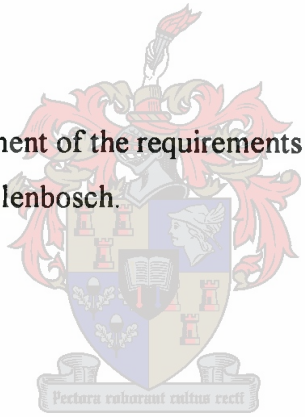
THE DEVELOPMENT OF A VISUALIZATION TOOL TO ASSIST TOPOGRAPHIC MAP USERS

Johannes Lodewikus van den Heever (BSc Honours)



Thesis presented in partial fulfilment of the requirements for the degree of Master of Sciences at the University of Stellenbosch.

Study Leader: Adriaan van Niekerk

December 2002

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that it has not previously in its entirety or in part, been submitted at any university for a degree.

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SUMMARY

The recognition and description of relief features from their contour patterns is recognized as the main challenge in topographic map education. Conducting field exercises can solve this problem, but can be very time consuming. Modern technology, however, provides an alternative teaching technique by creating depictions of terrain. Important issues raised by this new approach include questions such as what these depictions should look like and how it should be presented to the user.

Research presented here aims to address these issues by constructing design guidelines for terrain depiction. These design guidelines were derived from previous research and case studies. The guidelines focussed on research about how people perceive different representations of terrain and how these representations should optimally be presented. The design guidelines were constructed from research done in diverse fields such as cognitive psychology, cartography and engineering. Results of this research revealed that in order to develop an effective terrain visualization tool, it is crucial to incorporate different fields of expertise.

The design guidelines were implemented with ArcView GIS and its 3D Analyst extension, which has the ability to display spatial data in three dimensions. The final product is called Terrain Visualization Tool 1.1 (***TVT***) and was created by customizing an ArcView GIS project (***TV BUILDER***) and constructing a Website (***TV VIEWER***). ***TV BUILDER*** creates the visualization data in the form of 20 web pages per topographic area and links them to ***TV VIEWER*** that serves as a platform to view the data. The design guidelines were implemented successfully and show the advantages of using Geographical Information Systems (GIS) in related research.

Keywords:

Terrain, visualization, visualization tool, ArcView GIS, topographic map and topographic area

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OPSOMMING

Die identifisering en beskrywing van landskapelemente vanaf hul kontoere is geïdentifiseer as die primêre uitdaging in topografiese kaartonderrig. Hierdie probleem kan oorkom word deur kaartleesoefeninge in die veld te onderneem, maar dit neem baie tyd in beslag. Moderne tegnologie maak 'n alternatiewe onderrigmedium moontlik deur die skep van verskillende landskapsuitbeeldings. Hierdie alternatief laat die vraag ontstaan hoe die uitbeeldings moet lyk en hoe dit aan die gebruiker aangebied moet word.

Die doel van hierdie navorsing spreek hierdie vrae aan deur ontwerpriglyne vir landskap uitbeelding daar te stel. Die ontwerpriglyne is saamgestel deur bestudering van vorige navorsing en studies wat op hierdie gebied gedoen is. Die riglyne fokus veral op navorsing wat mense se reaksie op verskillende landskapuitbeeldings ondersoek. Die ontwerpriglyne is egter saamgestel deur navorsing wat gedoen is in velde soos kognitiewe sielkunde, kartografie en ingenieurswese. Hierdie navorsing het bewys dat inkorporasie van verskillende studievelde in die ontwikkeling van terrein visualiseringstoepassings essensieel is.

Die riglyne is geïmplementeer deur gebruik te maak van ArcView GIS en die 3D Analyst uitbreiding wat die vermoë het om data in drie dimensies uit te beeld. Die finale produk genaamd Terrain Visualization Tool 1.1 (***TVT***) bestaan uit twee komponente, naamlik 'n aangepaste ArcView GIS projek (***TV BUILDER***) en 'n webwerf (***TV VIEWER***). ***TV BUILDER*** skep die landskapsuitbeeldings van een topografiese area in die vorm van 20 web bladsye en verbind dit met ***TV VIEWER***, wat as 'n platform dien om die landskap uitbeeldings te beskou. Die ontwerpriglyne is suksesvol geïmplementeer, wat die voordele van Geografiese Inligtingstelsels (GIS) in hierdie en soortgelyke toekomstige navorsing demonstreer.

Sleutelwoorde:

Landskap, visualisering, visualiserings toepassings, ArcView GIS, topografiese kaart en topografiese area

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CHAPTER 1: CARTOGRAPHIC VISUALIZATION

"Visualization is the action of forming a mental image or becoming aware of something through graphical aids" (MacEachren & Garner 1990: 65).

Research, focussed specifically on cartographic communication, has undergone changes during two major phases. Since the 1950's cartography included the research methods of psychophysics and examined the stimulus response relationship of individual symbols. During the late 1970's, cartographic research developed in the direction of cognitive psychology and became concerned with how maps were mentally processed and remembered (Peterson 1994). These two phases shaped cartography into its modern context. Cartography is defined as the art and science of the organization and communication of geographically related information with maps (McDonnell & Kemp 1995). Cartography as a discipline is not only concerned with the production, but also with the conception, dissemination and study of maps. Swanepoel (1999) stated that these maps are primarily created to serve as a form of communication between a user and the area that the map present.

One of the oldest maps which survives today is the representation of northern Mesopotamia, scratched into an earthenware plate, dating from about 2400-2200 BC. This map displays mountains; portrayed from the side, as they would be seen when looking up from a valley. Such lateral portrayals also appear in the maps of medieval monks and in Portolan charts and copies of lost Ptolemaeic and Roman maps. Thus, a method of representation, corresponding directly to the natural appearance of the terrain, showing the rise and fall of the land in profile, was maintained throughout the centuries. In the early days neither the requirement nor the technical capability for depicting mountains more precisely and in plan form existed (Imhof 1965).

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The production of the 1:32 000 Züricher Kantonskarte, or Map of the Canton of Zurich (1667) by Hans Conrad Gyser (1599-1674) was a highlight in the history of terrain representation. With improved surveying equipment using graphic triangulation over considerable distance, and by diligently surveying in detail over a period of 30 years, Gyger created some outstanding topographic base maps. For the first time in the evolution of maps the whole relief was deliberately depicted in the plan view (Imhof 1965) and can be considered as the origin of topographic cartography as it is known today.

The word topography is compiled from the Greek words "topo" meaning "place" and "graphos" meaning "drawn or written" and is so named because it supplies the distribution of physical features that it includes. The large-scale topographic map is secondary only to the ground itself (Monkhouse & Wilkinson 1963) and renders the relief (three-dimensional variations) of terrain on a two-dimensional surface.

The relief on topographic maps is shown by contours. Contours are the most important element in the cartographic representation of the terrain and the only one that depicts relief forms geometrically. Imhof (1965) defines contour lines as lines on the map depicting the metric location of points on the earth's surface at the same elevation above sea level. The contour interval refers to the vertical distance between two consecutive contours and is always constant.

Although contours do not present as clear a visual picture of the earth's surface as, for example, hill shading or other modern 3D terrain representation methods that incorporated visual cues to mimic those cues present in real terrain, the immense amount of information that may be obtained by careful experienced interpretation makes contouring the most successful way of portraying relief on topographic maps and is still extensively used today. Not all derived contours, however, are of equal accuracy. Excluding the aerial photograph as a device from which to derive contours, the lines are usually drawn from a scattering of elevations, which might not be precisely located. It is also apparent that much of the usefulness of contours depends on their vertical spacing, and the choice of a contour interval is not an easy task. To portray slopes (gradients) is one of the major objectives of contour maps; consequently, contour intervals are almost always equal-step progressions. When an uneven contour interval is employed, slopes are difficult to visualize and

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calculate, and misleading impressions are likely. As the contour interval is increased, the amount of surface detail lost between the contours become correspondingly greater. If, because of a lack of data or scale, the contour interval must be excessive, other methods of presentation, such as hill shading, are likely to be more successful in portraying relief (Robinson, Sale, Morrison & Muehrcke 1984). If, however, contours are presented correctly on a topographic map effortless and precise terrain visualization by experienced topographic map users is possible.

Visualization is first and foremost an act of cognition (Miller 1984). MacEachren & Garner (1990) supported this in stating that visualization is the human ability to develop mental images. This ability can be facilitated and augmented by the use of tools with which visual representations can be made. These representations allow the visual and cognitive processes of users to focus on the objects depicted, rather that on mentally generating those objects.

Cartographic Visualization (CV) is a logical precursor to of cartographic communication and, in its modern context, is an extension of methods for imaginative data presentation and analysis, which have been present in cartography since the 18th century. In its contemporary form it uses computer-based techniques and can therefore lay claim to the utilization of scientific methodologies, whist incorporating the use of imagination, intuition and artistry, especially in the creation of new multimedia products and in the exploratory use of virtual reality (Taylor 1994). In CV, however, the term visualization has been extended to include elements of computer vision and pattern recognition, and to the production of images designed to aid understanding and problem solving. These processes of image generation and presentation are referred to by MacEachren & Garner (1990) as visualization tools. The most important role of visualization tools is to prompt mental visualization of spatial patterns and relationships with schematic information. **This allows the users of these tools to visualize phenomena or processes, even if unaided mental visualization does not come naturally** (MacEachren & Garner 1990). MacEachren & Garner (1990) further stated that developments in GIS are providing testing grounds for a variety of graphic visualization tools when implementing scientific visualization principles. These tools have the potential to increase the perception, synthesis and analysis capabilities of multidimensional spatial data.

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With digital geographic information display becoming increasingly widespread in cartography, modern focus is shifting further and further away from conventional paper maps. In certain study fields, however, it is not possible to disregard topographic paper maps completely. These maps have been used for centuries and have three advantages when compared to digital alternatives. Firstly, paper maps are relatively inexpensive and so are easily available to most people and institutions. Secondly, they are light, compact and portable which means they can be carried around with ease. Thirdly, they are familiar to most people that have either used a bus route map, a road map while hiking or driving, or a map in an atlas.

These advantages ensure that academic institutions, professions that require spatial information and defence forces around the world, still extensively use topographic paper maps. Reading a topographic paper map, however, is not easy and needs considerable practise especially for visualizing the relief of terrain. Monkhouse & Wilkinson (1963) stated that the recognition and description of relief from contour patterns provide considerable problems in cartographic education. McLellen (1994) stated that when using a two-dimensional (2D) map it is difficult for users to firstly visualize the three-dimensional (3D) physical landscape, and secondly to grasp how the information on the map inter-relates, because spatial thinking ability is not a natural process.

According to Nicholson & Morton (1966) the best way to become familiar with the fundamentals of contour lines is to examine topographic maps in the field, because of the difficulty of explaining concepts in the classroom. This is a very time consuming exercise and does not always have the desired success rate. Monkhouse and Wilkinson (1963) confirm this and suggest that the problem could be overcome by conducting an exercise with a physical model that represents the relief depicted on the topographic map. To create such a model is not easy and extremely time consuming. Technology has not, as of yet, provided an alternative to the advantages of topographic paper maps, in particular their compactness and portability, but has contributed to the way in which interpreting such maps can be taught to users. Nowadays, a digital 3D model of a topographic map can be generated on a computer screen with minimal effort. Since computers are increasingly becoming part of the classroom environment, this could present an alternative to the expensive physical models and field trips.

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1.1 RESEARCH AIMS

The **main aim** of this study is to develop a computerized visualization tool that will enhance the ability of users to visualize relief when studying contours on a South African 1:50 000 topographic map. The specific **objectives** are:

i. To compile a set of design guidelines from previous studies and literature.
ii. To design and develop a visualization tool by implementing the design guidelines.
iii. To demonstrate and evaluate the tool according to its functionality, ease of use, and portability.

1.2 TEST AREA

Before the location and extent of the test area can be described, an introduction of the South African 1:50 000 topographic map series is necessary. In South Africa, 1:50 000 topographic maps are compiled by the Chief Directorate of Surveys and Mapping using stereo-photographs, after which they are printed by the Government Printer. The largest scale at which official topographic maps are drawn in South Africa is 1:50 000. This scale was chosen because it was the largest feasible scale for coverage of the entire country. The maps are in metric units with contours at 20-meter intervals. Each map sheet covers a 15 x 15 minute area, which is generally referred to as the 1:50 000 topographic area (Nicholson & Morton 1966).

A six-character name (e.g. 2830CB) defines a map sheet. The name refers to its position in a degree-square (see **Figure 1.1**). A four-digit number specifies the first characters of the map sheet name and is defined by the values of the Latitude and Longitude at the North West corner designating the degree-square. The degree square is divided up into quarters and are lettered A,B,C and D. These letters define the first of the last two characters of the map sheet name. Each of the initial quarters is further divided into quarters and again lettered A,B,C and D. This letter defines the last character of the map sheet name. As an example, the hatched area in **Figure 1.1** indicates the coverage of the 2830CB topographic area of the 1:50 000 South African map series.

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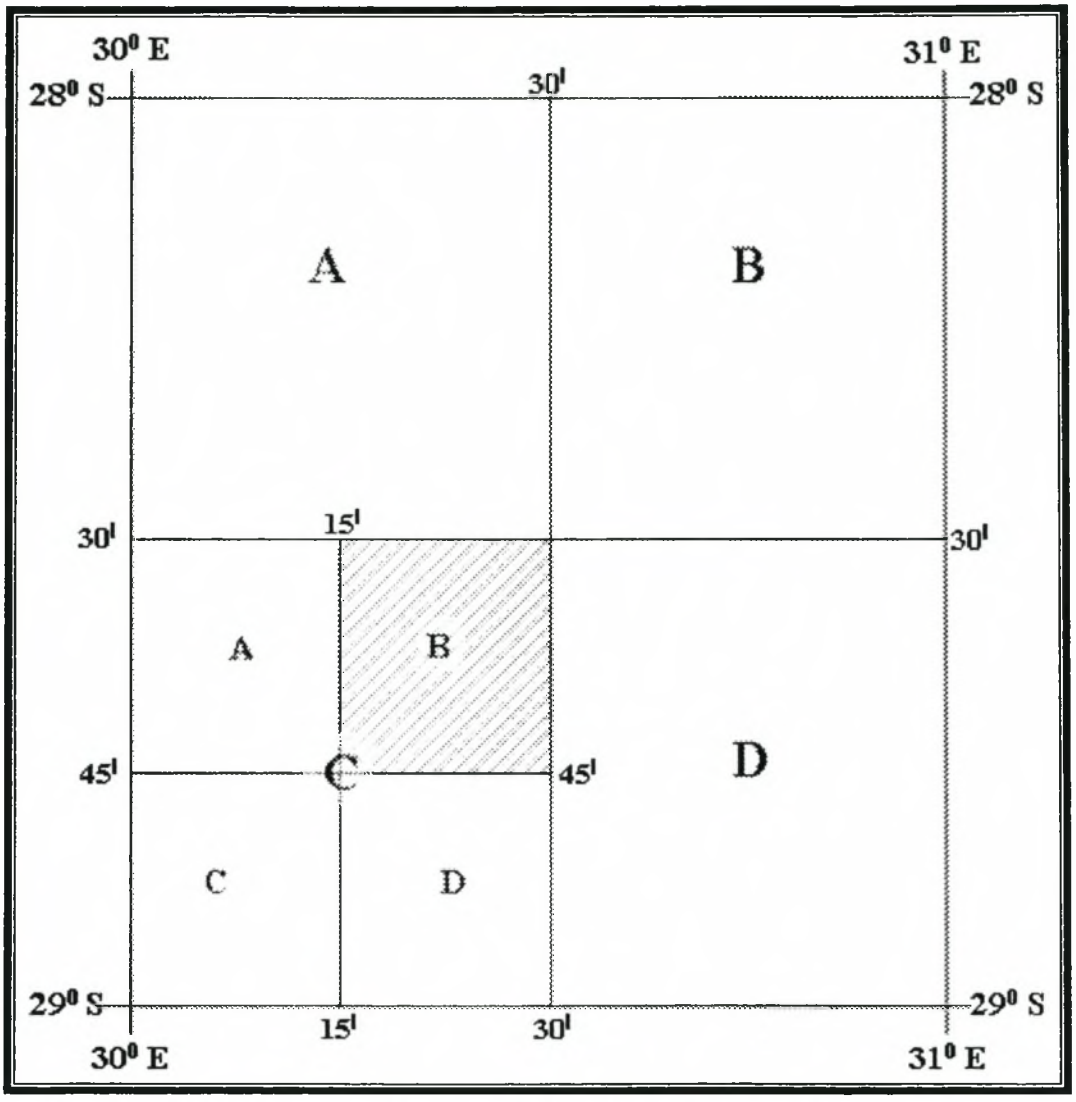

Figure 1.1: The 2830CB topographic area relative to a degree-square.

The 2527DD topographic area (see **Figure 1.2**) was chosen to test and demonstrate the visualization tool. The area is situated west of Pretoria in the Gauteng province of South Africa and includes the Hartebeespoort Dam in the north and the Lanseria airport in the south.

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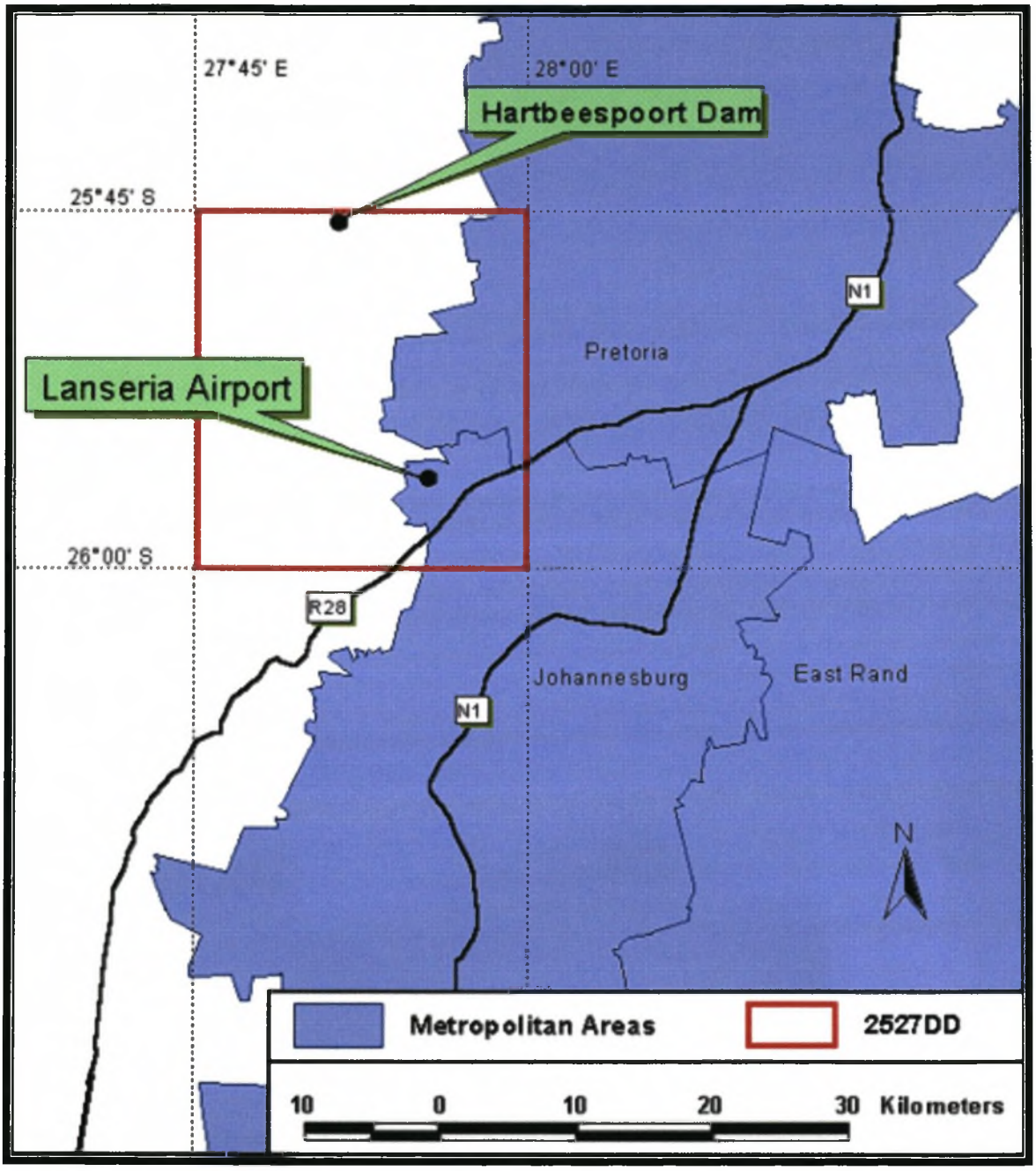

Figure 1.2: Position and coverage of the 2527DD topographic area.

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1.3 RESEARCH METHODOLOGY AND THESIS LAYOUT

The research was conducted in seven phases (see **Figure 1.3**).

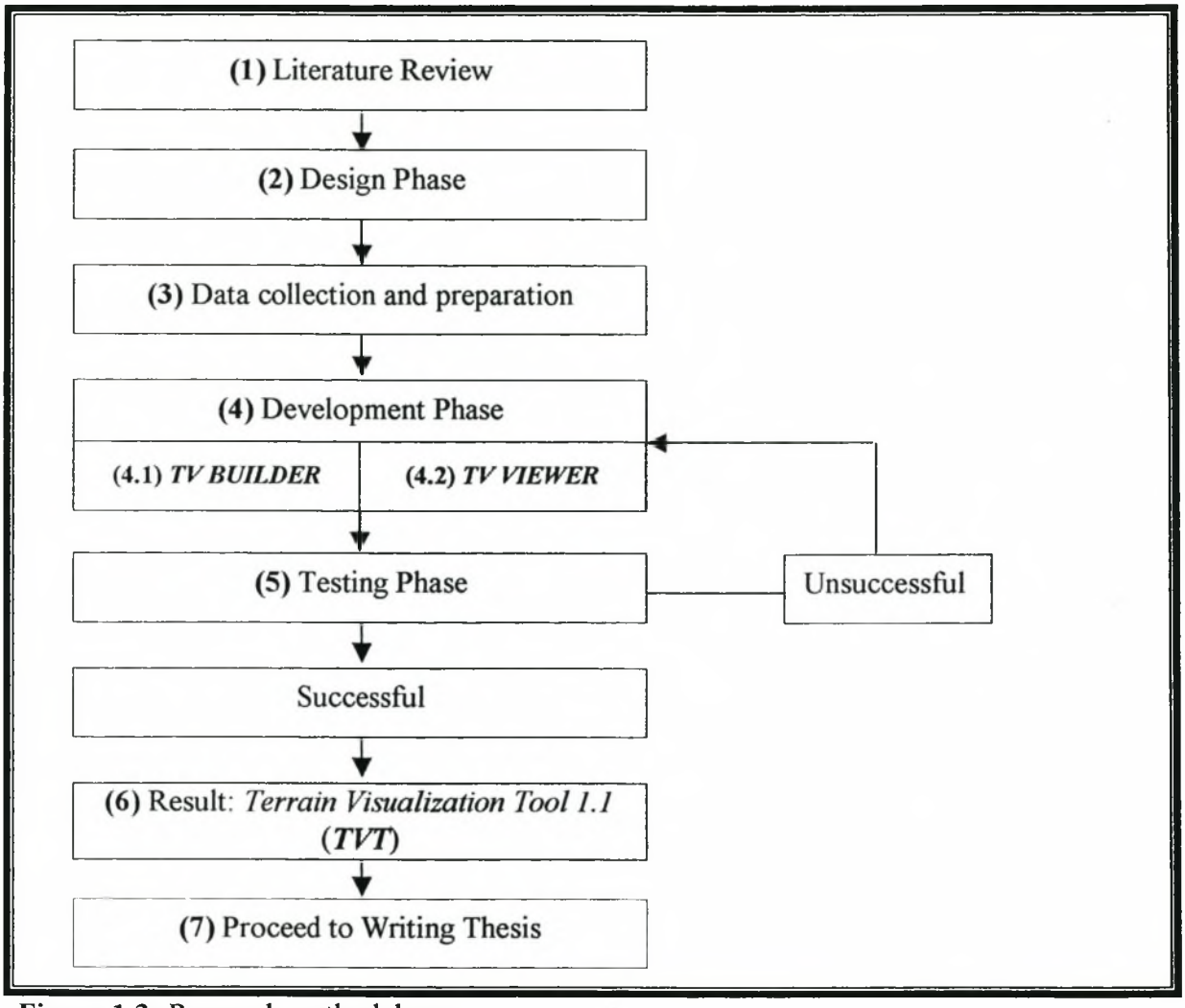

Figure 1.3: Research methodology.

NB – Certain terms used throughout the thesis are explained in Addendum A.

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The research project was initiated with a literature review (phase **1**) in which previous research was reviewed and guidelines for tool design (phase **2**) compiled. Chapter 2 provides an overview of these design guidelines. During phase **3** the contours and the digital topographic map image of the test area were collected and prepared.

Chapter 3 discusses the development phase (phase **4**) that involved the development of the Terrain Visualization Tool 1.1 (***TVT***). ***TVT*** consists of ***TV BUILDER*** (phase **4.1**) and ***TV VIEWER*** (phase **4.2**). Phase **5** involves the repeated testing of the development phase, using the data of the test area. Testing involved an assessment of the general functionality of the tool, how successfully the design guidelines were implemented, its ease of use, and its portability.

Whenever the testing was unsuccessful, the development phase was repeated, but when successful the final product (phase **6**) was derived. The conclusion of the development phase allowed the research to be documented in thesis format (phase 7). Chapter 4 demonstrates and discusses the final product before providing future research possibilities in the development of terrain visualization tools.

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CHAPTER 2: GUIDELINES FOR TERRAIN VISUALIZATION TOOL DESIGN

Despite the rather considerable attention given to developing visualization tools and models for representing terrain and other earth surfaces with dynamic 3D representations, fairly limited attention has been directed towards the perceptual and cognitive processes involved when developing and using these tools (Goldberg, MacEachren & Korval 1992). Slocum *et al.* (1994) supported this in stating that the developments in both hardware and software have led to (and will continue to stimulate) novel methods for visualizing geographical spatial data. It is their belief that those novel methods will be of little use if they are not developed within a theoretical cognitive framework. Attention should be directed at what people see when they look at 3D models (e.g. terrain) on a 2D surface (e.g. computer screen) to construct effective visualization tools. According to Goldberg, MacEachren and Korval (1992) visualization tools should also be constructed in such a way that models depicting terrain are presented in a logical manner to assist and not confuse the user. More resent literature (e.g. Cowen 1999; St. John, Oonk & Cowen 2000; St. John, Smallman, Bank & Cowen 2000) attend to this issue and will be reviewed in this chapter together with other studies in order to compile a set of terrain visualization tool design guidelines. These design guidelines where constructed in two phases. Firstly, terrain representations are assessed and secondly, a user-map interface is designed that will meaningfully present the terrain representations. To conclude this chapter, the design guidelines are summarized in a checklist in order to provide assistance during the development and evaluation stages of this research project.

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2.1 TERRAIN REPRESENTATION

Many military and civilian command and control tasks require quick comprehension of 3D objects and environments. Consoles that display data, such as terrain, in 3D seem to provide a natural solution to these needs. However, the empirical evidence supporting the use of 3D displays is decidedly mixed and Andre & Wickens (1995) caution that sometimes users want what's not best for them and prefer to use applications that hinder rather than enhance their performance. St. John & Cowen (1999) stated that across an array of tasks, many studies have found benefits for a 3D perspective of terrain over a 2D perspective (Bemis, Leeds & Winer 1988; Ellis, McGreevey & Hitchcock 1987; Van Breda & Veltman 1998). Other studies have found rough parity between them (Wickens, Liang, Prevett & Olmos 1996), while a third set of results have found 2D perspectives superior to 3D (O'Brien & Wickens 1997; Ware & Lowther 1997). These contradictory results highlight the importance of evaluating different terrain representations when attempting to design a terrain visualization tool.

This section firstly, discusses relevant concepts concerning terrain visualization and representation, secondly, it reviews the literature in order to assess advantages and limitations of different terrain representation methods and thirdly, investigates the use of artificial cues to assist users in visualizing depth even though terrain is represented on a 2D computer screen.

2.1.1 Terrain visualization and representation concepts

Nicholson and Morton (1966) stated that three central concepts are essential to visualizing the relief of terrain when studying topographic maps namely: terrain shape (visualizing the three-dimensional shape of terrain from a point of view); inter-visibility (visualizing whether two points are visible one from the other); and relative position (visualizing the position (height, longitude and latitude) of any point relative to another point). The significance of these concepts are apparent as they are repeatedly mentioned in the cartographic literature, and in particular in literature concerned with map reading. These concepts are also fundamental to three studies conducted by St. John, Oonk & Cowen (2000) discussed later in Section 2.1.2.

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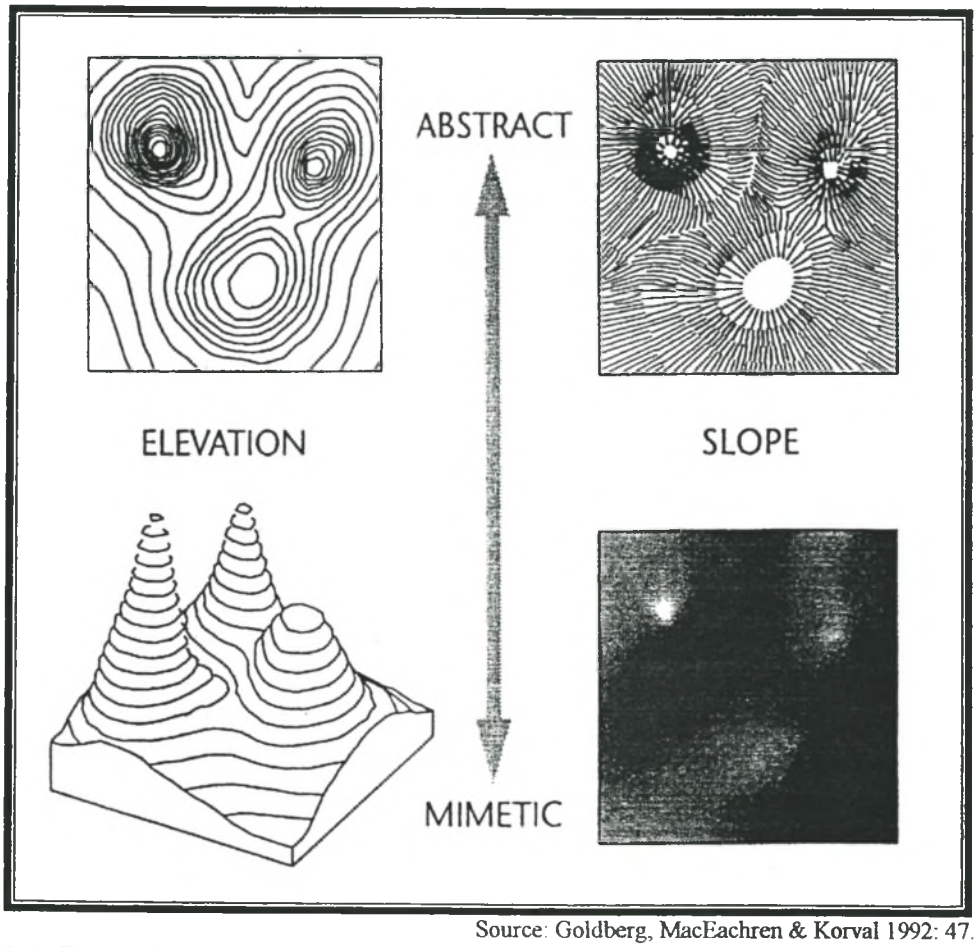
Apart from using contours, relief can be depicted on a 2D surface in numerous ways in order to enhance the ability of users to visualize these three central concepts. Goldberg, MacEachren & Korval (1992) classify these into abstract and mimetic methods (see **Figure 2.1**). Contours or hachures are widely used examples of abstract terrain representation methods. Mimetic representation methods like, for example, terrain shading or block diagrams utilize visual cues to mimic cues present in real terrain. Abstract representations are generally referred to as 2D views and mimetic representations as 3D views of terrain (St. John and Cowen 1999 – 2001).



Source: Goldberg, MacEachren & Korval 1992: 47.

Figure 2.1: Examples of representation methods.

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2.1.2 2D versus 3D views

Cowen (1999) recognized the basic geometric and functional differences between 2D and 3D views of terrain:

A 2D view, because it only represents two dimensions, is normally viewed at a 90-degree angle (directly from above), which allows the x and y dimensions to be represented faithfully, while the z dimension is lost entirely (see **Figure 2.2**). Represented faithfully means that the scaling is a linear transformation that preserves angles and relative distances in the x-y plane so that, for example, parallel lines remain parallel.

3D views are good for understanding the general shape of objects and the layout of a scene in that all three spatial dimensions of an object can be seen within a single, integrated view (Wickens & Carswell 1995). Natural cues to depth, such as shading, relative size and texture can be readily added to the view. Adding these cues can increase the perception of depth and thereby enhance the sense of three-dimensional shape.

Because all three spatial dimensions are represented in a 3D view, they can be viewed at different angles. In these views all three dimensions are foreshortened, an attribute that increases as the vertical viewing angle decreases. Change in the viewing angle provides uncertainties. **Figure 2.2** demonstrates ambiguity that occurs in the three dimensions when considering different viewing angles (Cowen 1999). As the vertical viewing angle of a 3D view of terrain decreases the area of terrain obscured to the viewer increases.

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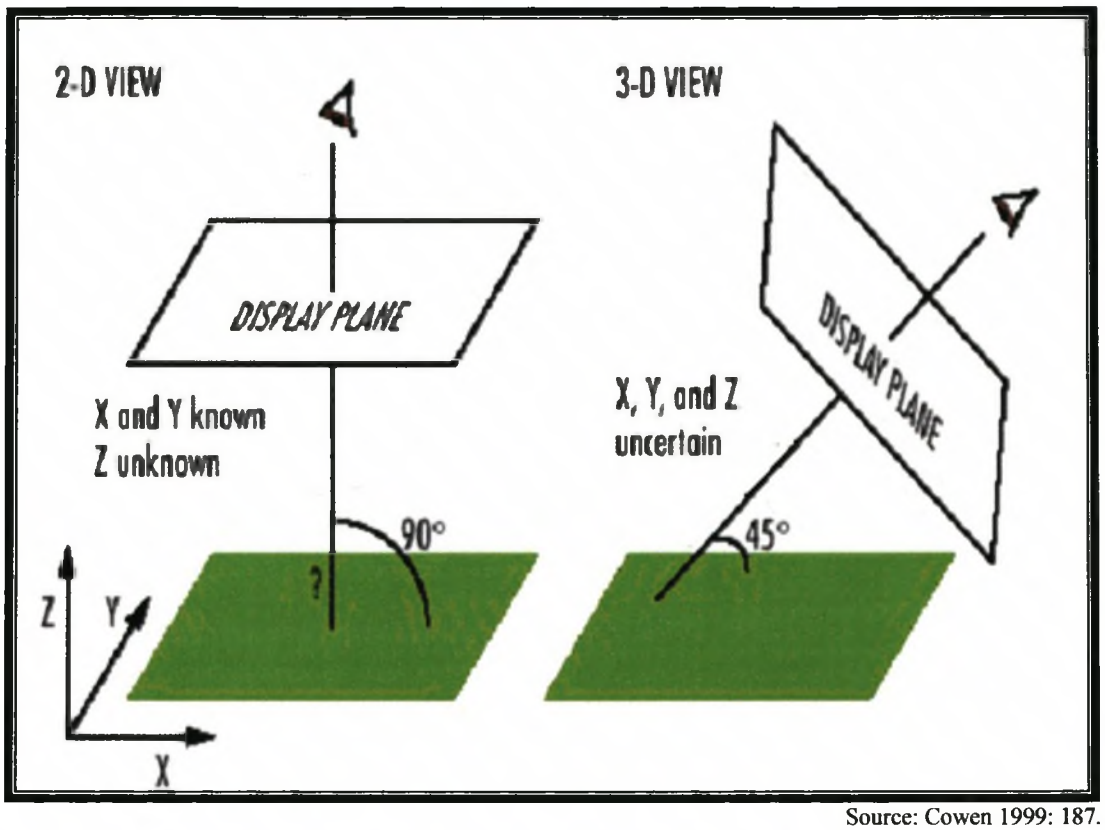

Source: Cowen 1999: 187.

Figure 2.2: Ambiguity demonstrated when considering different viewing angles.

St. John, Oonk & Cowen (2000) studied perceptual/cognitive aspects, of 2D and 3D, views considering the three central concepts (terrain shape, inter-visibility, relative position) essential to visualizing relief when studying terrain representations (See Section 2.1.1). In three studies considering these concepts, St. John, Oonk & Cowen (2000) requested participants to study the terrain of an 11 x 15km area viewed in:

- 3D from a 45-degree vertical angle (see **Figure 2.3c**);
- 3D from a 90-degree vertical angle (see **Figure 2.4a**); and
- 2D from a 90-degree vertical angle (see **Figure 2.4b**).

These views of terrain were chosen in accordance with earlier research by St. John & Cowen (1999) on visualization in object understanding and relative position. These experiments were unique in that the researchers displayed 2D and 3D block and ball shapes to test and formulate object visualization concepts. In further research, they applied these concepts to free-form objects, such as terrain.

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In the first study St. John, Oonk & Cowen (2000) tested the hypothesis that 3D views are superior to 2D views for terrain understanding. The task of the participants was to visualize the terrain standing in the centre of the surface facing a specified corner, and then to choose the correct ground-level view from four alternatives (the "Four-Corners" task displayed in **Figures 2.3**). The correct answer in **Figure 2.3** is **(b)**. This task resembles the mental rotation task used by St. John & Cowen (1999), who found a substantial 3D view advantage. In both studies, participants had to visualize an object viewed from different angles. Participants performed faster with the 3D views and their perceptions were more accurate with the 45-degree vertical 3D view than with the 2D topographic view. These results were statistically significant and support the hypothesis of St. John, Oonk & Cowen (2000) that 3D views are better for understanding the shape and layout of terrain.

In the second study the hypothesis that 3D views are better than 2D views for understanding inter-visibility was tested. The researchers identified two random points on a piece of terrain (similar to the terrain in **Figure 2.3**), and asked participants if they would be able to see point B if they were standing at point A (the "A-See-B" task). The three viewing conditions produced significantly different response times. Correct answers in the 3D 45-degree view was reliably faster than the 2D topographic view, while the 3D 90-degree view was consistently the fastest. St. John, Oonk & Cowen (2000) considered 3D terrain views more successful than 2D views when visualizing inter-visibility.

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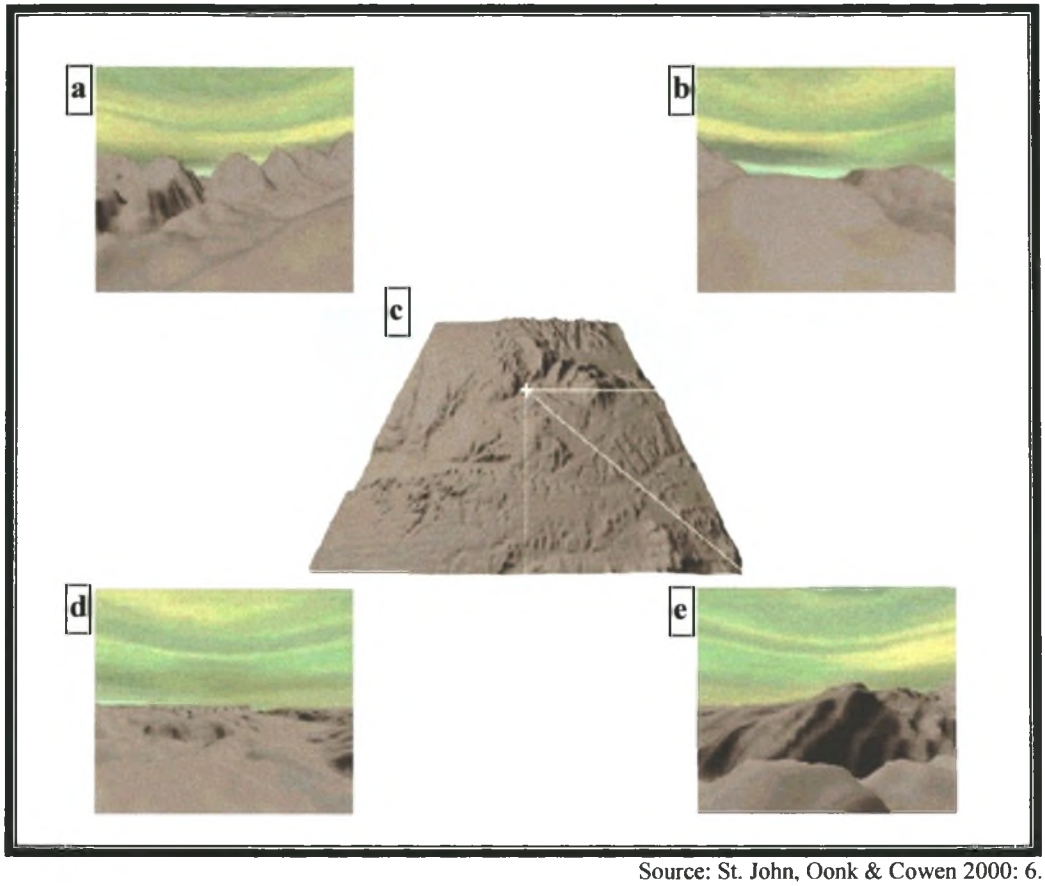
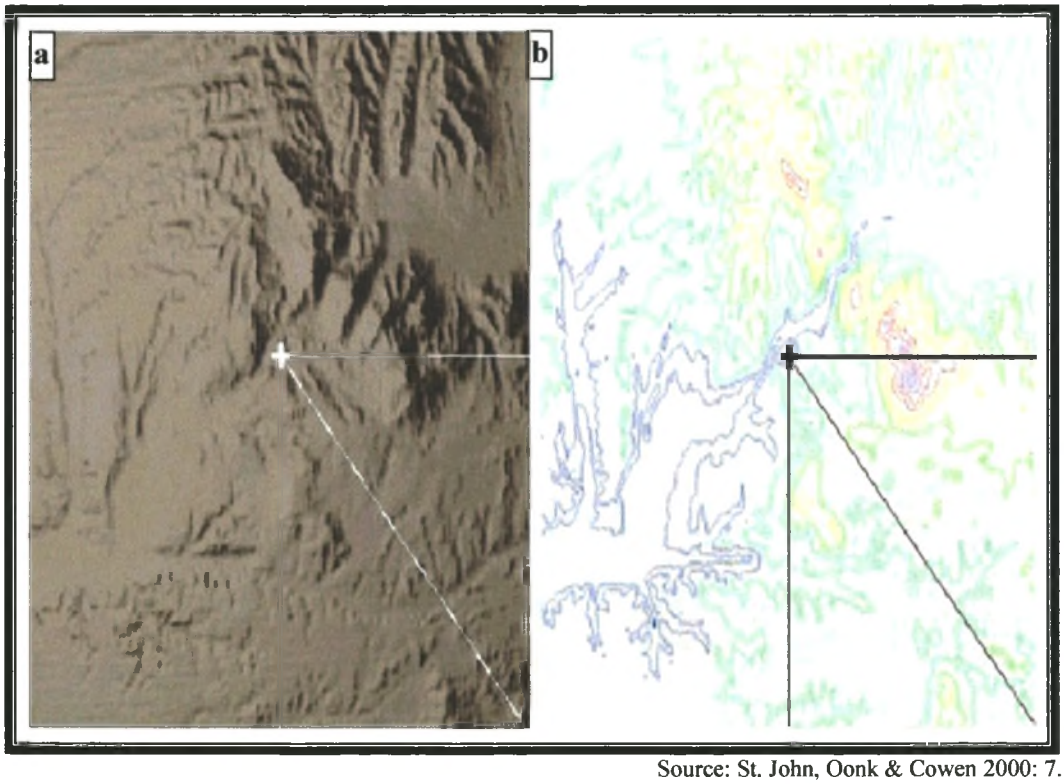


Source: St. John, Oonk & Cowen 2000: 6.

Figure 2.3: The "Four-Corners" task.



Source: St. John, Oonk & Cowen 2000: 7.

Figure 2.4: (**a**) 3D 90-degree and (**b**) 2D topographic views.

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In the third study the hypothesis that 2D views are better for judging the relative position of two terrain locations was tested. Participants judged the relative position of two points by looking at each of the views containing two identified points. They then had to judge which of the two points was higher. No statistical difference was found in response times. The greater accuracy of the topographic view supports the hypothesis by St. John, Oonk & Cowen (2000) that relative position judgments are easier to perform with 2D views than with 3D perspective views.

The case studies show that all three views produce positive results in different tasks. This indicates that a successful terrain visualization tool will have to incorporate all three these views.

2.1.3 Artificial cues

In some cases adding artificial cues – signs or symbols depicting depth (Bruno & Cutting 1988) – to 2D and 3D views may dramatically improve the user's ability to visualize relief. There are various artificial cues of which many are ineffective and it is therefore important to evaluate their perceptual/cognitive impact on the user (Gaggioli & Breining 2001). The following discussion of artificial cues was compiled from literature that focuses on these aspects.

A widely used artificial cue to depth in 3D terrain modeling is vertical exaggeration. This involves a 3D view in its conventional form, as something that can provide a three-dimensional reproduction of the landscape, with length (x dimension) and breadth (y dimension) to scale, though altitude (z dimension) is usually exaggerated to ensure a more dramatic depiction of relief. Although vertical exaggeration creates an inaccurate view of terrain, it definitely allows users to visualize the terrain better (Goldberg, MacEachren & Korval 1992).

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In the three studies by St. John, Oonk & Cowen (2000) (see Section 2.1.2) relative height was determined more easily in the topographic view, because height was rendered by the colour of contour lines (see **Figure 2.4b**). The colour-coded contours were grouped to depict areas of homogenous height. This explicit depiction of height helped the participants to mentally construct 3D shapes and enhanced the success of the 2D topographic view dramatically. Conversely, in the 3D views, the researchers enhanced relief by using artificial shadows, which were also considered to be an effective cue.

St. John, Smallman, Bank & Cowen (2000) refined this technique by augmenting the base conditions of the 3D views with colours that depict areas of homogenous height. They achieved this by dividing the Digital Elevation Model (DEM) into height classes and then assigned a different colour to each class. The same technique was used in the 2D topographic view, which ensures continuity and enables the user to relate the different terrain depictions in the different views to one another. A further addition was 3D grid lines on the 45-degree and 90-degree 3D views. Their research found that the combination of 3D grid lines and colours representing homogenous elevation areas substantially enhanced overall accuracy regarding relative position. In fact, adding these parameters to 3D views nearly doubled the respondents' performance.

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The colours used by St. John, Smallman, Bank & Cowen (2000) and St. John, Smallman, Bank & Cowen (2000) to show elevation were assigned randomly. A possible enhancement to this technique could be to correlate the colours used in the different views with colours used to depict elevation in atlases. This might be beneficial to users for two reasons. Firstly, the colours, colour combinations and colour classes used in atlases are carefully designed and tested by cartographers to optimize relief visualization and secondly, users of the visualization tool might have used atlases in schools and/or other institutions, and by drawing from their previous experience, would assist them to relate the colours to real terrain. This would make terrain visualization a more natural process. The *Times Atlas of the World* series (ten editions) is a widely used and highly acclaimed atlas series and would thus provide appropriate guidelines in this context. Times' atlases use hypsometric tints to depict areas of homogenous elevations. Green is used for lowlands, shifting to beige, brown, grey and white as elevation increases (Black 2000). Cartographers generally use these or closely related tints in atlases. Hamlyn (1966), for example, created a **relief atlas** in which green is used for lowlands, shifting to yellow, brown and grey as elevation increases. Robinson, Morrison, Muehrcke, Kimerling & Guptill (1995) stated that, although cartographers disagree on the maximum number of colour classes that can be used on a map before legibility is diminished, the limit is reached somewhere between eight and fifteen, depending on the size of coloured areas and map complexity.

To merely display the colours on the terrain depictions is not enough and St. John, Smallman, Bank & Cowen (2000) found it to be critical to display a legend explaining the colours used and that the legend should not be complicated. They found that legend information should be simply presented to inform, but not confuse, inexperienced users. The researchers accomplished this by expressing the heights of the colours in relative terms to one another, rather than stating their explicit absolute height values that tend to confuse inexperienced users.

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2.2 USER-MAP INTERFACE

"The rapid propagation of information graphics has clearly multiplied the demand for effective computer-assisted methods of graphic data presentation and analysis collectively known as visualization." (Asche & Herrmann 1994: 215)

The abilities of the users to work with spatial data will play a decisive role in the route that will be taken in designing the user-map interface for the Terrain Visualization Tool. McGuinnes (1994) emphasized that users were often rather "*shadowy figures*" (p. 185), not fully characterized and rarely allowed to differ from one another in attempts to design computer applications for visualization purposes. As in cartography, it is important to consider the map user's map reading skills during the map design phase (Robinson, Sale, Morrison & Muehrcke 1984). Similarly, the potential terrain visualization tool user's map reading skills should also be considered. Various researchers stated that in order to implement an effective visualization tool that will enhance topographic perception, it is essential for students to be familiar with maps in general and topographic maps in particular (Goldberg, MacEachren & Korval 1992; Nicholson & Morton 1966; Cowen 1999; St. John, Oonk & Cowen 2000). This would ensure that they are familiar with concepts like scale, direction and contours. The design of the visualization tool was undertaken, assuming that users are familiar with these concepts.

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2.2.1 User differences in interface design

The visualization tool is designed to accommodate users with low spatial ability which, according to Vicente & Williges (1988), require a limited amount of detail in the interface design. Research by McGuinness (1994), Asche & Herrmann (1994) and Kraak (1994) supported this and suggested that a Graphical User Interface (GUI) is preferable for such users to avoid unnecessary user input. Ambler (2000) recommends general and screen design guidelines for an effective GUI design.

Since the visualization stage is undertaken through a website, the GUI design guidelines should be complemented with web browser design guidelines. As with the design of any GUI, the web designer must first determine who will use the site and then design it accordingly (Millhollon & Castrina 2001). The website should, however, attempt to accommodate both computer novices and experts and must have consistency in its user interface. Interface standards including title bars, navigation bars, universal colour schemes and logos should be set and adhered to. In a website this means that when users move from one page to another, they must intuitively grasp that they are moving in the same website. Industry standards should be used so as to increase the chance that the applications will look and feel like other applications developed externally.

There must also be simple help facilities that provide relevant information for a specific operation. The rules of how the application works should be explained to the user. The explanations of rules should be consistent, simple and limited. Text must be worded consistently, positively and in full English.

Navigation both between screens and on a single screen is important. Colours and text fonts must be used sparingly and consistently. When developing an interface the contrast rule should be followed. Thus dark text should be put on light backgrounds and light text onto dark backgrounds. When options are unavailable to the user, they must be grayed out to allow the user to form accurate mental models. Integers must be right justified and strings left. Busy or crowded screens must be avoided in the interface and logically related items on the screen should be grouped together (Ambler 2000; Millhollon & Castrina 2001; Kraak 1994 and Carey P 2001).

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2.2.2 Effective presentation of different images

Kraak (1994) emphasised the importance of user orientation in 3D visualizations of terrain. This is supported by Asche & Herrmann (1994) who reiterate that users must be oriented at all times. This can be achieved by using an extra window displaying a more familiar view of the same area simultaneously and by synchronising their movements. St. John & Cowen (1999), St. John, Smallman, Bank & Cowen (2000) and St. John, Smallman, Bank & Cowen (2001) showed that 2D and 3D views of the same area displayed simultaneously on the computer screen enhanced the spatial ability of users in general. In the context of the present research project, the 2D view would refer to an image of the digital 1:50 000 topographical area. This would allow the user to relate the terrain visualization data with the 1:50 000 topographic paper map.

As explained in Section 2.1.2, the 3D 45-degree vertical view will obscure some features to the user. Planar rotation would thus be necessary to provide a more complete view of all features. Kraak (1994) showed that allowing users to change their horizontal viewpoint in 3D displays enhanced their visualization ability, but cautioned that allowing a user unlimited positioning of terrain in a three-dimensional environment is likely to result in him/her becoming disorientated due to a "strange" position of the display that might invoke visual illusions. To avoid this, Spoehr & Lehmkulhe (1982) implied that the rotation of displays should be confined to angles familiar to inexperienced users, such as the four compass directions (North, South, East and West). Especially for users with low spatial ability.

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2.3 DESIGN GUIDELINES CHECKLIST

To conclude this chapter, the design guidelines that were identified in the previous sections are summarized in **Tables 2.1** and **2.2**. These guidelines were used as requirements during the design and development phases and acted as a checklist for evaluation.

Table 2.1: Terrain representation design guidelines.

Number	Guideline
1	Use both abstract and mimetic terrain representation methods.
2	Use both 2D and 3D views displayed at a 45-degree and 90-degree angle.
3	Use vertical exaggeration to enhance the drama of the 3D views.
4	Group and colour-code contours in the 2D topographic view to depict areas of homogenous height.
5	Augment the base conditions of the 3D views with colours.
6	Apply the same colours and colour classes to the 2D and 3D views respectively.
7	Add shadows to convey relief of the 3D views.
8	Augment the 3D views with 3D grid lines.
9	Correlate the colours used in the views to colours used to depict relief in atlases as explained by Black (2000).
10	Restrict colour classes to eight.
11	Display a simple legend explaining the colours used in the terrain representations.

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Table 2.2: User-map interface design guidelines.

Number	Guideline
1	Use a GUI.
2	Design the GUI to accommodate both computer novices and experts.
3	Apply consistency to the user interface.
4	Use industry standards.
5	Provide simple help facilities.
6	Word text consistently and in full English.
7	Provide effortless navigation between and on screens.
8	Use colours and text fonts sparingly and consistently.
9	Put dark text on light backgrounds and light text onto dark backgrounds.
10	Gray unavailable options on the interface out.
11	Right justify integers and left justify strings.
12	Avoid busy or crowded screens on the interface.
13	Group logically related items on the interface screen together.
14	Display an extra window containing the digital 1:50 000 topographic map image simultaneously with the terrain representation image to orientate the user.
15	Planar rotate the 3D 45-degree view to provide a holistic view of terrain to the user.
16	Confine the rotation of displays to the four compass directions (North, South, East and West).

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CHAPTER 3: TERRAIN VISUALIZATION TOOL DEVELOPMENT

"*The computer facilitates direct depiction of movement and change, multiple views of the same data, user interaction with maps, realism (through three-dimensional stereo views and other techniques), false realism (through fractal generation of landscapes), and the mixing of maps with other graphics, text, and sound. Geographic visualization using our growing array of computer technology allows visual thinking/map interaction to proceed in real time with displays presented as quickly as an analyst can think of the need for them*" (MacEachren & Monmonier 1992: 198).

The design guidelines introduced in Chapter 2 provides a framework for the development of the Terrain Visualization Tool 1.1 (***TVT***). The development was done by customizing an ArcView project (***TV BUILDER***) to create the terrain representations and a website that presented them (***TV VIEWER***). These two components interact with one another and together make up the ***TVT***. In this chapter an overview of Geographical Information Systems (GIS) and the implementations used to develop the ***TVT***, is provided after which the development process is described.

3.1 GIS AND IMPLEMENTATIONS USED IN THE DEVELOPMENT STAGE

Computers have made methods and techniques accessible to more general-purpose users of geographic information. Nowhere has this been more evident than in the field of GIS (Clarke 1990). GIS is a relatively new discipline that was initiated through computer mapping programs in the early 1960's. The development of SYMAP, a mapping package and the famous ancestor of GIS software, was strongly influenced and guided by geographical applications, especially by research in spatial analyses (Steinitz 1993).

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Although there are many different definitions of GIS, the definition by Prescott (1994) is most applicable to this research:

> "A GIS is a computer software system (often including hardware) with which spatial information can be captured, stored, analysed, displayed and retrieved, and that links non-graphic attributes or geographically referenced data with graphic map features to allow a wide and fuller range of information processing and display operations, as well as map production, analysis, and processing" (Prescott 1994: 166).

This definition was chosen because of Prescott (1994) particularly mentions the ability of GIS to link non-graphic attributes with graphic map features for display operations. This ability of GIS provides an effective way of creating 3D terrain visualization data and sets it apart from other graphical software packages.

3.1.1 ArcView GIS

ArcView GIS is a sophisticated desktop mapping and GIS application that brings the power of geographic analysis to the average personal computer (PC) user. The application is a complete system for accessing, displaying, querying, analysing and publishing spatial data. It links traditional data analysis tools such as spreadsheets and business graphics, with maps for a completely integrated analysis system and is developed by the Environmental Systems Research Institute (ESRI). According to Hatton (2001), the main advantages of ArcView GIS are that the application:

- has an easy and intuitive user interface;
- can integrate multiple data types;
- can access data across networks;
- have tools for high-quality mapping;
- can edit geographic and tabular data;
- can be integrated with tabular databases;
- possesses Database Management Systems (DBMS) analysis tools;
- can integrate raster images;

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- is a spatial data analysis tools; and
- can by customised effortlessly.

3.1.2 3D Analyst

3D Analyst is an extension to ArcView GIS that adds support for 3D shapes, surface modelling, and real-time perspective viewing. It can create and visualize spatial data using a third dimension to provide insight, reveal trends, and solve problems. ArcView 3D Analyst features relevant to this research project include its capability to (ESRI 1998):

- create realistic 3D surface models such as Triangulated Irregular Networks (TIN) from point, line and polygon feature types;
- drape two-dimensional features or image data on three-dimensional surfaces;
- take a snapshot of the display in a 3D Scene Viewer that can be exported in several image formats, including JPEG, Windows BITMAP, and GIF formats; and
- provide options in a 3D Scene Viewer such as pan, zoom, interactive tilt and rotate, which can create the desired view.

In the 3D Scene Viewer the interactive tilt creates a problem in viewing the displays at set angles. This can be overcome by using the Avenue Camera (see **Figure 3.1**). The application encapsulates the parameters for the 3D projection in a Viewer. Avenue Camera can be manipulated by setting its attributes in Avenue scripts to produce displays at set angles. These attributes include (Neudecker 1999):

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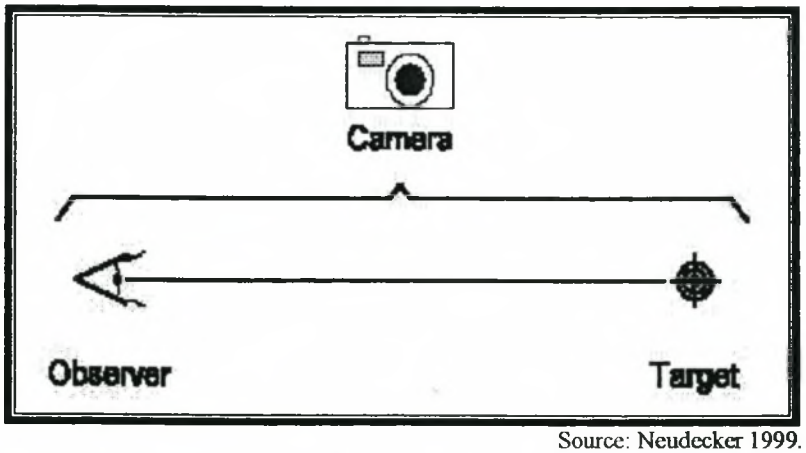
- Target – the location at which the Camera is positioned (see **Figure 3.1**) is defined by Cartesian X, Y and Z coordinates (see **Figure 3.2**). The real world coordinates of the displayed theme define these coordinates.
- Observer – the location of the Camera (see **Figure 3.1**) can be defined as absolute with Cartesian coordinates or relative with Polar coordinates (see **Figure 3.3**) from the target. When Polar coordinates are used, the Altitude, Azimuth and the Distance from the Target are used to define the position of the Observer (see **Figure 3.3**).
- ViewFieldAngle – the angle of the field of view of a Camera. It is the angle at the Observers position from which the current 3D projection in the Viewer window is seen.
- RollAngle – turns the Observer around the axis defined by the line between the Target and the Observer.



Source: Neudecker 1999.

Figure 3.1: Avenue camera *observer* and *target*.

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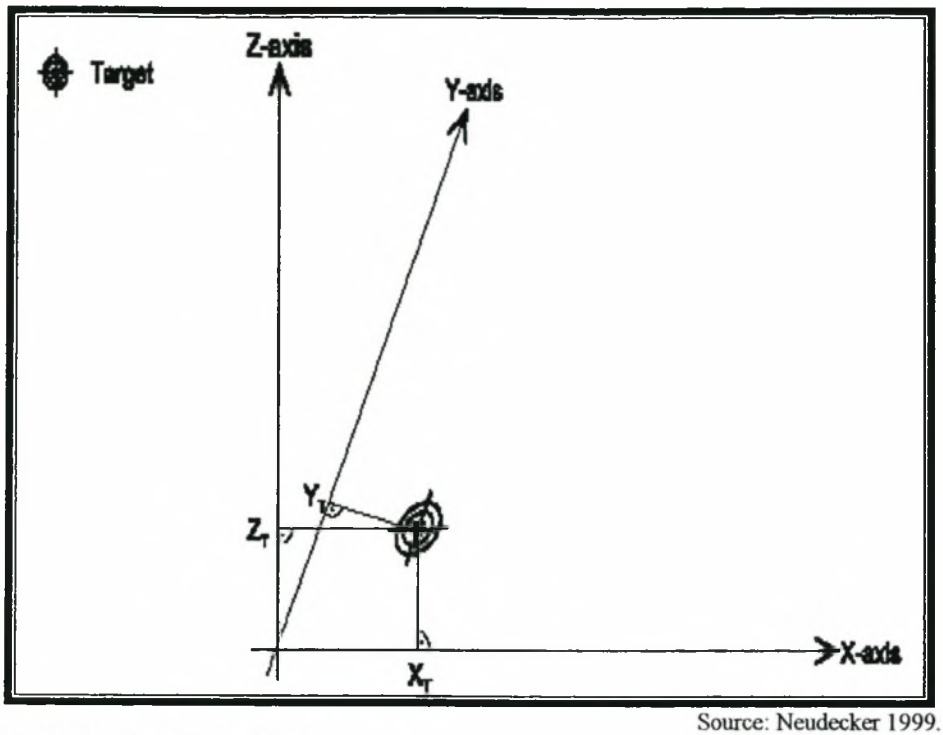
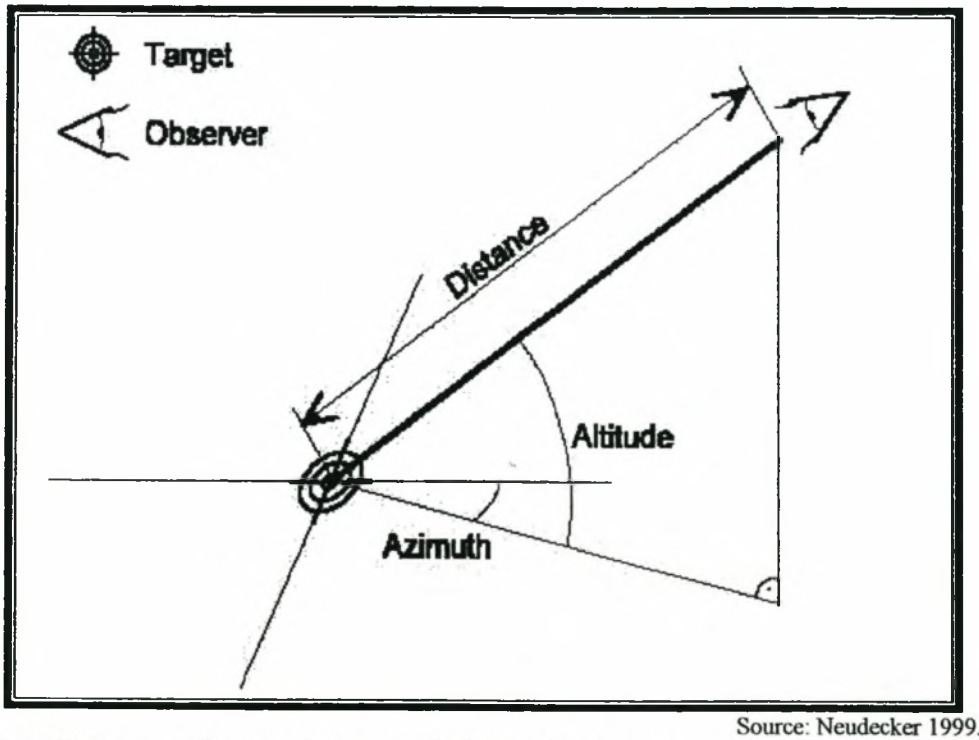


Source: Neudecker 1999.

Figure 3.2: Cartesian plane *target*.



Source: Neudecker 1999.

Figure 3.3: Polar coordinates *observer* relative to the *target*.

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3.1.3 Choice of programming

Two different programming languages were used in this study. The ArcView project was customized with Avenue – ArcView's internal programming language – and the website was created with Hypertext Markup Language (HTML).

3.1.3.1 Avenue

In procedural programming languages, writing code consists of establishing routines that call other routines. It maintains the state of the program in variables and these routines operate on the state of the variables. Avenue language on the other hand maintains and controls the state of the system in the objects that have been instantiated. It is thus referred to as an object orientated scripting language, and has three basic components (Razavi 1995):

- Classes – define a common set of attributes and operations that create objects. Objects in ArcView are thus members of a class hierarchy that are organized into functional categories related to all aspects of the application.
- Objects – entities that represent elements ArcView works with. They can be controls, document windows etc. Avenue identifies objects and sends them requests. An object resembles a package that is comprised of tightly coupled data and functionality and, instead of calling functions explicitly with arguments, the language sends a request to them. When an object receives this request, it performs actions.
- Requests – create, control, or get information about objects. Each Avenue class provides requests that operate on the class or instances of that class. The requests trigger methods that are class-specific. Avenue statements are used to organize and structure when and how requests are made.

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Scripts are used to implement Avenue. An Avenue script control how and when requests get sent to ArcView objects and are used to customize the look and functionality of ArcView. Just like macros, procedures, or scripts in other programming or scripting languages, ArcView scripts group together the means to accomplish three general objectives: automate tasks, add new capabilities to ArcView, and build complete applications.

3.1.3.2 HTML

HTML is the most widely used web page creation language on the World Wide Web (WWW). When the browser locates a Web document on a server, it needs to interpret what it finds. HTML was designed to describe the contents of the Web page in a general way in that it does not describe what an object on a web page looks like, but uses code that describe the function it has in a document. The advantages of HTML are that it is fast and works with a wide range of devices.

HTML files are simple text files and the only software package needed to create them is a basic text editor such as Windows Notepad. An HTML document has two elements: document contents and tags. Document contents is the part that the user of the web page will by able to see, such as text and graphics. Tags are the HTML codes that control the appearance of the document content (Carey 2001).

HTML can also be created with editors. These editors supply visual ways of creating web pages. An HTML editor saves time and effort, because it takes objects in a graphical format and converts them to HTML code (Millhollon & Castrina 2001). The HTML editor used in this research project was Microsoft FrontPage 2000.

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3.2 CONSTRUCTION

The Terrain Visualization Tool 1.1 (***TVT***) is the integration of two components. The first component is a customized ArcView project named ***TV BUILDER*** that creates the terrain representations and incorporates them into, the second component, a web site specially constructed to view them (***TV VIEWER***). This section discusses the construction of these two components and the interaction between them illustrated in **Figure 3.4**. The GUI design guidelines (see Section 2.2.1) were adhered to in both components.

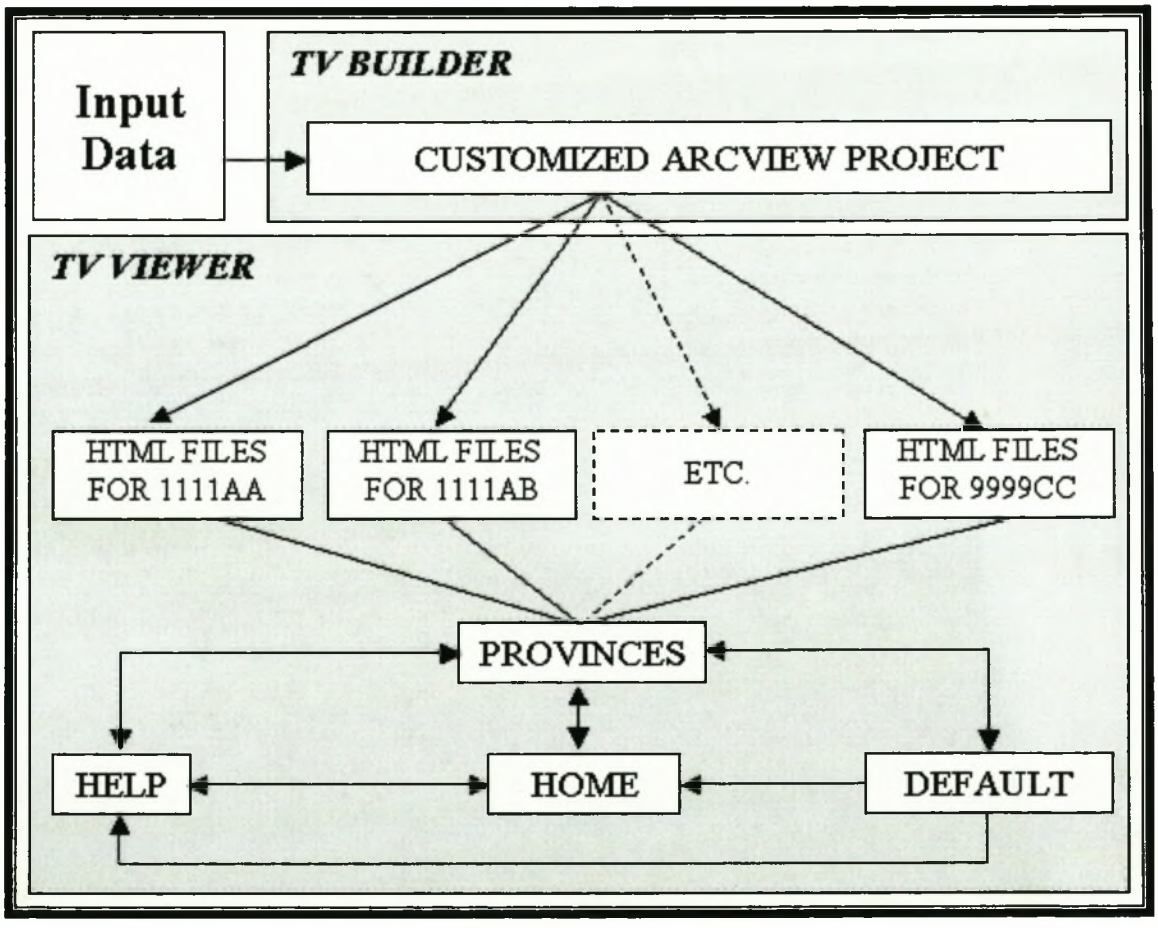

Figure 3.4: Components of the Terrain Visualization Tool 1.1.

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3.2.1 *TV BUILDER*

The main objective of ***TV BUILDER*** is to create 20 HTML files that were developed in accordance with the user-map interface design guidelines (See Section 2.2). In order for the ***TV VIEWER*** to create the web pages, it first has to create digital images of terrain representations that can be linked to them. These images are created from the contours and a digital topographic map image of a 1:50 000 topographic area (e.g. 2527DD) and exported in JPEG format to a user specified directory created by the application. The contours and a digital topographic map image are collectively referred to as **input data** in **Figure 3.4**.

TV BUILDER was constructed by customizing an ArcView GIS project. This means that customized settings were created with Avenue. ArcView reads the customized settings every time the project is started. These settings then override the system default settings. This allows the applications to be used on any computer with ArcView 3.2 installed. ***TV BUILDER*** is an integration of a number of scripts, each performing a different function. These scripts form part of the customized setting. Avenue can call scripts from other scripts. This allow tasks to be atomized by performing a succession of functions.

TV BUILDER is an atomized application that needs limited input from the user before a sequence of events is triggered. This process is initiated by allowing the user three options automatically presented to the user when the project is opened **Figure 3.5**. Unfortunately it was not possible to make the interface more attractive by means of font or color in ArcView 3.2. It is expected that future versions will have this capability.

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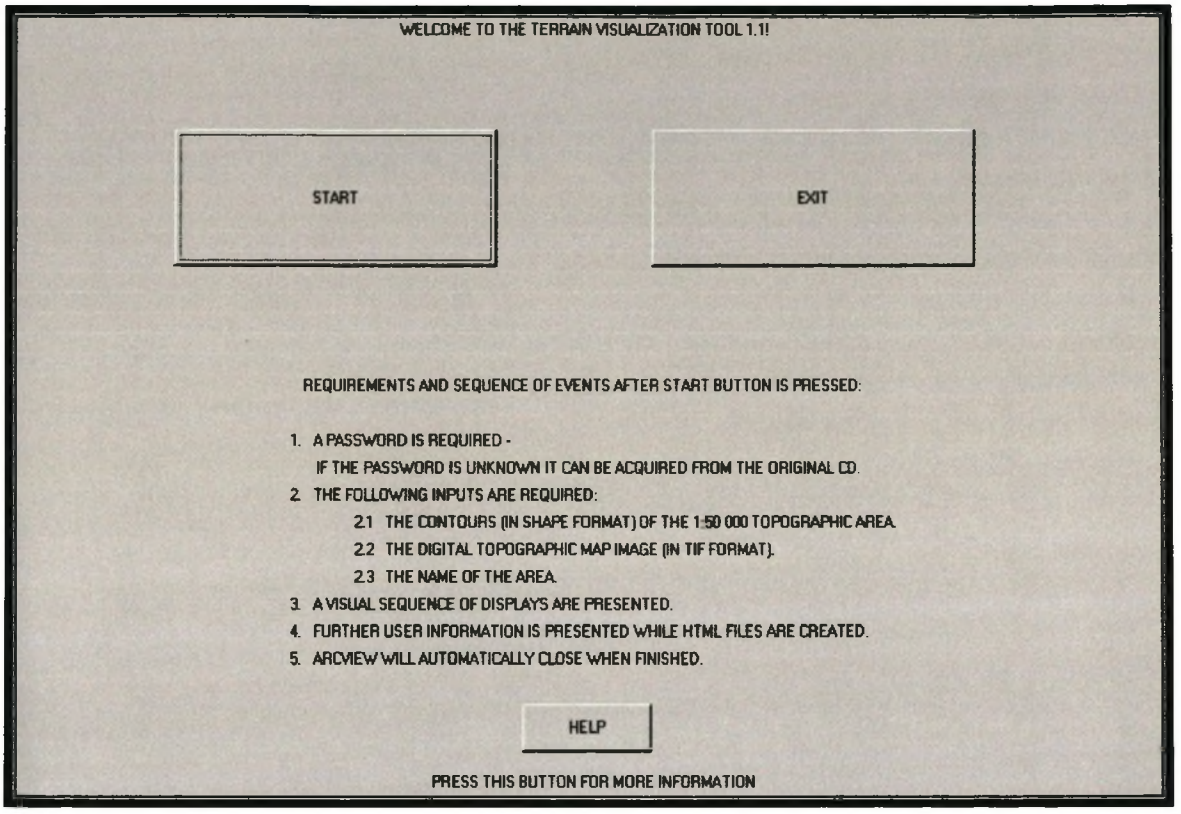

Figure 3.5: User interface presented by ***TV BUILDER.***

TV BUILDER was constructed using 82 scripts. **Figure 3.6** illustrates the different scripts used and the interaction between them. The START, EXIT and HELP boxes symbolize the options presented on the user interface in **Figure 3.5**. The white blocks represent the scripts used and the arrows the movement between them. **Figure 3.6** illustrate that the TVT.DIALOG6 script is automatically initiated when ***TV BUILDER*** is started and creates the interface presented in **Figure 3.5**. The scripts illustrated in **Figure 3.6** are described in **Table 3.1**. Scripts performing similar functions have been grouped and described together. The complete code of each script is available in Addendum C.

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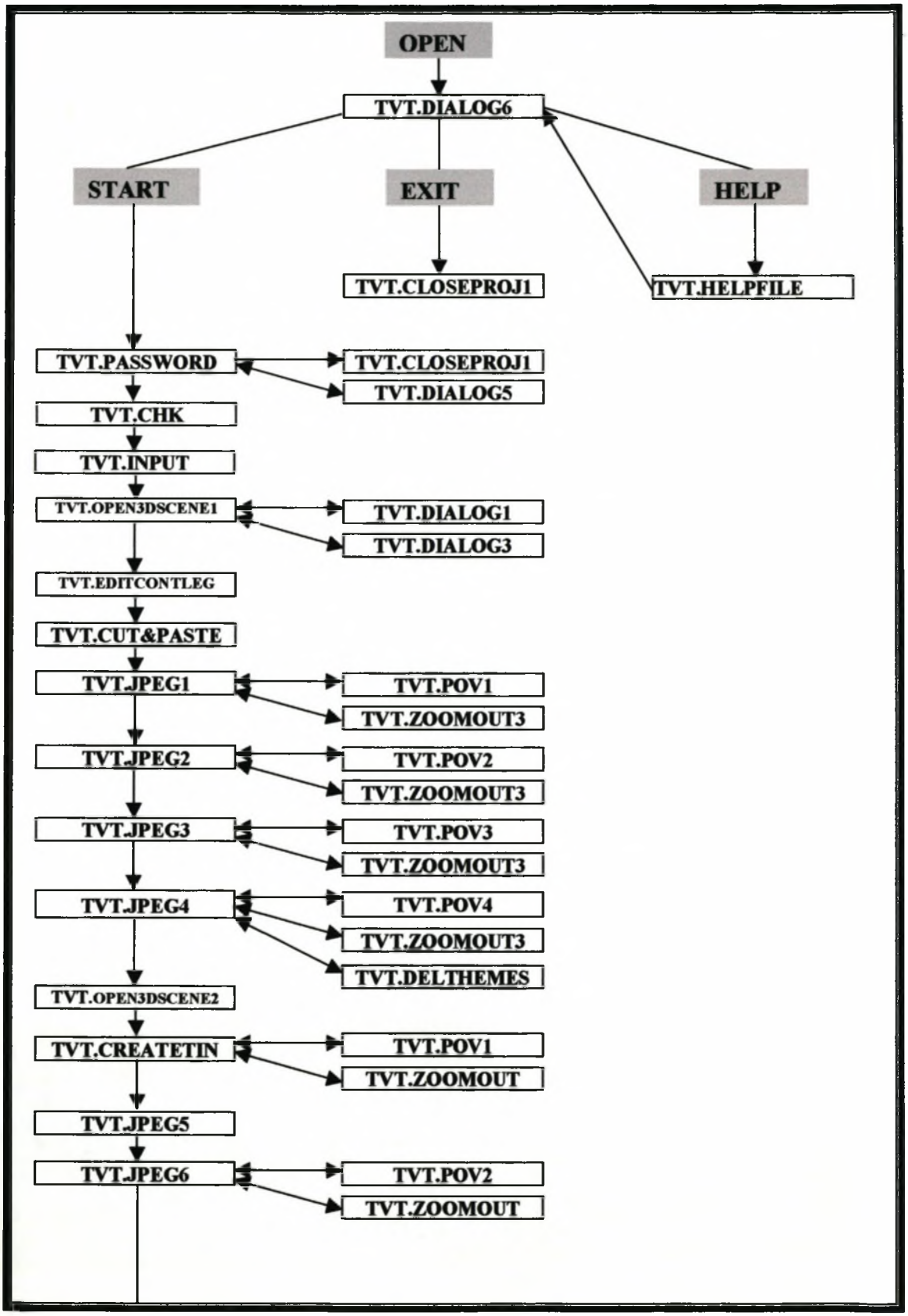

Figure 3.6: ***TV BUILDER*** structure.

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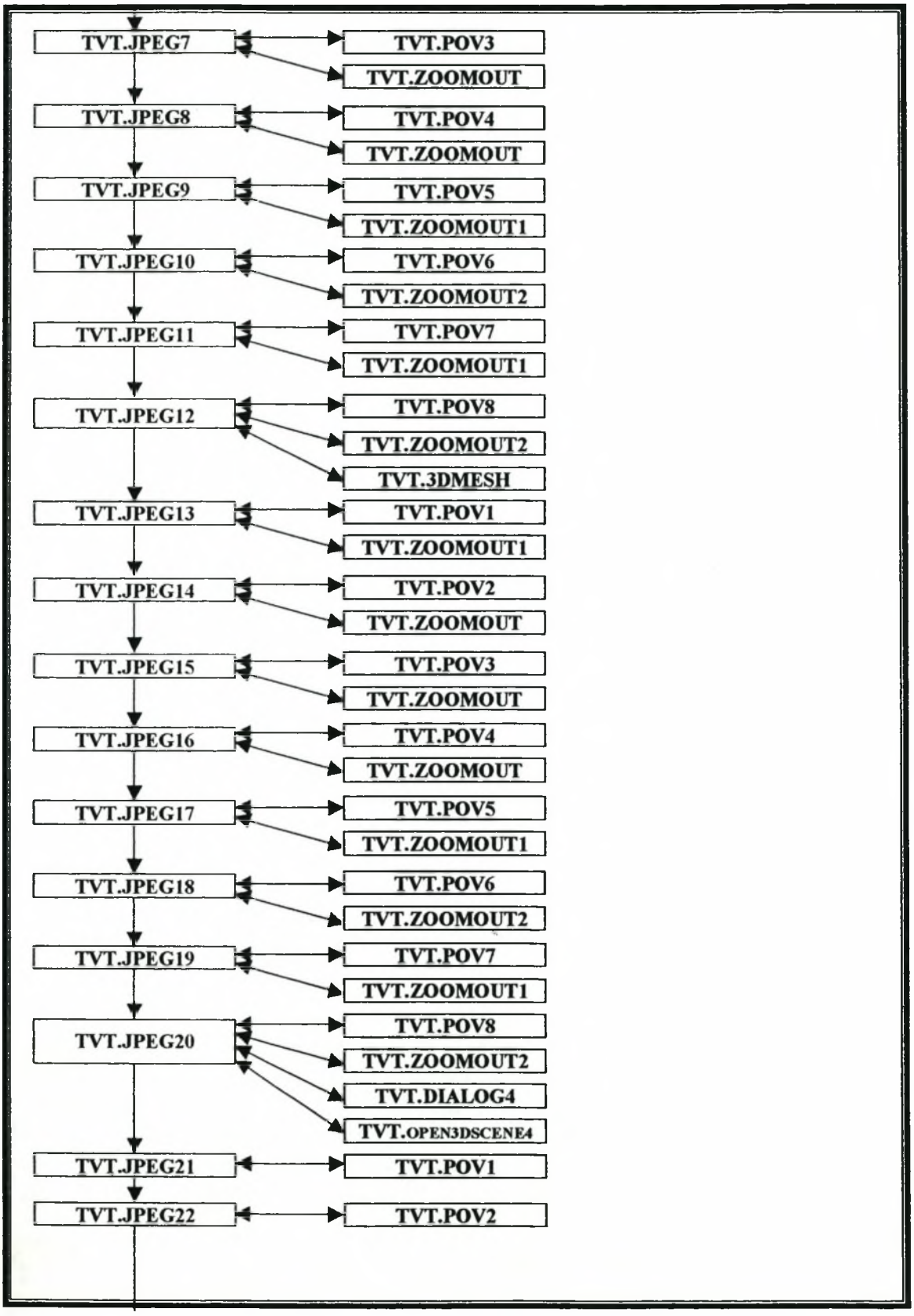

Figure 3.6: ***TV BUILDER*** structure (Continued from p. 35).

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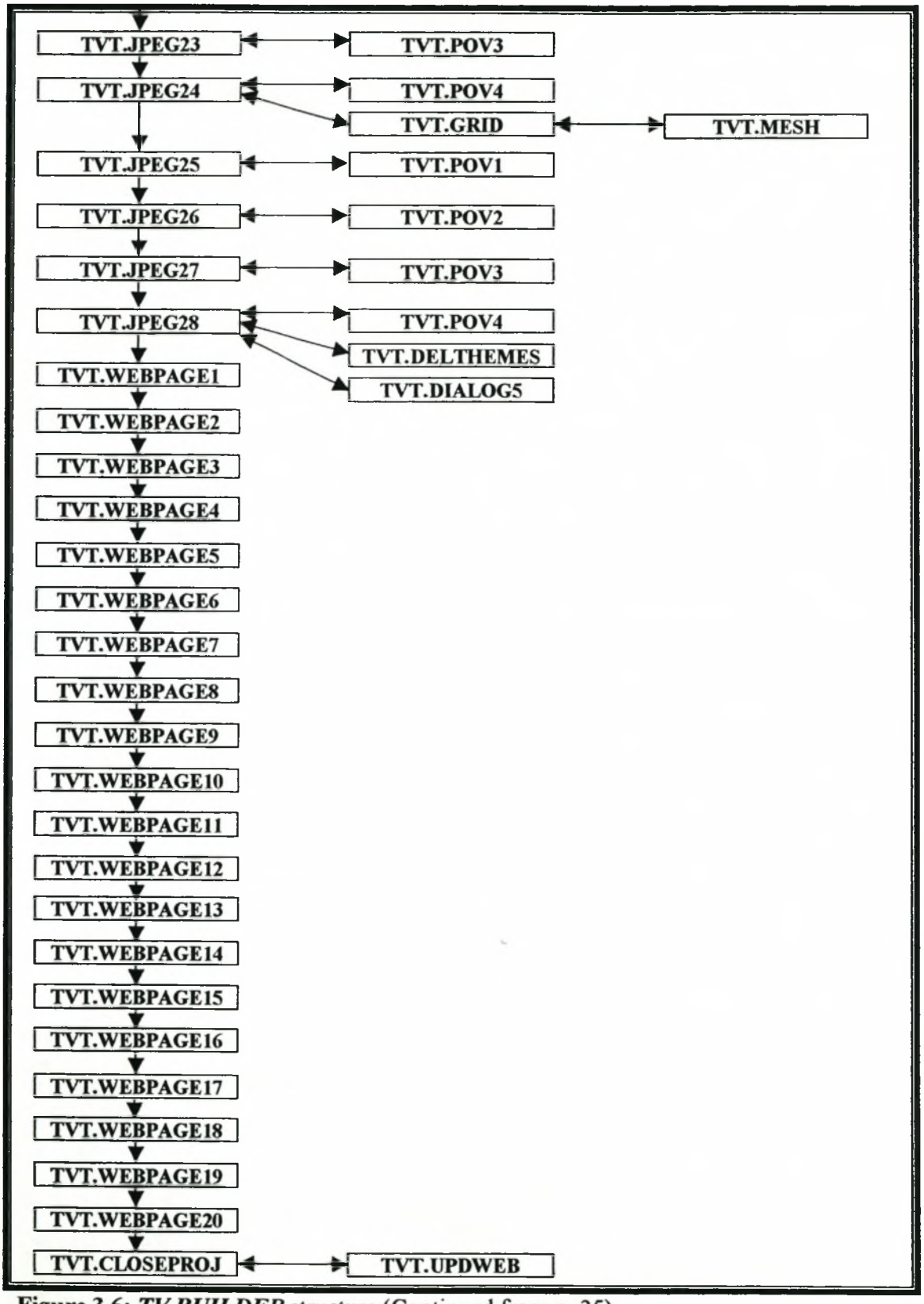

Figure 3.6: ***TV BUILDER*** structure (Continued from p. 35).

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Table 3.1: Description of scripts used in ***TV BUILDER***.

Script Name	Description
TVT.3DMESH	• Calculates a mesh of 3D lines from the active TIN. • The lines are written to a shapefile that is added as a theme to the active view or scene. • Saves the shapefile in a specified directory.
TVT.CHK	• Checks if 3D Analyst extension is installed.
TVT.CLOSEPROJ	• Exit ArcView. • Used when all the data have been created to close the application.
TVT.CLOSEPROJ1	• Exits ArcView GIS. • Used when there are problems with data inputs or when the user wants to close the application.
TVT.CREATETIN	• Uses the height values to create a TIN from the contours shapefile.
TVT.CUT&PASTE	• Cuts and pastes the contours shapefile to display them in the 3D Scene Viewer.
TVT.DELTHEMES	• Deletes all active themes from the active 3D Scene.
TVT.DIALOG1	• Creates a dialog that protects the application from the user. • Lets the user know that JPEG-images are created.
TVT.DIALOG3 - 4	• Creates a dialog protecting the buttons on a 3D Scene Viewer from the user.
TVT.DIALOG5	• Creates a dialog that protects the application from the user.
TVT.DIALOG6	• Creates dialog presented in **Figure 3.5**. • Opens automatically when ***TV BUILDER*** is opened and provides an interface for the user. • Provides information and help.
TVT.EDITCONTLEG	• Divides the contours in the contour theme into eight classes and assigns a specified color to each class.
TVT.GRID	• Converts the topographic map image to grid and saves it to a specified directory.
TVT.INPUT	• Asks for all the necessary inputs like the contours, digital map image and area name and sets them as global variables. • Combines variables to create file paths. • Creates a directory, named after the topographic area that all the data is saved to.
TVT.JPEG1-4	• Takes a snapshot of the present view in the active 3D Scene Viewer. • Exports the snapshot as a JPEG file in a specified folder. • Creates images of perspective orientation of the color-coded contours. • Set the image name as global variable.

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Table 3.1: Description of scripts used in ***TV BUILDER*** (Continued from p. 38).

TVT.JPEG5-12	• Takes a snapshot of the present view in the active 3D Scene Viewer. • Exports the snapshot as a JPEG file to a specified directory. • Creates images of perspective orientation of the color-coded TIN. • Sets the image name as global variable.
TVT.JPEG13-20	• Takes a snapshot of the present view in the active 3D Scene Viewer. • Exports the snapshot as a JPEG file to a specified directory. • Creates images of perspective orientation of the color-coded TIN with a 3D mesh draped over it. • Sets the image name as global variable.
TVT.JPEG21-24	• Takes a snapshot of the present view in the active 3D Scene Viewer. • Exports the snapshot as a JPEG file to a specified directory. • Creates images of perspective orientation of the topographic map image. • Sets the image name as global variable.
TVT.JPEG25-28	• Takes a snapshot of the present view in the active 3D Scene Viewer. • Exports the snapshot as a JPEG file to a specified directory. • Creates images of perspective orientation of the topographic map image with grid. • Sets the image name as global variable.
TVT.OPEN3DSCENE1	• Open a 3D Scene and adds the contours shapefile as an active and visible theme to the scene. • Displays an error and exits the application if the wrong theme has been specified.
TVT.OPEN3DSCENE2	• Opens a 3D Scene and adds the contours shapefile as an active, but not visible theme to the scene.
TVT.OPEN3DSCENE4	• Opens a 3D Scene and adds the topographic map image as an active and visible theme to the scene. • Displays an error and exit the application if the wrong theme has been specified.
TVT.PASSWORD	• Asks for a password in order to continue. • The application will automatically provide information and then close after two incorrect attempts by the user.

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Table 3.1: Description of scripts used in ***TV BUILDER*** (Continued from p. 38).

TVT.POV1-4	• Sets the point of view of a theme in a 3D scene using the Avenue camera. The scripts turn a display in a 3D Scene into the desired position for a snapshot to be taken. • Rotates the theme at a 90-degree (the observer directly above the target) angle into the four compass directions namely: North, South, East and West.
TVT.POV5-8	• Sets the point of view of a theme in a 3D scene using the Avenue camera. The scripts turn a display in a 3D Scene into the desired position for a snapshot to be taken. • Rotates the theme at a 45-degree angle in the four compass directions namely: North, South, East and West.
TVT.UPDWEB	• Reads a specified text file as a line file. • Finds and replaces a specified string in the line file. • This script is used to update the PROVICES website – containing all the names of the 1:50 000 topographic areas in South Africa -by replacing HTML text. This allows the user to see for which topographic areas data is available.
TVT.WEBPAGE1-20	• Creates HTML files using the WRITEELT Avenue command. • The global variables created by TVT.JPEG1-28 are concatenated with their file paths. These concatenated strings of text are then incorporated as links.
TVT.ZOOMOUT & TVT.ZOOMOUT1-3	• Zooms to a display in a 3D Scene Viewer to a specified extend.

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3.2.2 *TV VIEWER*

Implementing the user-map interface design guidelines by means of a website dramatically enhances the portability of the ***TVT***. A web browser enables data to be created at one location and viewed at another location in a matter of minutes using the Internet.

The main objective of ***TV VIEWER*** is to provide a platform to view the HTML files created by ***TV BUILDER***. In order to achieve this, four web pages were created with Microsoft FrontPage 2000, namely HOME, PROVINCES, HELP and DEFAULT, with links allowing the user to move between them (see **Figure 3.4**). The functions of these four pages can be describes as follows:

- HOME – Provides an overview of the research.
- PROVINCES – Allows the user to choose a 1:50 000 topographic map sheet (see **Figures 4.2 & 4.3**).
- HELP – Provides help.
- DEFAULT – Lets the user know that there is no data for the chosen area.

This platform allows ***TV BUILDER*** to link the HTML files, by finding and replacing HTML text in the PROVINCES web page with the TVT.UPDATE script. **Figure 3.4** illustrates how the web pages for new 1:50 000 topographic areas are linked to ***TV VIEWER***. The links between the web pages in ***TV VIEWER*** with the addition of the web pages is also illustrated in **Figure 3.4**. The following chapter demonstrates both ***TV BUILDER*** and ***TV VIEWER*** before discussing and evaluating the ***TVT***.

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CHAPTER 4: DEMONSTRATION AND DISCUSSION

This chapter provides a demonstration of the Terrain Visualization Tool 1.1 (***TVT***), and is followed by a discussion of this tool. The chapter concludes with suggestions for further research possibilities.

4.1 DEMONSTRATION OF THE TERRAIN VISUALIZATION TOOL 1.1

The demonstration of the ***TVT*** is divided into two parts, firstly creating the data for visualization purposes with ***TV BUILDER*** and secondly, visualizing the results with ***TV VIEWER***. The complete ***TVT*** application is available in Addendum C.

4.1.1 Data creation stage

TV BUILDER facilitates the set-up of the data and will normally be undertaken by someone in an authorized position (e.g. school teacher or instructor). When ***TV BUILDER*** is opened, an interface with three options is presented (see **Figure 3.5**). The **Exit** button will close the application and the **Help** button will provide more information. After the **Start** button is pressed, the application will first require a password in order to continue. Once the correct password is entered, the following inputs are required:

- An ArcView Shapefile containing contours of a 1:50 000 topographic area.
- An ArcView Tiff file containing a digital map image of the same area.
- The name of the 1:50 000 topographic map sheet (e.g. 2527DD).

To demonstrate the ***TVT*** an ArcView Shapefile containing contours of a 1:50 000 topographic area was obtained from the Chief Directorate of Surveys and Mapping. The data are available in separate units similar to the 1:50 000 map sheets (see Section 1.2) and are subjected to a licensed agreement. These data are available for the entire South Africa and includes most of the features on the paper topographic maps. A topographic map had to be scanned, clipped and geo-referenced to create the digital map image. A company called Geographical Information Management Systems (GIMS) undertook this process.

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The first two inputs are used to create different displays in order to construct the terrain representations. The topographic map sheet name allows the application to assign unique names to the directory, files and hyperlinks in the web pages. It also allows ***TV BUILDER*** to update the PROVINCES web page (see **Figure 4.2 & 4.3**) with the appropriate link to indicate that data for a 1:50 000 topographic map sheet have been created. When the inputs are completed the application will:

- Create a directory with the name of the area.
- Create 28 JPEG images of perspective displays and export them to the directory.
- Create 20 HTML files (web pages) (see **Figure 4.4**) and save them in the directory.
- Update the PROVINCES web page (see **Figure 4.2 & 4.3**).

The 3D Scene Viewer is displayed (see **Figure 4.1**) to the user, while creating the JPEG images. The buttons of the 3D Scene Viewer are protected from the user to ensure that the process is not interrupted. Once the 28 images are created the application will create the 20 HTML files while user information is displayed. When finished creating the HTML files, ***TV BUILDER*** will close automatically.

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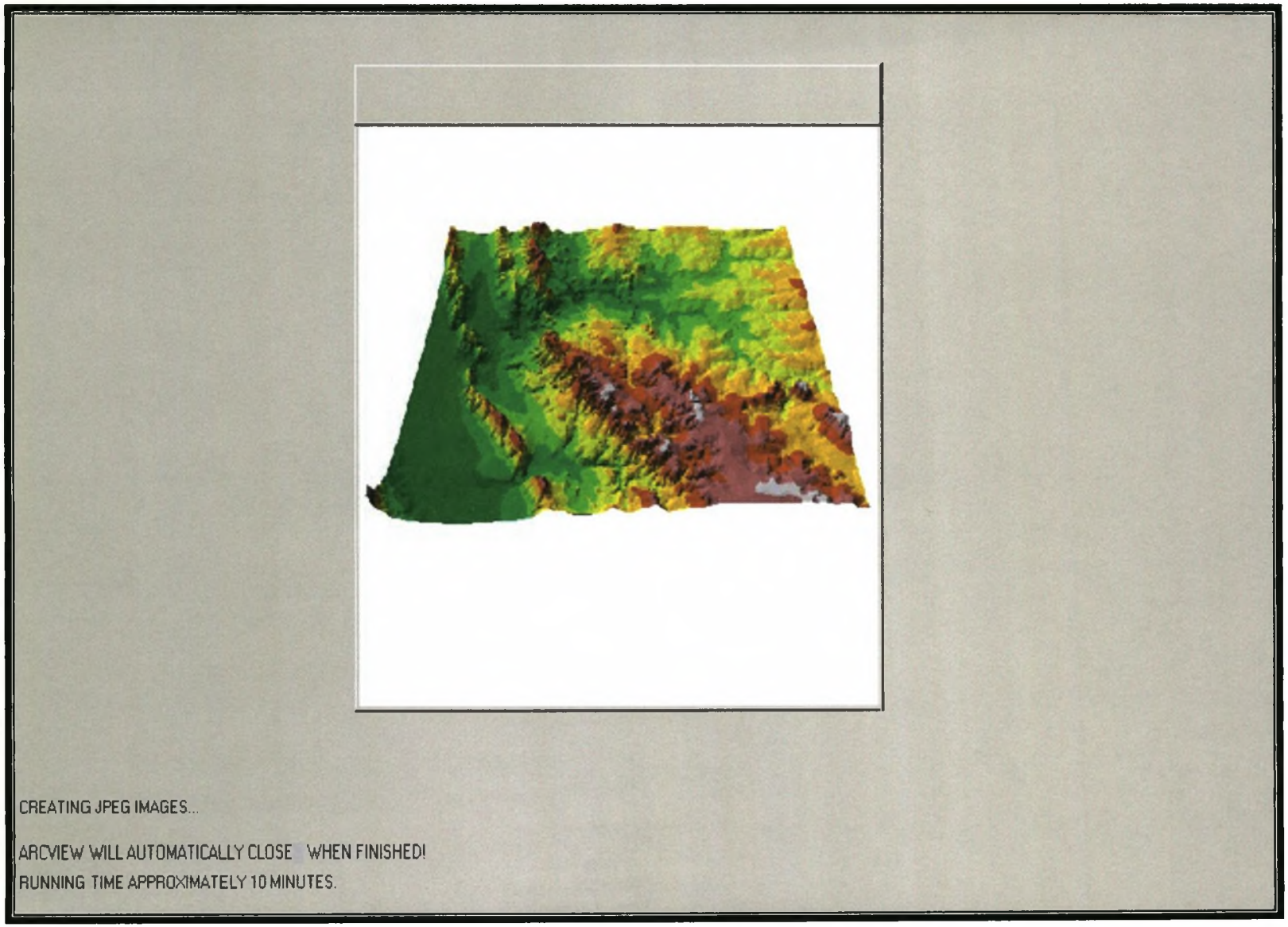

Figure 4.1: A 3D Scene Viewer creating a JPEG image of a 3D display viewed from a 45-degree vertical angle.

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4.1.2 Visualization stage

TV BUILDER creates the terrain representation images and the layout of the HTML files in accordance with the design guidelines checklist (see **Table 2.1** & **2.2**). This section specifies the guideline(s) adhered to for each component while demonstrating ***TV VIEWER***.

TV VIEWER was developed to assist topographic map reading. This was achieved by designing the application so that it mentally connects the user with the topographic paper map (see Section 2.2.2). It is thus necessary to have a topographic paper map of the same 1:50 000 topographic area at hand during the visualization stage. Users in a learning position (e.g. school pupils or army recruits) will normally undertake this task.

TV VIEWER has four main web pages as explained in Section 3.2.2. These web pages were constructed in accordance with the interface design guidelines (see **Table 2.2** number 1-13). The PROVINCES web page (see **Figure 4.2 & 4.3**) was constructed to allow the user to choose a 1:50 000 topographic area according to the province in which it is located. All the provinces in **Figure 4.2** (right) are linked to a table containing the map sheets located in them (see **Figure 4.3**). Thus, by clicking on a province, the user can view all the 1:50 000 topographic areas located in that province. The yellow cell with black text (2527DD) in **Figure 4.3** already has the HTML files linked to it. ***TV BUILDER*** automatically changes the link and the appearance of the cell after it has created the HTML files for that specific topographic area. The white cells with grey text are all linked to the DEFAULT web page, informing the user that data has not yet been created for those topographic areas.

When the user clicks on a topographic area with the linked HTML files, a web page will be displayed with the following features so indicated by the letters in **Figure 4.4**:

a. Topographic map image (see **Table 2.2** number 14).
b. Terrain representation image (see **Table 2.1** number 1-10).
c. Control box.
d. Legend (see **Table 2.1** number 11).
e. Link allowing the user to return to the HOME page.

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The control box is a matrix (see **Figure 4.4c**) that presents 20 options to the user. Each of these options will display a different web page created by ***TV BUILDER***, creating the illusion of rotating and alternating the images (see **Table 2.2** 15 & 16). By clicking horizontally across the options, the user is able to alternate the 5 different terrain representation. They are:

- Colour coded contours (see **Table 2.1** number 1,2,4,6,9 & 10).
- 3D display viewed from a 90-degree vertical angle (see **Table 2.1** number 1,2,3,5,6,7,9 & 10).
- 3D display with a grid viewed from a 90-degree vertical angle (see **Table 2.1** number 1,2,3,5,6,7,8,9 & 10).
- 3D display viewed from a 45-degree vertical angle (see **Table 2.1** number 1,2,3,5,6,7,9 & 10).
- 3D display with a grid viewed from a 45-degree vertical angle (see **Table 2.1** number 1,2,3,5,6,7,8,9 & 10).

The display of a grid on the topographic map image (see **Figure 4.4a**) and the terrain representation image (see **Figure 4.4b**) are synchronized. By clicking vertically on the matrix the user can rotate an image in the four compass directions (North, South, West and East). The movements of the topographic map image and the terrain representation image are synchronized. The design guidelines indicate that only the 3D 45-degree view needs to be rotated, but to provide continuity to the user all the views can be rotated. Because the 3D grid lines will obscure certain areas of the 3D views the user is able to *remove* them.

If the user requires information about the topographic map image, the terrain representation image or the legend (see **Figure 4.4d**), the mouse cursor can be left motionlessly on the desired option (see **Figure 4.5**). The user can view data of a different 1:50 000 topographic area by clicking on the RETURN HOME link (see **Figure 4.4e**). Specific web pages with the different terrain representation images are presented in Addendum B.

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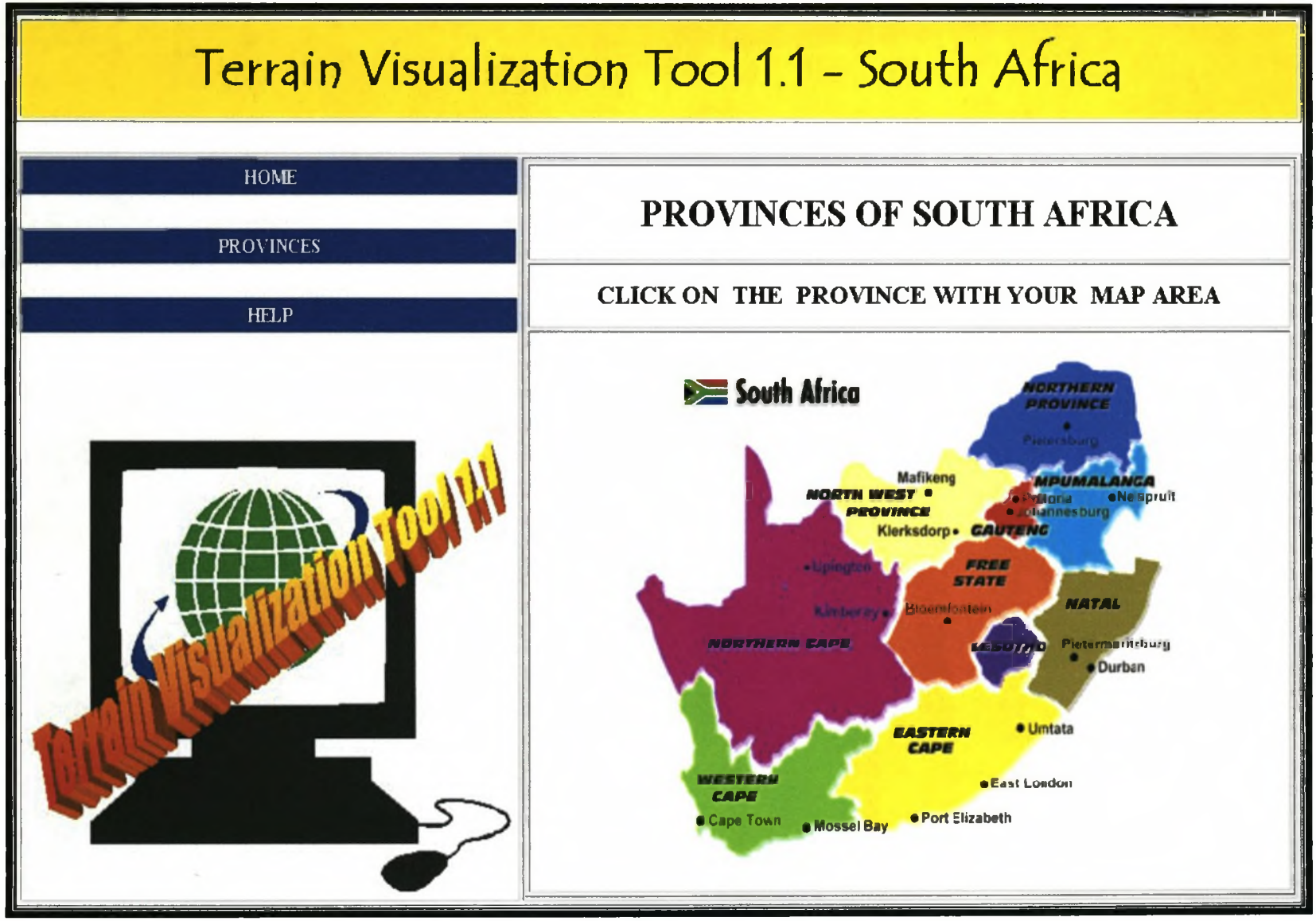

Figure 4.2: The PROVINCES web page.

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GAUTENG			
SQUARE 2527	**SQUARE 2528**	**SQUARE 2627**	**SQUARE 2628**
2527AA	2528AA	2627AA	2628AA
2527AB	2528AB	2627AB	2628AB
2527AC	2528AC	2627AC	2628AC
2527AD	2528AD	2627AD	2628AD
2527BA	2528BA	2627BA	2628BA
2527BB	2528BB	2627BB	2628BB
2527BC	2528BC	2627BC	2628BC
2527BD	2528BD	2627BD	2628BD
2527CA	2528CA	2627CA	2628CA
2527CB	2528CB	2627CB	2628CB
2527CC	2528CC	2627CC	2628CC
2527CD	2528CD	2627CD	2628CD
2527DA	2528DA	2627DA	2628DA
2527DB	2528DB	2627DB	2628DB
2527DC	2528DC	2627DC	2628DC
2527DD	2528DD	2627DD	2628DD

TOP

Figure 4.3: Table containing the names of all the 1:50 000 topographic areas in the Gauteng province of South Africa.

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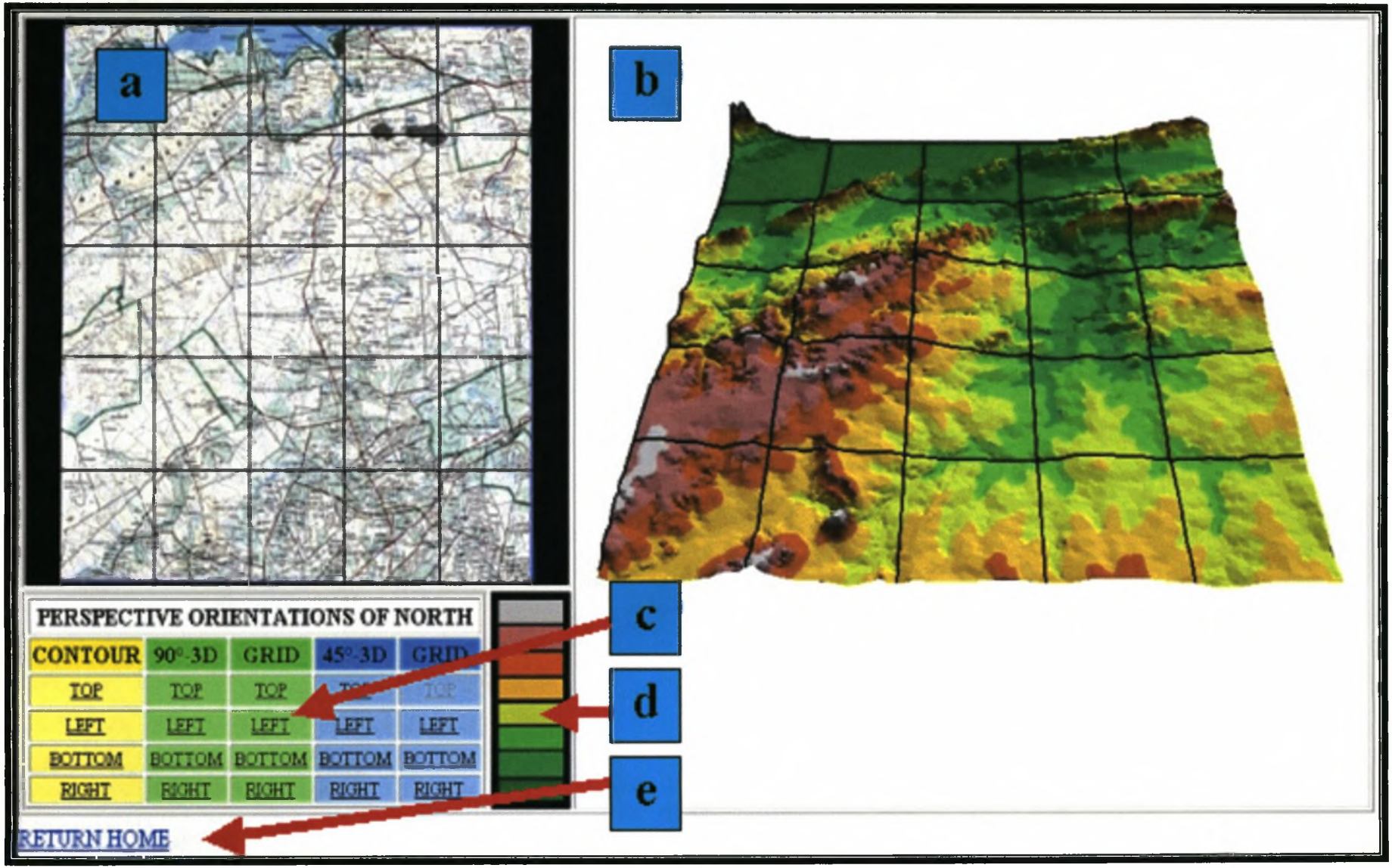

Figure 4.4: One of the twenty web pages for 2527DD created by ***TV BUILDER***.

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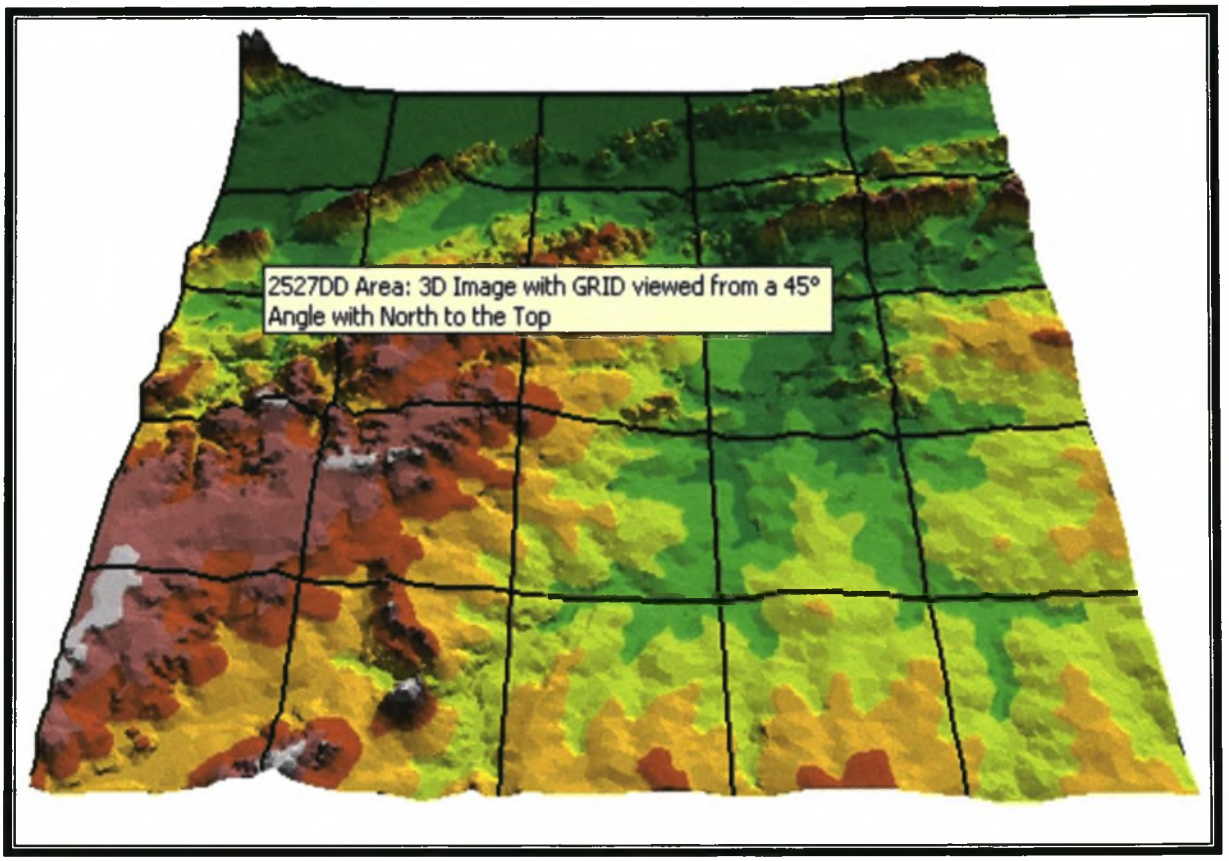

Figure 4.5: Information displayed when the mouse cursor is left motionlessly on an image or legend.

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4.2 DISCUSSION AND EVALUATION

Although the ***TVT*** was not tested in a classroom environment, it is discussed and evaluated in terms of its user value, advantages and limitations and to what extend the design guidelines were met.

The ***TVT*** addresses the specific problem users experience with visualizing terrain when they look at a South African 1: 50 000 topographic map in which contours are used to depict the relief of the terrain. Although this is only one aspect of map reading, it has been identified as one of the greatest obstacles to inexperienced map users (Nicholson & Morton 1966). The application was designed in such a way that the user can relate the visualized data (see **Figure 4.4**) to the topographic map. This allows the user to visualize the terrain better than when only studying contours on the topographic paper map.

The real value to a user, however, can only truly be assessed after the application has been implemented and used by various users. The ***TVT*** can be evaluated nevertheless in terms of certain advantages and limitations in its functionality. Some of its main features are:

Ease of use – ***TV BUILDER*** is customized to a high degree, which makes the creation of new data extremely easy. When viewing the data, ***TV VIEWER*** guides the user and provides help.

Speed and portability – New visualization data are quickly created and automatically linked to the main web site. Thus, visualization data can be created at one location and viewed at another location in a matter of minutes.

Availability of data – There are digital contour and topographic map image data available for the whole of South Africa. The Directorate of Mapping and Surveying supplies these data in a format compatible with the ***TVT***.

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Low hardware and software requirements – The visualization data can be created and visualized on a personal computer (PC) with ArcView GIS, which is a very popular and commonly used GIS package. It can be viewed on any PC capable of running a web browser.

Because of these features it is expected that the ***TVT*** would be of great value to the cartography teacher and topographic map users in schools, the defence force and/or in the private sector. Some limitations, however, were also identified:

Restricted to South Africa – ***TVT*** was constructed within a South African context. To adapt the application for use in other countries would require the input of a programmer.

Cost of data – The contours and digital topographic image data must be purchased. Depending on the budget of the user, this might be considered as a limitation.

Cost of software and hardware – ArcView GIS 3.2 with its 3D Analyst extension is expensive, which might be a limitation, depending on the budget available to the user. The web pages created by ***TV BUILDER*** have been developed and tested on a XVGA (1024 x 800) resolution computer screen (the web pages will not show the whole picture on the screen when viewed at lower resolutions and would require the user to scroll to the edges).

All the design guidelines (see Section 2.3) were successfully implemented with ArcView GIS and its 3D Analyst extension. The ability of GIS software to work with spatial data allows easy and effective creation of 3D and 2D terrain displays. This characteristic benefitted the development of the ***TVT***. The design guidelines were constructed from research done in the fields of cognitive psychology, cartography and engineering. This research project revealed that in order to develop an effective terrain visualization tool, it is crucial to incorporate these different fields of expertise.

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Slocum *et al.* (1994) supports this in stating that the effective visualization of spatial data will require an interdisciplinary effort, involving geographic information scientists, cognitive scientists, usability engineers and computer scientists. Cognitive scientists and usability engineers would be involved in the design stage of the terrain visualization tool and computer scientists in the development stage. The use of GIS implemented by the geographic information scientists would, however, be invaluable in creating terrain visualization data. This is supported by Hackley (2002), who discusses the effective role of GIS in creating Computer Generated Images (CGI) when creating applications in numerous fields such as environmental planning, scientific/geographic visualization, geographic information, **geography education** and others. These applications are developed through an initiative called Virtual Reality GIS (VRGIS), which is undertaken to enhance visualization of geographic/spatial phenomenon that include the relief of terrain.

4.3 FUTURE RESEARCH POSSIBILITIES

This study stopped short of testing the ***TVT*** in a classroom environment. A further research possibility would thus be to empirically do so.

Although the research by St. John, Oonk & Cowen (2000) is invaluable, further research is necessary in cognitive terrain visualization. There are infinite ways of representing terrain on a computer screen, many of which have not been evaluated in a classroom environment. The combined expertise of the geographer and the cognitive psychologist would be important in this regard.

The research has shown the possibilities of GIS for the development of terrain visualization tools. During the last decade, several research projects have merged GIS with virtual reality that allows great opportunities for visualizing spatial data (Hackley 2002). Thus, hardware and software developed in these initiatives should be investigated to ensure successful implementation of futures design guidelines. This includes developments in virtual environments, and particularly the WWW.

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A framework for the use of diverse study fields in the development of future terrain visualization tools should be further investigated as mentioned by Slocum *et al.* (1994). The development of such a framework will assist future research in constructing more effective applications. This will create an environment within which future terrain visualization tools could be developed and repeatedly evaluated which will ultimately insure more effective applications.

4.4 CONCLUSION

Topographic paper maps are still extensively used in South Africa and around the world, but reading these maps can be difficult. In this research, the main challenge in topographic map education was identified as being the recognition and description of relief features from their contour patterns. Conventional teaching methods such as examining topographic maps in the field, or comparing maps to 3D physical models can be costly or simply not viable. The ***TVT*** was developed to provide an improved teaching technique and, in its present form, is a completely functional application, designed to assist South African 1:50 000 topographic map users. An additional advantage of the ***TVT*** is that it was developed in such a way that it can be effortlessly incorporated into the classroom environment. It will benefit both teachers/instructors and learners, and might instigate future research and developments in electronic media that might further improve topographic map education in South Africa.

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ADDENDUM A: CONCEPTS AND TERMS

3D Scene..... The 3D Scene provides a means to the 3D Analyst Extension of displaying and querying a collection of user-defined Themes.

3D Scene Viewer..... A 3D Scene can possess multiple Viewers, which are used to display the data contained in the Scene using a 3D perspective. Each of the Scene's Viewers can look at the Scene's data using a different perspective.

BIPMAP.....An unstructured grid image in which data values are recorded as either 1 or 0. The term is often used to refer to graphics composed of pixels, for example, scanned in maps or photographs (McDonnell & Kemp 1995: 16).

Drape..... When base heights of a theme in a 3D Scene are set to a 3D surface it will display on top of that surface as though it were draped, over it (as a carpet).

DBMS..... Database Management Systems (DBMS) is a collection of software for organizing the information in a database. Typically it contains routines for data input, verification, storage, retrieval and combination.

GIF..... Graphical Interchange Format (GIF) saves images as monochrome (line art) or 8-bit (grayscale or 256-color) images.

GUI..... Graphical User Interfaces (GUIs) rely on the user to direct the application in executing functions. This entails selecting menu items or pushbuttons, thereby avoiding the display of irrelevant questions.

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Internet..... A computer network consisting of many hosts from many organizations and countries. It is physically created from many smaller computer networks and is linked together by a common set of Internet protocols (Williams *et al.* 1996: 69). Protocol refers to a set of rules or standards that describes ways to operate so as to achieve compatibility.

JPEG..... File Interchange Format (JPEG) is an image compression option that reduces the number of bits in the image by eliminating repetitive image data or image data that is hard to see. JPEG achieve much greater compression than most other methods.

Links..... Objects (e.g. text) that contain links to other objects or documents. These objects can be chosen by the user in order to move around in or between documents.

Psychology..... Science of the human mind its aspects, operation, powers and functions or the systematic investigation of mental phenomena, especially those associated with consciousness, behavior, and the problems of adjustment to the environment.

Relief..... The shape of the earth's surface (Mayhew & Penny 1992).

Shapefile..... ArcView GIS shapefiles is a simple, non-topological format for storing the geometric location and attribute information of geographic features. A shapefile is one of the spatial data formats in ArcView.

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TIFF..... Tag Image File Format (TIFF) is a commonly used raster file format developed by Aldus Corporation (McDonnell & Kemp 1995: 86). It saves images as monochrome, 8-bit, or 24-bit (true color) images.

TIN..... A TIN Theme represents one or more geographic layers, where space is partitioned into a set of non-overlapping triangles. Attribute and geometry information is stored for the points, lines and faces that comprise each triangle. This information is used for display, query and analysis purposes. A TIN theme is often used to represent continuous elevation surfaces (McDonnell & Kemp 1995: 87).

Virtual Reality..... Virtual Reality is a step beyond visualization. It is a simulation that includes stereovision, stereo sound and the ability to control the display. Virtual reality in theory allows users to experience almost any activity completely without moving from his or her chair (Faust 1995: 262).

Web Browser..... Software designed to provide users access to the resources on the Internet, e.g. Netscape Navigator and Internet Explorer (Williams *et al.* 1996).

Web Pages..... Distinct subsections of individual web sites; loosely analogous to chapters in a book, these are publicly available computer files stored in text, sound and graphic format (Williams *et al.* 1996: 69).

Web Sites..... Unique HTML-based locations containing information, files and documents (Williams *et al.* 1996: 69)

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WWW..... The World Wide Web (WWW) runs on the Internet, displaying hypermedia objects to members, so that routes through to new documents and related information on different servers on the Internet may be traced (Worboys 1995: 352).

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ADDENDUM B: VISUALIZATION DATA

Addendum B presents five of the twenty web pages for 2527DD created by ***TV BUILDER***. The web pages present the five different terrain depictions (**Figure 4.4**, #2) namely:

- Colour coded contours;
- 3D display viewed from a 90-degree angle;
- 3D display with a grid viewed from a 90-degree angle;
- 3D display viewed from a 45-degree angle; and
- 3D display with a grid viewed from a 45-degree angle.

The five web pages present the images with north orientated to the top.

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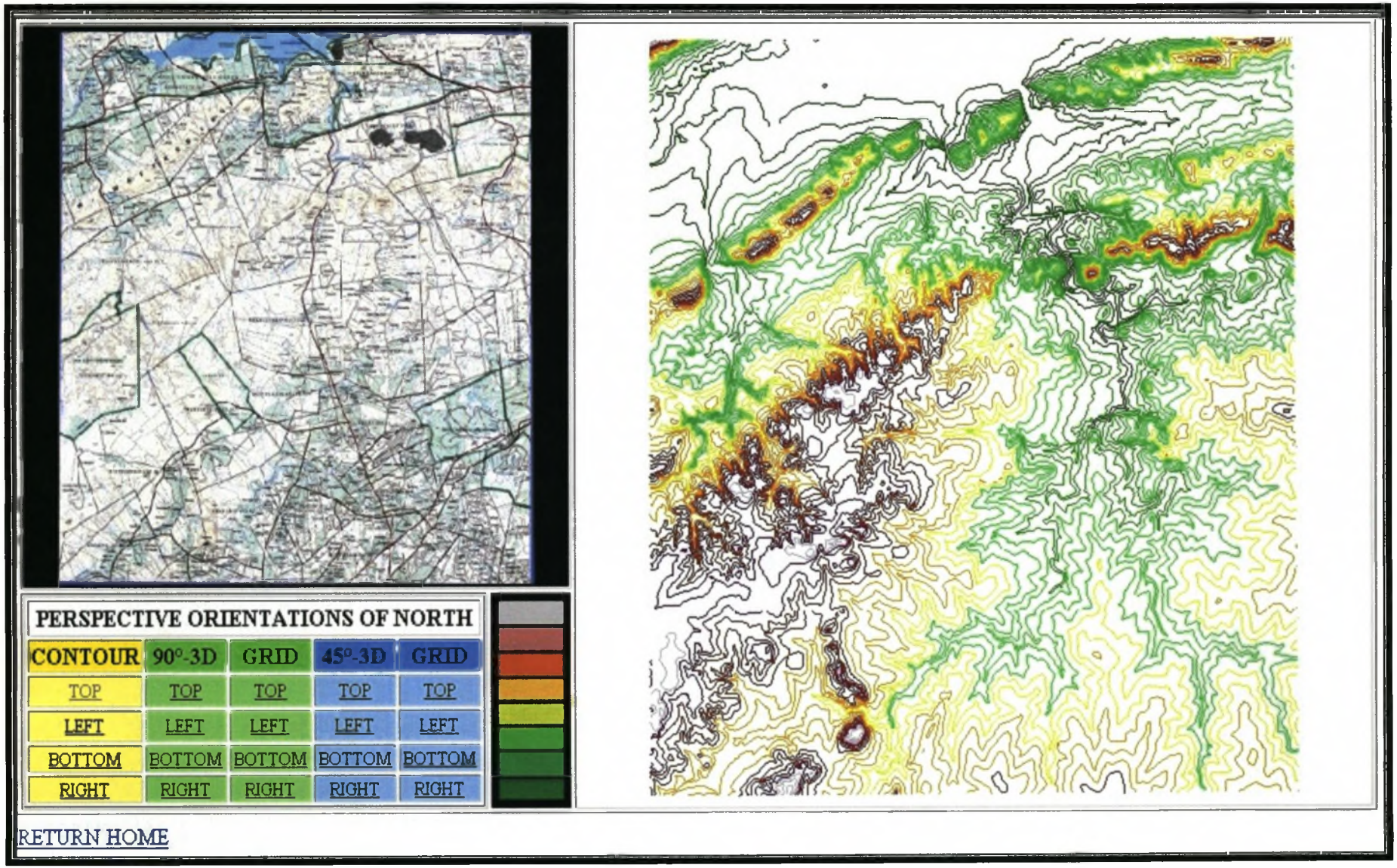

Figure B.1: Colour coded contours.

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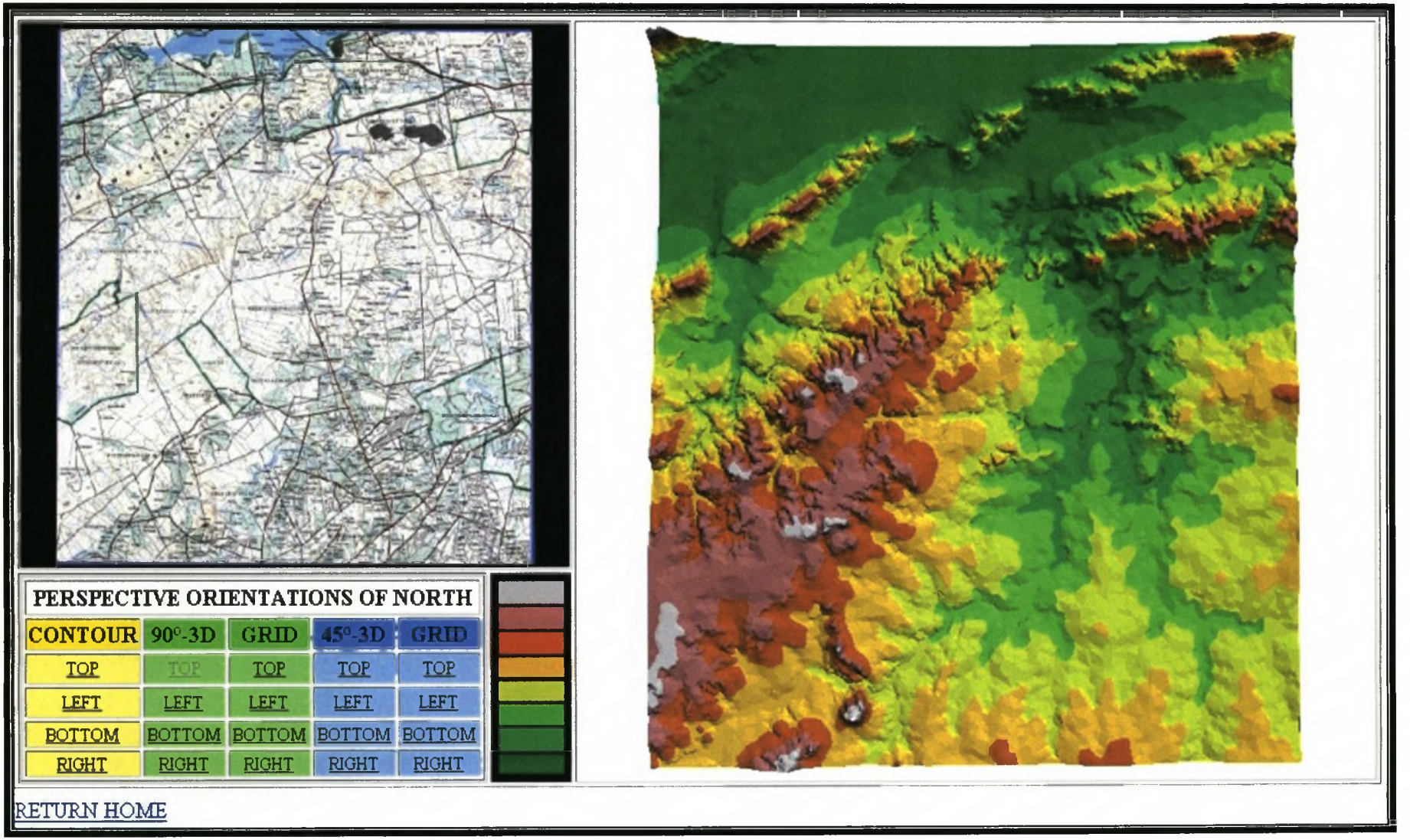

Figure B.2: 3D display viewed from a 90-degree angle.

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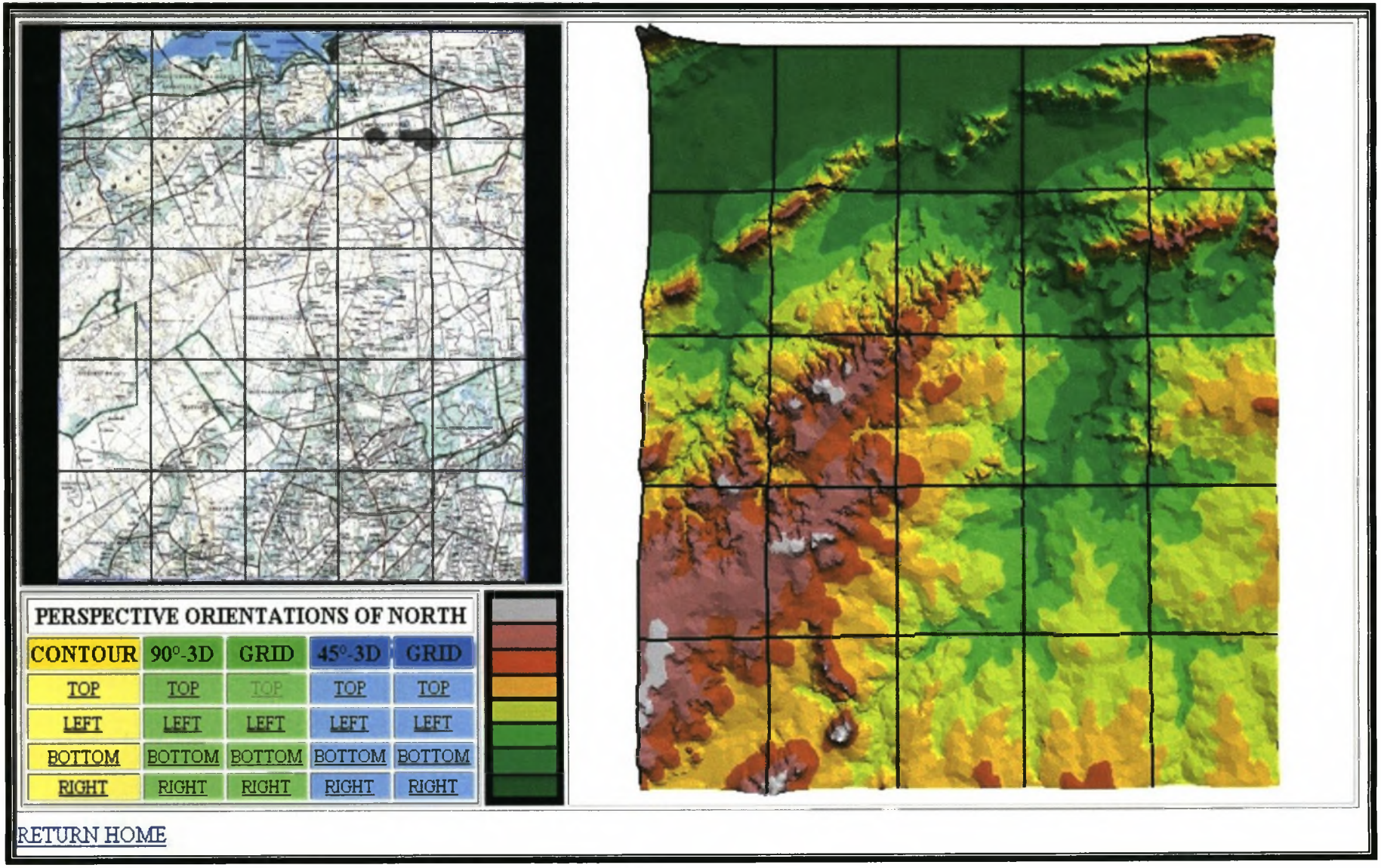

Figure B.3: 3D display with a grid viewed from a 90-degree angle.

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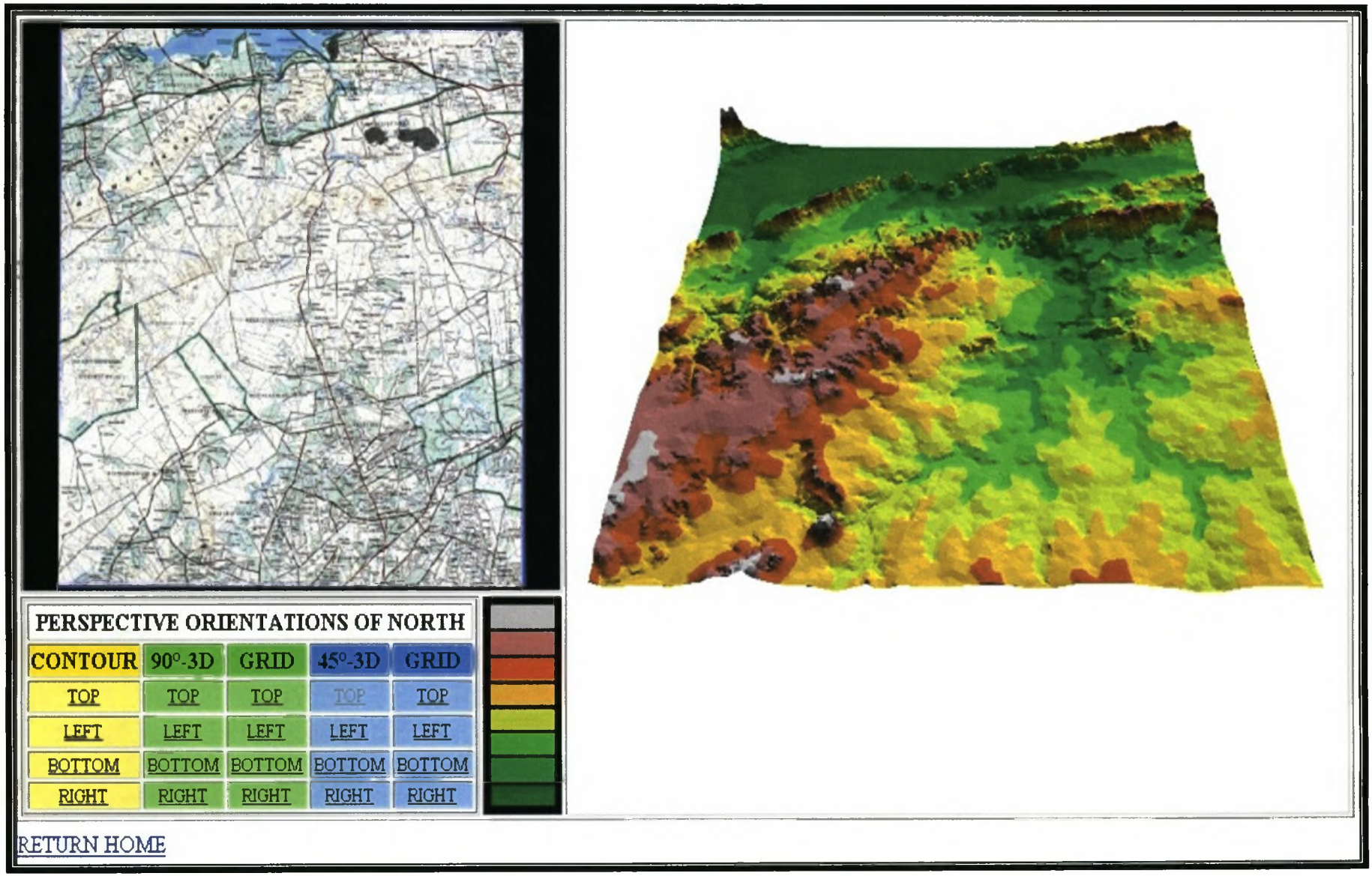

Figure B.4: 3D display viewed from a 45-degree angle.

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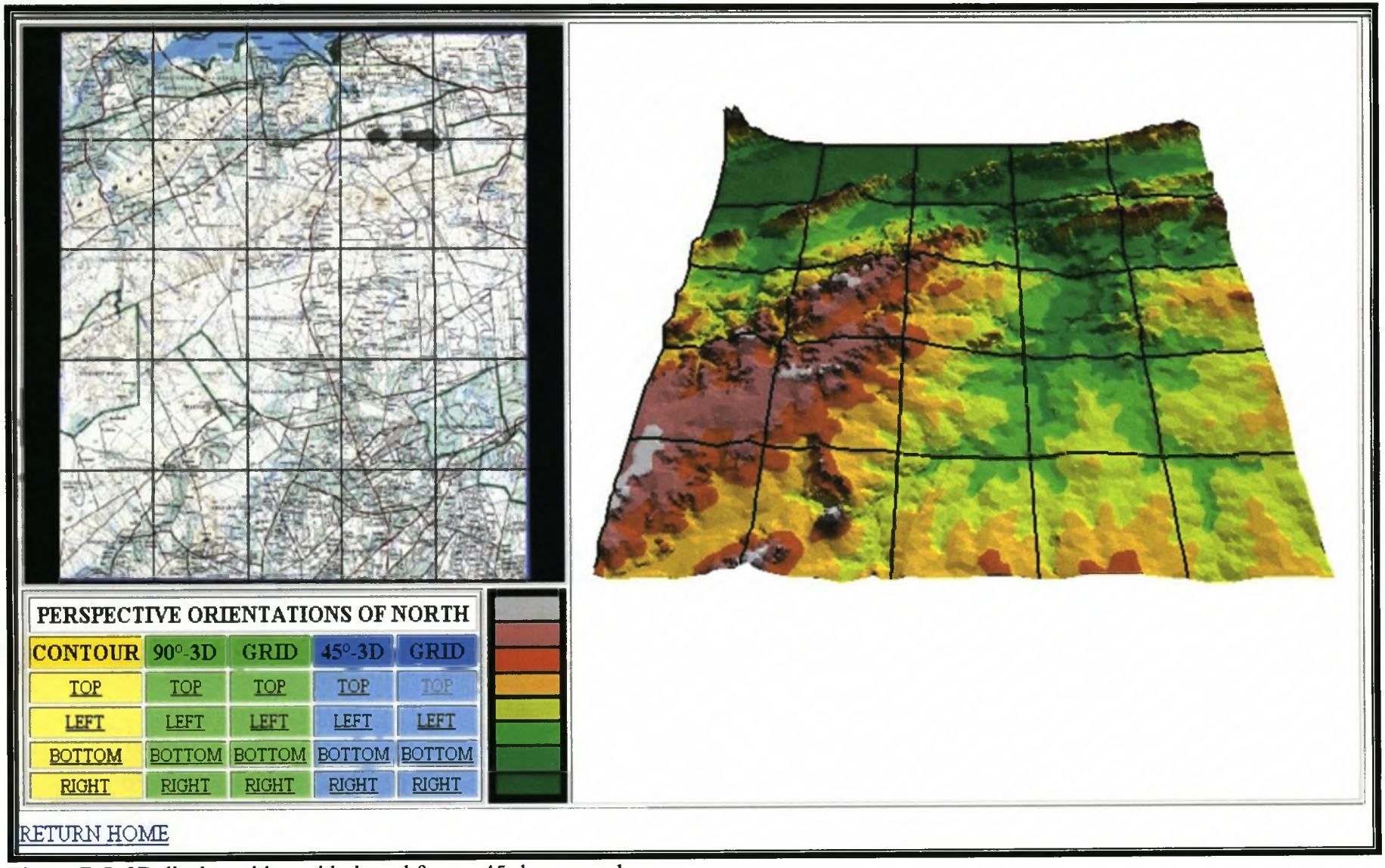

Figure B.5: 3D display with a grid viewed from a 45-degree angle.

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ADDENDUM C: THE *TVT* AND SCRIPTS USED TO DEVELOP *TV BUILDER*