of design object capture: the constraint that design objects must conform to the existing terrain and the integration of derived DTM parameters in user defined placement rules.

Design Object - DTM Conformity

When the landscape designer is placing design objects into the model of the landscape, the system ensures that there is a consistent fit between the existing DTM and the design object. The interaction of the design object with the DTM is treated in the same way as landscape objects previously described.

DTM Constraints on Design Object Entry

During the initialisation of the project, the user defines the type of design objects to be integrated and analysed in the landscape design eg, electricity tower types and tree types. This involves the user defining generic descriptions of the objects in design object libraries. The definition has two components:

1 Geometric Definition

Scale independent definitions describing the geometry of the design objects. These are subseqently instanced through transformations when the design objects are positioned in the landscape model.

2 Placement Rule Definition

These user defined rules impose constraints on the placment of design objects. The rules are normally based on a combination of DTM derived and other environmental parameters. An example that does not use terrain information is the constraint to place plants within specific soil types. However, terrain parameters can be used to influece the position of the design object. In forestry design, rules governing the placement of tree species include restrictions based on slope and aspect criteria derived from the DTM.

In more complex applications, the placement rule is based upon the geometry of the design object in combination with the terrain. This is the situation found in the planning of transmission lines. Apart from cost considerations, the major constraint on the detailed placement of transmission towers is the clearance of the associated catenary formed by the suspended conductor between the towers. Safety regulations dictate the minimum clearances allowable variety of land-use types.

During the placement of design objects, the system can display the existing data in perspective as well as the default orthogonal transformation simultaneously. This provides the designer with the possibility of positioning design objects directly on the perspective display that in many cases is more natural to a designer.

SELECTION OF PROJECT AREA SUBSET FOR ANALYSIS

All data associated with a project ie DTM, landscape objects and design objects are stored in a single definitive version called the project database. When a designer wishes to work on a project, the required portion (logical and physical subset) is extracted from the project database and copied into a working subset called a partition database. On completion of the design work in the partition database, any changes to the data are integrated back into the project database in a controlled environment to ensure data integrity. This mechanism avoids problems associated with data corruption in a multi-user environment.

Formation of a Regular Grid DTM

Historically, the CAVIA package used a regular grid DTM. Although this has been superseded by the TIN based DTM, several of the application analyses still use a regular grid DTM. During many of the preliminary analyses in the design process, the designer is more concerned with broad patterns than with the detailed accuracy of the result. This can be achieved more easily in an interactive environment using a regular grid rather than a triangular DTM, due to the higher speed of processing. Therefore, the system derives a regular grid DTM from the TIN and carries them in tandem for the duration of the analysis. Once the analyses are complete, only the TIN is permanently retained for future use. The TIN is the definitive state of the DTM and all other elevation information is derived from this source.

DESIGN ANALYSIS

Once both the landscape and design objects have been captured, the designer can then analyse and optimize the proposed landscape design using the created computer simulation. Two sets of tools are available: visibility and visualisation analysis.

Visibility Analysis

Based on the principle of intervisibility, this set of tools allows the designer to:

- determine the degree of visibility of design objects in the landscape.

- quantify what portion of the visible design objects protrude above the horizon.

- analyse the degree of sensitivity of visibility to the placement of screens such as hedges and trees.

- determine the optimal position of screens

The result of these analyses is a design that "hides" or minimizes the visual impact of the design objects in the landscape.

In all the visibility tools, the geometry of the terrain is provided by the DTM and ray analysis takes into account earth curvature and atmospheric refraction and variable viewing heights.

Due to the sensitivity of the degree of visual impact on the influence of landscape objects such as buildings and vegetation, in most cases it would be false to analyse a bald landscape. Therefore, the system integrates user specified categories of landscape objects into the visibility analysis. Individual landscape features can be interactively included/excluded from the analysis to determine their influence on visibility. In effect, the landscape objects are integrated into the DTM for the duration of the analyses.

To enable the effect of vegetation screens on visibility to be judged over time, their height can be varied interactively to simulate growth between analyses.

The results of visibility analysis are normally maps illustrating visibility polls for the area of interest.

Visualisation Analysis

These tools allow the designer to view the proposed design on the graphics screen at varying degrees of realism depending on the stage of the design process.

During the early design phase where a high degree of interactivity is required to support the inevitable number of design iterations, the designer can display perspective views of the design proposal on the graphics screen. Due to performance constraints on the current hardware configuration, only approximate wire frame models of the landscape and design objects are portrayed. Hidden line removal is an option.

It has been found that the display of a wire frame, regular grid DTM is more easily interpreted than the equivalent triangular mesh. Landforms such as ridges can be easily identified, there is less possibility of mis-interpretation and relative distancing more quickly quantified. However, it is felt that a triangular mesh is superior in visual interpretation over a grid when shading is incorporated into the displayed image.

When the finalized design proposal has to be presented to the client or at a public enquiry, a high quality viualisation of the design is created. At present, this is achieved by combing a field photograph panorama with a corresponding computer generated vector plot of the design objects to create a photomontage (see figure 4). The interior and exterior orientation parameters of the camera are simulated during the generation of the computer plot to guarantee registration of the component images. The DTM is not normally included in the photomontage, except in the case where the terrain itself will be changed by the design. Since the DTM is usually used to position the design objects, any discrepancies between the plotted positions and the photgraphed terrain clearly highlight any inadequacies of the DTM's fidelity.

Current research is investigating procedures to create a photomontage directly from the graphics screen where a framegrabbed image of the photograph is directly combined with an enhanced image of the design objects. The technique applies lighting and distancing effects, matching that of the photograph (Nakemae, 1986), to produce a high degree of realism. This also opens up the possibility to use remotely sensed data to increase realism. Although Thematic Mapper data has been used to identify vegetation types and aid in the routing through environmentally sensitive areas, the data can also be used to control texturing of perspective views.

OTHER LANDSCAPE DESIGN TOLLS UTILIZING THE DTM

Apart from the use of the DTM in the visibility and visualisation tools of the CAVIA component, the DTM is used extensively within other facets of the Landscape Design package. This includes:

- Slope Analysis
- Drainage analysis
- Cross Sectioning
- Cut and Fill Calculations
- 'Bill of Material' Quantity Surveying Tools

The DTM's role within the Landscape Design package ranges from simple cross sectioning, through intricate visiblility analysis to sophisticated imagery textured visualisations. The DTM is fundamental to the computerized approach described and will continue to find new applications within Landscape Design. However, the wide spread use of these techniques is presently inhibited by the current lack of publicly available digital landscape data. The current 1/1250 digital data has sparse coverage, is only applicable to large scale urban projects and lacks the essential 3rd dimension. This approach and other related ones would benefit from the Ordnance Survey providing full 3-D landscape data at large and medium scales.

GENERAL CONCLUSION

The natural and man-made environment is under increasing stress. We are entering a phase when the exploitation of energy resources is likely to cause a dramatic acceleration in our rate of impact on the natural environment; in particular there is cause for serious concern regarding the damaging visual impact of energy related developments such as oil terminals, dams, power stations, transmission lines, open cast mining, on remaining areas of relatively unspoilt rural landscape. At the same time the need to renew our inner cities places enormous responsibilities on architects and planners who seek to integrate elegantly and economically the new with the old.

The political will exists to address the problem, a recent EEC directive recognises landscape and, by implication, visual impact, as an issue within environmental impact analysis. What is lacking is the means to appraise and compare the visual impact of alternative proposals objectively, economically and, above all, in a manner which is understandable to the range of interests involved in the design and planning process. CAVIA is a computer aided system which attempts to meet these requirements.

Computer techniques such as CAVIA are now beginning to be recognised to have an increasingly important role in aiding in the resolution of planning and design problems. The challenge is to integrate a diverse range of techniques from several disciplines into one system.

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