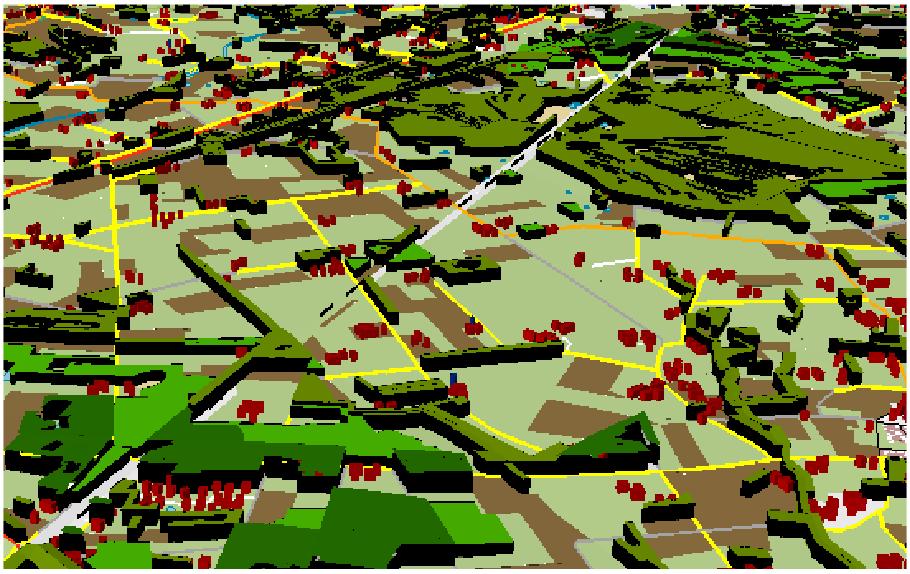
Centre for Geo-Information

Thesis Report GIRS-2007-19

Information Intensity of 3D Geo-visualisation

Rahel Getachew Messele

August 2007



WAGENINGEN UNIVERSITY
WAGENINGEN UR

Information Intensity of 3D Geo-visualisation

Rahel Getachew Messele

Registration number 80 12 12 560 070

<u>Supervisors</u>:

Dr. ir. R.J.A van Lammeren

A thesis submitted in partial fulfilment of the degree of Master of Science at

Wageningen University and Research Centre, The Netherlands.

August, 2007

Wageningen, The Netherlands

Thesis code: GRS-80436
Thesis Report: GIRS-2007-19
Wageningen University and Research Centre
Laboratory of Geo-Information Science and Remote Sensing

Acknowledgments

First and for most I would like to praise my Lord Jesus, who helped me through out my study and to reach at this stage.

I am greatly indebted to my supervisor Dr. ir Ron van Lammeren for his invaluable comments, suggestions and recommendations in shaping up my thesis. I would like to thank Ing. Aldo Bergemans for his assistance in putting the questionnaire on web.

My appreciation also goes to my families for their moral support. Above all, my husband Andualem Kebede deserves especial thanks for lifting up my spirit and being there for me.

Furthermore, I would like to thank all my respondents who devoted their valuable time to fill out my questionnaire.

This thesis would not be finalized with out the help of all these people.

Abstract

The overall objective of this MSc thesis is dedicated to explore the term information intensity as introduced by Heim (1998) in the domain of 3D geo-visualisation. This thesis report presents an insight on the definition of information intensity. For that reason it refers to Shannon information theory, especially to measure information intensity. Based on theoretic notions these measurements are related to three levels; geo-data, visualisations of the geo-data, and 3D visualisations of geo-data in relation to users' visual perception and prior knowledge of the data.

Results of the literature review confirm that information intensity is primarily related to level of detail of visualisation. In 3D geo-visualisations, information intensity is the amount or degree of visual forms of a geo-data displayed in a 3D scene.

This thesis was done in context of the case study, the Achterhoek, the Netherlands. Geo-data of this case study is classified and converted to 2D and 3D visualisations according to three European countries classification standards respectively. The countries' 1:50000 topographic map legends are used for the classification. Shannon's information calculation is used to measure and compare the information intensity of Achterhoek geo-data and visualisations of the geo-data. The method is usable especially for thematic information calculation from the geo-data and visualisations of the geo-data. However it has some limitations. The theory is based on assumption of equal probability and occurrence of events which is not always true in case of geographic phenomena. Besides, it is not expedient method to measure geometric and topologic information.

Analysis of the results indicated that data conversion to geo-visualisation determines information intensity of the visualisation. The intensity calculations show as the number of thematic class change with different classification standard, information intensity of the visualised geo-data also changes.

A web-based questionnaire was also developed to find out about the third level of information intensity i.e. information intensity of geo-visualisation in relation to users' prior knowledge and visual perception. The questionnaire was delivered to a pre selected reference groups of MGI students. However the responses obtained were not enough to draw conclusion thus, this research discusses the proposed methodology and recommends further research.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

This chapter introduces the background and problem definition. It also includes the research objective and related research questions together with an overview of the thesis.

1.1 Background

Since early ’90 Geographical Information Systems (GIS) has become a very interesting and sophisticated system for spatial data capturing, structuring, maintaining analyzing, and presenting. With the advancement of technologies in the field of GIS, the need for Three-dimensional (3D) information increased rapidly in different disciplines. Its application covers wide areas: 3D urban planning, environmental monitoring, telecommunications, public rescue operations, and landscape planning (Stoter and Zlatanova, 2003).

Nowadays, with the increasing demand of 3D information, geo-visualisation systems are developing very fast (Yun et al., 2004). Geo-visualisation is *“the use of concrete visual representations … to make spatial contexts and problems visible, so as to engage the most powerful human information-processing abilities, those associated with vision*” (MacEachren et al., 1992 as cited in MacEachren et al., 1999). It is also defined as “*a three dimensional visual representation of visual data, which has a geographic reference”* (Hoogerwerf, 2005).

3D geo-visualisation of GIS databases is the most common and effective way of presenting large amounts of complex information to users with or without GIS background (Al-Kodmany, 1999; Bishop, 1994 in Appleton et al., 2002). The incorporation of different 3D technologies in the area of GIS made 3DVirtual Reality (VR) a more realistic and advantageous ways of visualizing our world. It enhances interaction with users, provides realistic views, options of orientation and navigation selection and query, and manipulation and analysis (Verbree et al., 1999).

Many researchers attempted to give different definition for the term Virtual Reality from their point of view. Fisher and Unwin (2002, p.1) defined VR as: “*the ability of the user of a constructed view of a limited digitally-encoded information domain to change their view in three dimensions causing update of the view presented to any viewers, especially the user*.” Burdea and Coiffet (2003) in their book of “Virtual Reality Technology” stated, *“VR has application that involves solution to real world problems. Therefore the extent to which an application is able to solve a particular problem that is, the extent to which a simulation performs well, depends therefore very much on human imagination.”*

Mahmoud (2007) stated that there is no standard definition for VR. In general, VR is a computer-generated technology for representing the real world where users feel immersed as if they are in real environmental settings.

1.2 Problem definition

Many researches believed that 3D geo-visualisation techniques overcome the limitations of traditional methods of graphic display i.e. 2D geo-visualisation (Al-Kodmany, 1999; Danahy, 1999; Appleton et al., 2000; Shiode, 2001). Lammeren et al. (2004) pointed out that VR environments are visualized better with three-dimensional methods using two- or three-dimensionally georeferenced geo-data sets.

In 3D geo-visualisation, the extent of similarity between the representation and the real world is determined by “virtuality” of the VR. Burdea and Coiffet (2003) were the first to introduce the three “I” factors: “Immersion, Interaction and Imagination” to define VR. Later on, Heim (1998) and MacEachren et al. (1999) introduced the four I’s that contributed to the ‘Virtuality’ of Geo Virtual Environment (GeoVE). Heim introduced the first three factors: ‘Immersion’, ‘Interactivity’ and ‘Information intensity’ and MacEachren added the fourth factor ‘Intelligent objects’.

Information Intensity, sometimes denoted as Information Density is the third “I” factor that deal with the *level of detail* of a representation (Heim, 1998; MacEachren et al., 1999; Wachowicz et al., 2002). This MSc thesis emphasizes on finding out more about information intensity, from the viewpoint of 3D visualisation, its relation with data conversion and user interaction.

Different research actions have been conducted on the “I” factors with different objectives. Particularly, the first two I’s have received considerable attention in geo-visualisation literatures. Nevertheless, Information Intensity is rather unexploited. There is very limited number of literatures with limited discussion on information intensity.

It is expected that the findings of this thesis serve as guidelines related to information intensity of 3D geo-visualisation that could inform users of 3D visualisation at different level about the information transmitting quality of 3D geo-visualisation. It is also hoped to draw the attention of 3D geo-visualisation designers to take information intensity of 3D scenes in to consideration. Besides, this thesis is believed to serve as launching pad for interested researchers to work further on 3D geo-visualisation regarding information intensity.

1.3 Research objective and research questions

This study is an explorative study aiming at defining and illustrating the term ‘Information Intensity’ related to 3D geo-visualisation. Based on this objective, the following research questions are advanced to guide this study

1. What definitions could be found for the term ‘Information Intensity’?
2. Has Information Intensity to deal with the conversion of geo-data in to a 3D visualisation?
3. Has Information Intensity to deal with the graphical details of 3Dgeo-visualisation?
4. How do people interact with 3D visualisation? Will Information Intensity increase or decrease?

1.4 Thesis overview

In order to achieve the research objective, each research question is addressed in separate chapter. The remainder of this thesis is organized in six chapters as follows:

- Chapter 2. Refers to the different definitions of information and information intensity based on literature research. This chapter answers the first research question.
- Chapter 3. Describes an existing formula called Shannon Entropy and three levels of information intensity. It also measures information intensity of geo-data and 2D visualisation of the same geo-data with different classifications. Chapter 3 answers research question number 2
- Chapter 4. Attempts to measure information intensity from 3D visualisation using case study. The measurement includes comparison among 3D scenes with varying viewpoint, graphical detail and scale.
- Chapter 5. Discusses the proposed methodology, which is a web-based questionnaire on selected reference groups to assess how users’ visual perception and stock of knowledge could influence information intensity of 3D geo-visualisation.
- Chapter 6. Includes conclusions, discussion and recommendation based on the results obtained.

Chapter 2: What is Information Intensity?

2.1 Introduction

Chapter 1 already mentioned that the "virtuality" of a representation depends on the four "I" factors. In this chapter, readers can find the definition of Information Intensity based on the different definitions of information given in different disciplines.

2.2 What is Information?

It is common to encounter the word information in daily activities; in the books we read, conversations we have, and things we hear etc. However, it has different meanings in different occasions. This thesis starts by discussing the source of the term and its context in different disciplines.

The Oxford English Dictionary (OED) indicates the word information has its root in the Latin word "Informare" (Soanes and Stevenson, 2004, p.729). All scientific disciplines use the concept information in their field of studies and it is very difficult to get one specific definition for it'. The word Information implies different meaning in different disciplines. This chapter deals with definitions given in GIS, Cartography, Visualisation, Information Science and Psychology. These particular disciplines deal with information at different level. The first four disciplines overlap to each other for they have close interdisciplinary relations. Psychology has a direct relevancy to the rest of the disciplines and their interaction with human.

Hilgard et al. (1975, p.4) specified, "*Psychology touches almost every facet of our lives*." Moreover, as a science, it focuses mainly on mental processes. In similar manner, it touches every discipline that involves human interaction. It deals with concepts like perception, interpretation, cognition etc. that are of importance to GIS, Cartography, Visualisation and Information Science. Especially, for the four disciplines, the visual sense is very important to work with information. Therefore, in order to understand how information is retrieved, processed and presented in these disciplines, it is necessary to see the definition of information in Psychology. Besides, Psychology, in its domain of sensory processes, clearly explains how human beings receive and process information and finally respond to it.

2.2.1 Information in GIS

Is there a difference between data and information? Do these terms mean the same thing? Starting with the basic difference of these two terms is a wise approach of indicating the perception of information in GIS. Most of the time, in the discipline of GIS, information is confused with data and the terms are used interchangeably in written materials and by the experts. However, an important difference exists between the two terms.

Davis (2001, p.31) defined data and information in short as follows: *“Data: A collection of facts in the database; multiple entries. Information: The meaning or interpretation of data. Information is the knowledge obtained from data and implies explanation of significance of the collective facts or numbers.”* The difference between data and information is also articulated in simple mathematical formula: “Information = data + context” (Worboys and Duckham, 2004, p.5). According to Worboys and Duckham, *context* refers to the steps that data passes through starting from its collection to its final application and users understanding. From these definitions, one can recognize that there is interrelationship between data and information. The latter is the output of the former. Hence, information in GIS is interpretation of collected data or an output. The output can be in different forms such as an analysis report, a map, a graph etc.

According to (Pickles, 1995, p.2), “*GIS is a special case of information systems in general, in which information is derived from the interpretation of data ‘which are symbolic representation of features’*” .

Couclelis, in his definition of information also mentioned, *“Contrary to some common misconceptions, information is not a thing – i.e. a bunch of bits – but a relation between a sign and an intentionality: the sign(s) being, in this case, the various graphic and other forms of GIS output, and the intentionality, the purposeful human intelligence giving meaning to these signs*” (Couclelis, 1999 as cited in Schroeder, 2003).

2.2.2 Information in Cartography

The scientific objective of cartography is making different type of maps, which graphically represents the reality of our world. (MacEachern, 1995) stated cartography’s function as *“...creating interpretable graphic summaries of spatial information (i.e., representations)...”*.The collected geospatial information is systematically transformed to graphical symbols to communicate information to different users.

The understanding of information in Cartography is the same as GIS for the two disciplines are linked closely. According to the cartographic communication process, the different data set collected by professionals (geodesists, photogrammetrists, geographers, statisticians, etc) is information (I) for cartographers. The cartographer transfers this information in a map format. The same map may serve as information (I') to the readers or as data (starting point) for someone who is interested to derive specific data from the already interpreted data (Kraak and Ormeling, 2003). It should be considered that, what is "Data" at some stage or for someone or a discipline could be "Information" for another. Therefore, information could be data at some stages of cartographic processes.

2.2.2 Information in Visualisation

The discipline 'Visualisation' is broad by itself. It has number of branches: Scientific Visualisation, Information Visualisation, Knowledge Visualisation, 3D Visualisation, Geo-Visualisation, etc. This chapter deals with visualisation as a technique of communicating the out put of geospatial data.

Visualisation is a concept applied to both Cartography and GIS. In Cartography, it has two components: communication and analysis. Communication always deals with information. Thus in this aspect information is understood as data which is transmitted from one person to groups, computer to person, etc using different forms such as paper, digital maps, etc (Jiang, 1996).

Visualization creates a link among information, data, knowledge and human mind, which is a powerful processor of information (Gershon and Eick, 1998). As the word visualization indicates, visualisation involves transformation of information, data and knowledge to visual forms. This indicates that information in visualization has some form of visual representation. Similarly, in geo-visualisation, which is one branch of visualization, geo-data are converted to visual forms such as objects, graphics, etc that provide information about the phenomenon represented.

2.2.4 Information in Information Science

For some disciplines including information science, information is broadly associated with messages. Saracevic (1999) came up with three different level of understanding information. These levels of understanding have ordered of sequence from simple to complex i.e. narrow, broader and broadest.

In the first sense, considers information as signals and messages only. The second sense considers it as an output of interaction between two cognitive structures; '*mind*' and '*text*'. The third sense treats information in a context. "*It involves not only messages (first sense)* *that are cognitively processed (second sense), but also a context—situation, task, problem-at-hand, and the like. Using information that has been cognitively processed for a given task is an example. In addition to other senses, it involves motivation or intentionality, and therefore it is connected to the expansive social context or horizon, such as culture, work, or problem at-hand. In information science, we must consider the third and broadest sense of information, because information is used in a context and in relation to some reasons"* (Saracevic, 1999).

Buckland (1991a) came up with three principal uses of the word 'information': Information - as- knowledge, Information- as- process and Information - as- a thing. The first one refers to what somebody knows or what is intended to add in to already existing knowledge. The second one refers to the perception of someone and the last one refers to any informative things including data, texts and documents, objects and events. Information science has a special interest on the third use of information and deals with this perception of information (Buckland, 1991b).

2.2.5 Information in Psychology

The Dictionary of Psychology defines information as "*knowledge acquired by learning*" (Colman, 2002, p.365). The formation of information starts with the arrival of external signals at our sense organs. External signals also referred as stimuli are interpreted information by the brain. External signals or messages could be sound, visual image, smell, touch of an object etc. The conversion of signals to internal representations indicates the basic stages of information processing called Encoding. "*If information is to have any effect at all, it must be first registered perceptually. That is to say, a person must see, hear, feel or otherwise sense some energy change in the environment for there to be any information for further processing*"(Bourne et al., 1986).

2.3 The Three Levels of Information

As already mentioned in the earliest part of this chapter, different disciplines have different understanding of information. This different understanding also excites among scholars. The scholars could be from the same or different disciplines. I will use the perception of Saracevic (1999) and Buckland (1991) in combination to measure information intensity from geo-data and visualisations of the same geo-data. Saracevic and Buckland came up with different understanding of information. Even though they used different words to explain what information meant, there is association between their understandings.

Table 2.1: Information Perception

	Knowledge	Process	Thing
Signal/Message			x
Mind-text	x		
Context		x	

Source: the first row is adopted from Buckland (1991) and the first columns is adopted from Saracevic (1999)

2.4.1 Information as a Thing or Signal

The first level refers to any informative objects it could be data, documents, texts etc. Therefore, information contained in the geo-data, which is used in this thesis, is first level information for the records and attributes are communicating information.

2.4.2 Information Knowledge or Mind-text

The second level is information as cognitive interaction between mind and text that refers to change in the state of mind. Information obtained from geo-visualisation (2D/3D) is second level information i.e. Knowledge or Mind-text interaction because it gives more information and helps for better understanding than the geo-data.

2.4.3 Information as Context or Process

The third level of information is complex when compared to the first two levels. Saracevic (1999) stated “*Using information that has been cognitively processed for a given task*”. This could be a good example to explain the contextual usage of information in the third level. In other words, when some one is informed about something, it could be visualizing a 2D or 3D scene, the already existing knowledge of that person changes. We should be careful not to confuse ‘change in state of mind’ of the second level with ‘change in the already existing knowledge’ of the third level. This level of information greatly deals with the “stock of knowledge” and perception of users. For instance, if the person is already familiar to a scene, no knowledge is imparted which implies low information intensity of the scene. However, if the person is not familiar to the scene at all, knowledge is communicated in the person’s mind i.e. there is a change in the already existing knowledge which leads that person to think that the scene has high information intensity. It should be clear that the information intensity of the scene is same, what changes is viewers’ perception about the information intensity of the scene.

2.4 Information Intensity

The word 'Intensity' is widely used in the domain of natural science such as physics and chemistry to refer to the amount or degree of something with measurable quality. From this definition of intensity, one can understand that information intensity is something measurable.

Wachowicz (2002) grouped information intensity under GeoVR Construction factors which are relevant for the creation of GeoVR environment. Information intensity also refers to degree of proximity of objects in geo-visualisation to what they represent from the real world. MacEachren et al. (1999) specified that *"The virtualness of an environment will be enhanced if its objects have sufficient detail to appear like real world objects and features.....What is required is a level of detail that corresponds to what we expect of real world objects at particular distances. Additionally, increasing proximity to an object should allow a participant to see increasing detail, as it does in the real world …. Just as it is possible to use a magnifying lens in the real world to see even more detail, a virtualness of a GeoVE will be enhanced if zooming to scale beyond those of normal vision continues to provide additional detail"*.

However, it is important to consider the fact that, individuals form their own cognitive map about real world. It is difficult to understand how these cognitive maps or mental representations formed for there is no way of measuring them at least at this thesis level. Factors such as viewers' prior knowledge, past experience etc. also influence information intensity or amount of information presented in visual displays. The degree of viewers' familiarity to a scene determines the information intensity of the scene and their interpretation (Kulhavy, 1996).

2.5 Conclusions

It is difficult to find one specific definition for information. The same thing applies to information intensity. It may have different meanings according to the definitions of information in different disciplines. Paragraph 2.2 pointed out that Visualisation, Cartography, GIS and Information Science have close interdisciplinary relation. Therefore, this chapter considers the definition of information given by these disciplines to define information intensity. All the definitions given so far in these disciplines have one thing in common i.e. information is an output or a thing or something concrete in the visual representation. Hence, in 3D geo-visualisation, information intensity is the amount or degree of visual forms of a geo-data displayed in a 3D scene.

Chapter 3: Methods to Measure Information Intensity from Geo-visualisation

3.1 Introduction

In the previous chapter a short over view has been given on how information is interpreted and used in different disciplines. It is also pointed out that it is possible for information intensity to have different meanings according to the understanding of information. However this thesis sticks to the definition of information intensity as the amount of visual forms of the geo-data displayed in a given 3D scene.

The geo-data passes through different cartographic process before it is displayed in a scene. Due to these processes it is obvious that there will be a difference between information intensity of the geo-data and the graphic display; 2D and 3D scene. Before concluding that data conversion decrease or increase information intensity, it is wise to see how geo-data are transformed into visualisation and what processes are involved. This chapter has four parts; the first part will explain what processes are involved geo-data transformations, second part discusses how information intensity can be measured, the third part is a case study and the last part presents the results and conclusions of the case study.

3.2 Conversion of geo-data in to a 3D visualisation

Today, the availability of digital geo-data and rapid development of computer technologies made 3D representation of reality possible in the field of geo-visualisation. Since reality presents vast and detailed information, it is difficult to represent the whole data at one time. Thus there is a need to reduce the detail and scale of the geo-data. Reduction involves two main consecutive processes; selection and generalization. According to the traditional cartographic process, selection takes first and the selected objects are generalized depending on the purpose and required scale of representation (Timpf, 1995). To ensure that the phenomenon being represented is shown effectively some part of the geo-data has to be filtered.

There is always the risk of unclear visualisation or miscommunication in mapping unprocessed data (Kraak and Ormeling, 2003). Monmonier (1996) in his book of “How to Lie with Maps” stated generalization is important to represent 3D realities in 2D maps. He emphasized the necessity of generalization as *‘Indeed, a map that did not generalize would be useless.’* Monmonier said this for 2D representation of realities; however 3D representations are not exceptions to the idea of generalization (Forberg and Mayer, 2002). In 3D visualisation there is generalization of features with height in to one type of extruded objects irrespective of their variations in reality.

3.2.1 Cartographic transformation

There are two simple types of cartographic transformation; map projections and generalization (Perkal, 1958 as cited in Tobler, 1979).The first one involves mathematical operations to represent the surface of the earth on maps where as the latter involves a purposeful reduction of details in the process of representing some aspects of the reality. This chapter focuses on the second part of cartographic transformation; Map generalization. Even though Perkal categorize cartographic transformation in two parts, Tobler (1979) agreed that the entire process of making and using map is a sequence of transformations. According to Monmonier (1996); Davis (1999); Kraak (2003), the sequence of transformations can be divided in to two:

- Spatial transformations/Graphic generalization
- Attribute transformations/Conceptual generalization

Spatial transformations:

This type of generalization is comprised of sub processes namely *Selection, Simplification, Enlargement, Displacement, Merging* etc. These processes deals with the geometric component of geospatial data but have no effect on the symbology. It should be noted that there are different types of graphic generalization for point, line and area features. This thesis makes no attempt to provide further explanation on the different types of graphic generalization.

Attribute transformations:

Also known as conceptual or content generalization, involves process of *Selection* and *Classification.* These processes are linked to the attribute component of the data resulting change of symbology. This thesis is rather interested on content generalization and attempts to find out if it has any effect on information intensity.

There are factors to be considered before carrying out any kind of transformations. The map purpose and required scale are decisive factors for each decision to be made in cartographic process. "*Scale is a central factor in the traditional cartographic process. The map scale like other design choices is governed by the map purpose. …Scale is of central importance as it acts as a filter for the information content of the map*" (Morehouse, 1995, p.22-23). That is, the choice of a map scale determines the level of detail or the amount of information to present on a map Scale in this sense refers to the exaggeration or compression applied to features so as to have proportional representation of reality on maps (Joăo, 1998).

Nowadays, with the current web technology such as Google Earth, GIS and others, Level of detail is used. The digital world offers the option of zooming in/out to visualize different details. As a result the principle of generalization becomes dynamic. " *However, the scale at which the original data were digitized is still a limiting factor for the amount of features, shapes, level of detail,.., that the user can see*" (Joăo, 1998, p.3). The required detail has to be specified i.e. choices have to be made on what will be seen and at what level of detail.

Depending on the required scale, there is a need for generalization or omission of features from the representation. Such actions require decision of the cartographer or author of the representation (Monmonier, 1993). This leads to another factor called *subjectivity*. Different individuals, including cartographers, map authors and others, have own decisions regarding selection and classification of attributes for the same geo-data. The difference in individual decision results different information content among the classification results and between the geo-data and the classification results. "*The practice of generalisation is often described as 'subjective' because individual cartographers use their knowledge and judgement to carry out processes of selective omissions, simplification and so on"* (Keates,1989, p.40).

Different countries or mapping agencies have different map-making procedures and cartographic traditions. This in turn contributes to the subjectivity factor. In addition to the cartographer own experience and perception each decisions made by cartographers is under the influence of either the cartographic tradition of their country or specific rules of mapping agency (Joăo, 1998).

3.3 Measuring Information Intensity

It is important to clearly state what is being measured. This thesis attempts to measure information intensity in three levels. These three levels are taken from the three levels of information mentioned in chapter two. The first level measures information intensity of the geo-data, second level measures information intensity of the visualisation of the geo-data: 2D and 3D of the same geo-data. The third level measures information intensity of a visualisation in relation to users' perception.

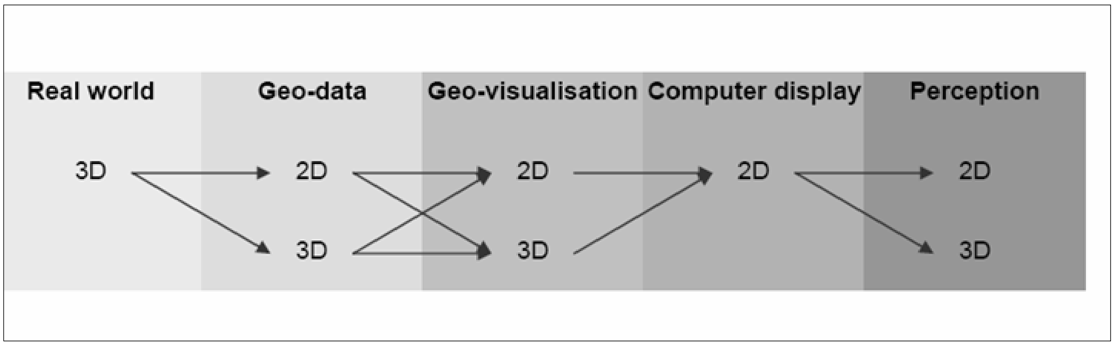


Figure3. 1: From 3D real world to 2D or 3D perception of a scene (Lammeren et al., 2007)

As figure 3.1 by Lammeren et al. (2007) depicts, geographic phenomena gathered from the real world can be saved in the form of 2D or 3D geo-data. The saved geo-data can be visualised using 2D or 3D visual transformation. Depending on the type of transformation, users will have 2D or 3D perception about the geo-data they visualise. This chapter focuses on information intensity of 2D geo-data and its 2D visualisation. Information intensity of 3D visualisation of the geo-data will be discussed on the next chapter.

3.4.1 Information Intensity of Geo-data

Shannon Entropy [1] is one of the most well known information measure. Claude Shannon, "the father of information theory" is the first person to quantifying information using *bits* in his mathematical theory of communication (Shannon et al., 1969, p.32; Ebanks et al., 1998, p.1-3).

$$Hn\,(P) = \sum_{i=1}^{n} \mathrm{Pi}\ \log P_i \qquad [1]$$

Where, P is the probability, for this thesis, the probability of the objects of the Achterhoek data to fall in to its thematic classes.

Shannon's theory can be adopted in this context to measure the information intensity of the geo-data. In this example I make use of available geo-data like land cover types, roads, housing data of Achterhoek, part of the Netherlands, with cartographic scale of 1:50000 and Digital Elevation Model (DEM) of the same extent with 5 meter resolution.

Achterhoek data has number of attributes. It is meaningless to include all attributes of the dataset in the calculation. Some of the attributes are not even part of the observation or measurement from reality such as FID (Feature Id), TDN_CODE, TOPO_CODE, etc. FID is automatically generated number and has nothing to do with reality. TDN_CODE and TOPO_CODE refer to the same thing as TDN_ENG i.e. the English description of thematic classes. Attributes included in the calculation are: from the thematic attributes TDN_ENG and from the geometric attributes GEOM_AREA and GEOM_LENGHT.

In some literature, for instance Pelaez (2000), information content (*I)* of attributes associated with ratio or interval measurement scales is calculated differently. The fundamental of the calculation is still based on Shannon entropy but it considers range and precision of the scale.

$$I = \log_2 {}^{(\text{range / precision})} \qquad [2]$$

Where, range refers to the difference between maximum and minimum attribute value and precision to the smallest accurate measurement.

However, in this calculation there is a probability of having both the maximum and minimum value from the same thematic class. In such cases it is not convenient to compare two data sets with different number of thematic classes. Despite the different number of thematic classes; there is a possibility of having the same information intensity (*I*) if they have common thematic classes with maximum and minimum values. Therefore, in this chapter the same entropy calculation for both thematic attribute with nominal scale and geometric attribute with ratio scale is used.

Thematic information intensity ($I_{Thematic}$)

$$I_{Thematic} = \sum_{i=1}^{n} \text{Pi} \ \log P_i \qquad [3]$$

Where, P is the probability, for this case the probability of the objects to fall in to the thematic classes of Achterhoek data

Concerning the geometric information, this thesis focuses on the size of objects only i.e. area and length attributes.

Geometric information intensity ($I_{Geometric}$):

$$\text{P}_\text{i} = \frac{\text{An}}{A} \qquad [4]$$

$$\text{P}_\text{i} = \frac{\text{Ln}}{L} \qquad [5]$$

Where, P is the probability, An and Ln are area and length of n^{th} object respectively and A and L are the sum of area and length of n objects respectively.

$$I_{Geometric} = \sum_{i=1}^{n} \text{Pi} \ \log P_i \qquad [6]$$

For equation [6], Pi can be calculated separately based on equation [4] and [5]

Shannon's theory assumes that outcomes of an experiment or in this context geo-data entities, are independent of each other and do have an equal probability of occurrence. These assumptions may not always hold true for spatial data. However the information contained in the Achterhoek data is first level information. Since it is not converted in to visualisation, the spatial relationship is not yet recognized.

3.4.2 Information Intensity of Visualised Geo-data

The information intensity of visual displays is quite different from the information intensity of the geo-data. The conversion of geo-data to 2D visual displays involves number of factors. Depending on the type of projection, generalization and scale factor used the thematic and geometric value of the geo-data as well as the information intensity of the 2D map varies.

Scholars like (Sukhov, 1967 and Neumann, 1987 as cited in Li, 2002) are the pioneers in applying Shannon information theory to cartographic communication. Recently Li (2002) introduced new sets to measure the information content of maps. He came up with a new line of thought to measure information content of maps from their symbols using *Voronoi diagram.* The approach is based on the basics of Shannon entropy. Li (2002) classified information content of a map in three groups and developed a set of measurements for each.

- (Geo) Metric
- Topological
- Thematic information

<u>(Geo) Metric:</u>

This type of information measure considers the space occupied by map symbols. The space occupied by each symbol has an inverse relation with the information content of the map. If the space occupied by each symbol is similar then the map has higher information content. If the space occupied by each symbol is different then the map has lower information content. This can be obtained by using a *Voronoi diagram*. Metric entropy calculates the probability mentioned in Shannon entropy as:

$$P_i = \frac{Si}{S} \qquad [7]$$

Where S is the whole area and S_i is the area of the Voronoi region.

Based on this, Metric entropy *H (M)* is defined as follow:

$$H\,(M) = H\,(P_1, P_2 \ldots Pn) = \epsilon \sum_{i=1}^{n} \mathrm{Si/s}\,(lnS_i\ \epsilon\ ln\ S) \qquad [8]$$

Moreover, Li (2002) pointed out that this type of information measure is dependent on number of symbols of a map. In case of maps with different number of symbols, he suggested normalizing entropy as follows:

$$H(M)max = H(P_1, P_2 \ldots Pn\ /\ _{P1=\ P2=\ldots=\ Pn}) = log_2\ ^n \qquad [9]$$

$$H\,(M)_N = \frac{H(M)}{\mathrm{H\,(M)max}} \qquad [10]$$

Where, H(M) is geometric information , H(M)max is maximum geometric information and $H(M)_N$ *refers to normalized geometric information.*

Topological:

The topological entropy of a map is computed by generating d*ual graph (triangulation)* of *Voronoi region.* The calculation is based on the number of neighbours for each vertex of the dual graph. To indicate the *complexity* of a dual graph, the average number of neighbours for each vertex is used. The average number for each vertex is calculated as follows:

$$H_T = N_s / N_T \qquad [11]$$

Where, H_T *is topological entropy,* N_s *is sum of numbers of neighbours for all vertices and* N_T *is the total number of vertices in a dual graph*

Thematic information:

As the name itself indicates this type of measure is based on the thematic types of features. The *Voronoi diagram* is also used in this measure to define neighbours of thematic features. If a symbol has neighbours with different thematic type then the information content of such symbol is regarded as higher. If a map has more such type of symbols i.e. symbols with higher information, then the thematic information content of that map will be higher. The thematic information of i^{th} map symbol H(TM) is defined:

$$P_j = n_j / N_i \quad j = 1, 2 \ldots M_i \qquad [12$$

$$H_i(TM) = H\,(P_1, P_2 \ldots P_{M1}) = \epsilon \sum_{i=1}^{n} \mathrm{nj/Nj}\ \ln\,(\mathrm{nj/Nj}) \qquad [13]$$

Where, P_j *is probability of* j^{th} *neighbour,* n_j *is neighbours of* j^{th} *thematic type,* N_i *is total neighbours for* i^{th} *map symbol, and* M_i *types of thematic neighbours*

The *Voronoi diagram* is explained as "*the only and currently available*" solution to describe the relation between spatial objects (Gold, 1992 as cited in Li et al., 1999). It is also mentioned that there are two ways of computing a *Voronoi diagram*: Vector-based and Raster-based. However, most existing methods of vector-based Voronoi diagrams face shortcomings when it comes to line and area features (Li et al., 1999). The absence of empty space between line and area features makes the practicality of the method even more complicated.

Li (1999) came up with innovative idea of extending the raster-based methods so they can easily be used for line, area and other complicated objects. Because it is out of the scope of this thesis, there will be no further explanation on the different types of Raster-based methods.

Even though Li's information content calculation is based on Shannon entropy like this chapter, his approach is in reverse direction to this thesis approach. Li's approach is map based approach in which the graphics are scale dependent metrics whereas this thesis has database approach where the table metrics are similar to real world. Li's approach is entirely based on map symbols and their *Voronoi* region. In all the three measures, information content of maps is measured from their symbols. The *Voronoi diagram* is employed to identify the closest features i.e. neighbours for each feature because the space between map symbols is assumed to be empty (Lee et al., 2000 as cited in Li, 2002). For data set with no empty space between its features like the case of Achterhoek data, *Voronoi diagram* based calculation of entropy can not be applied.

To find out the effect of data conversion (transformation of geo-data to visualisation) on information intensity comparison is made between information intensity of the geo-data and 2D-visualisations of different classifications. The comparison is limited to thematic and geometric information only.

3.4.3 Information Intensity of Visualisation in relation to users' perception

The third level of information intensity is difficult to quantify. It is very different from Shannon's concept of communication i.e. sending signal from a source and measuring the information content of the received message at a destination. When it comes to visualisation, individuals have their own way of interpreting maps and graphics. The human visual perception plays important role for effective visualization and interpretation (Dastani, 2002). Besides, there are number of factors influencing perception of visual displays: context, attentional focus expectations, prior knowledge, past experiences and subjective biases (Healey et al., 1999 as cited in Wunsche, 2004). In general, these numbers of factors can be labelled as the personal stock of knowledge. Thus, chapter five will discuss the third level of information intensity in relation to users' visual perception and stock of knowledge.

3.5 Cartographic Information

In paragraph 3.2, it is indicated that the process of data conversion in general and generalization in particular results change of information from reality. Paragraph 3.2.1 lists factors that affect content generalization and result in different out puts. Of these factors, a classification standard by different countries is considered. Since the data used in this chapter is from part of the Netherlands, it is feasible to consider classification standards of different European countries. Besides, recently the European Commission is intending to synchronize map layouts of the different European Union countries.

I have managed to get official legends (1:50000 topographic maps) of six European countries; Belgium, France, German, Netherlands, Portuguese, and United Kingdom. Three are purposefully selected; Belgium, Netherlands, and United Kingdom. The first two countries do have an English translation for their legends. Achterhoek data is classified according to the official legends of these three European countries and converted to 2D maps. ArcMap of the ESRI ArcGIS 9.2 is used to present the 2D maps of the Achterhoek.

3.6 Results

In this chapter the results of the information intensity calculation are present in two levels as follow:

3.6.1 First level of Information Intensity

The first level of information intensity is measured according to Shannon's entropy and based on the Achterhoek data. It offers the following results.

Achterhoek data includes land cover data with 16 thematic classes, road data with 11 thematic classes and house data with 2 thematic classes. Regarding the geometric attributes, data with polygon entities i.e. land cover and housing data have both GEOM_AREA and GEOM _LENGHT attributes. Whereas, data with polyline entities i.e. road data has GEOM _LENGHT attribute only. The thematic classes are according to Netherlands Ordnance Survey standards.

Table 3. 1: Information Intensity of Achterhoek data

Data Type	Thematic Information	Geometric Information	**Total**
Land cover	2.76 bits	20.97 bits	23.73 bits
House	0.34 bits	21.6 bits	21.94 bits
Road	2.54 bits	11.49 bits	14.03 bits
Total	5.64 bits	54.06 bits	59.7 bits

It should be taken in to consideration that the unit *bits* refer to information intensity i.e. the amount of information actually contained in the Achterhoek data.

3.6.2 Second level of Information Intensity

The second level of information is measured from the 2D visualisation of Achterhoek data. The data are classified according to the classification standard of three countries. The thematic classes of each data are generalized according to the respective country's official legend of 1:50000 topographic maps.

Table 3. 2: Number of Thematic Classes

Countries	Land cover	Road	Housing
Netherlands	13	9	2
Belgium	9	7	1
United Kingdom	6	8	1

The three countries' official legends are different not only in their number of thematic classes but also in the colourings used to represent the different landscape features. The difference can be associated with number of factors however it is outside the scope of this thesis. For the sake of simplicity and clarity, this chapter used same colouring for the three classifications.

Figure 3.2 depicts the classification standard of the three countries with different number of thematic classes. The difference in classification standard resulted different information intensity for the same geo-data. Information intensity is calculated for each data set: Housing, road and land cover data.

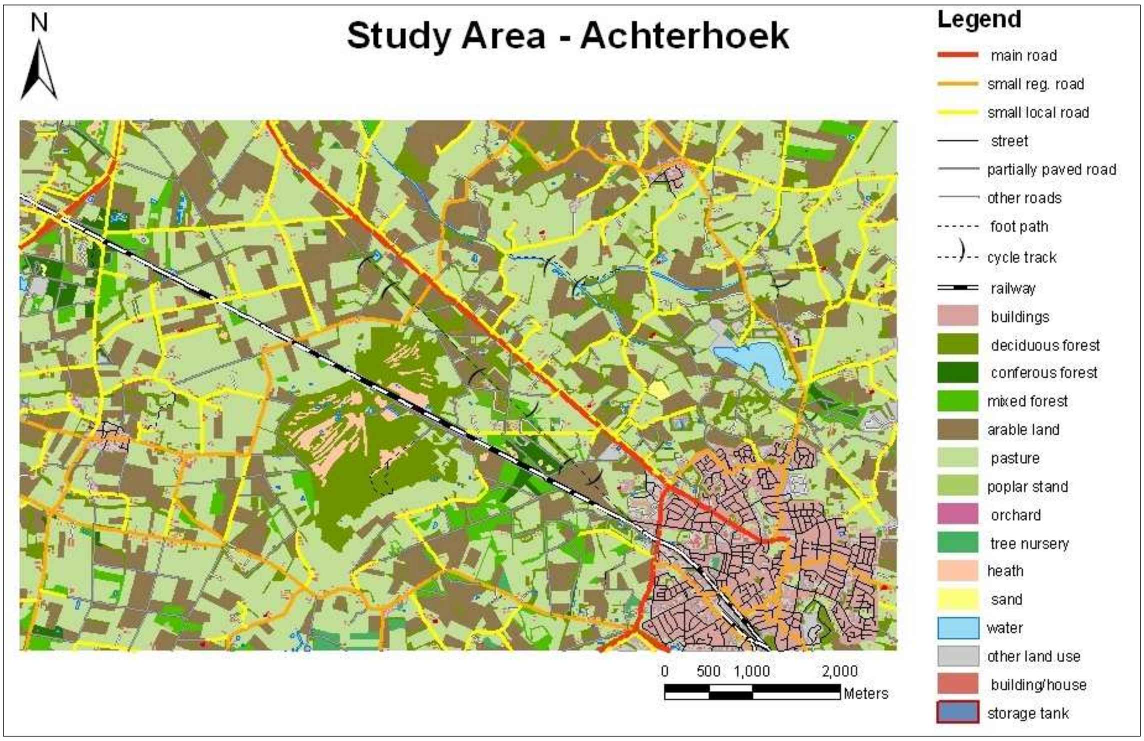


Figure 3.2 a: Netherlands classification

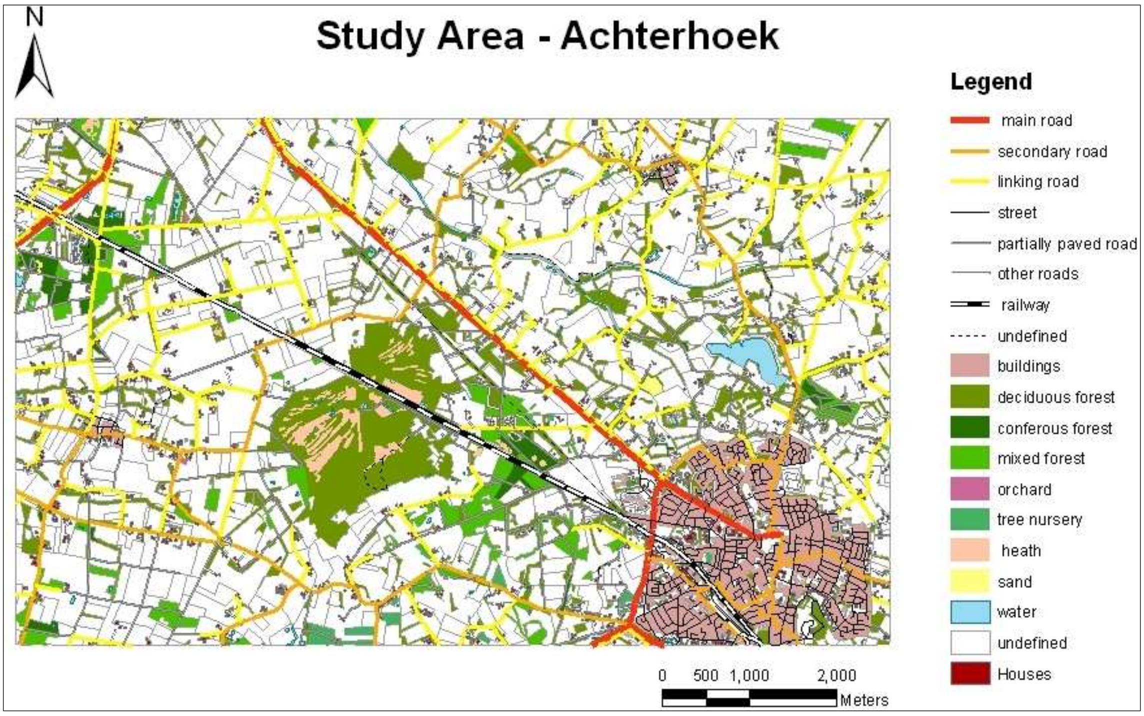


Figure 3.2 b: Belgium classification

The legend 'undefined' refers to the data that are available in the Achterhoek data set but they don't have legends according to Belgium 1:50000 topographic legends.

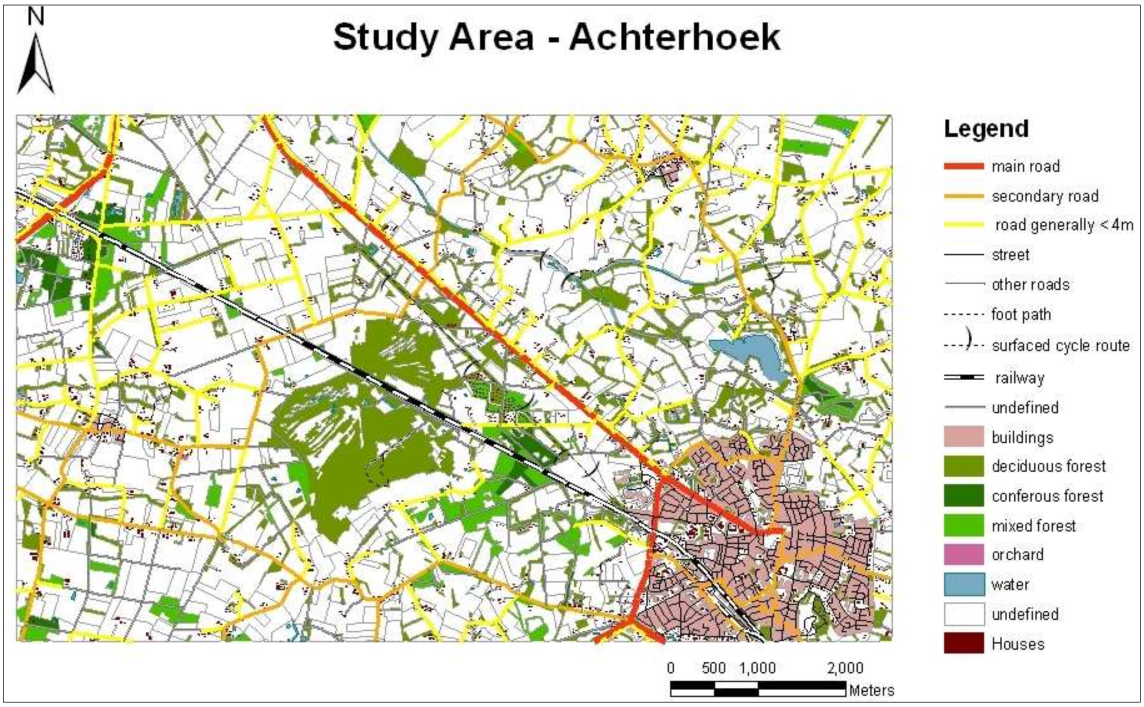


Figure 3.2 c: UK classification

The legend 'undefined' refers to the data that are available in the Achterhoek data set but they don't have legends according to UK 1:50000 topographic legends.

Since map is a small scale representation of reality (geo-data) what we see from maps, especially the geometric aspect is totally different from what we know from reality. This is due to two main reasons: The first one is the geometric distortion which is introduced by map projection. The data set used in this thesis has small extent with local projection. Thus, the distortion is insignificant. The second reason is the scale used. The geometric value of the 2D visualization is a scale reduction of the geo-data. However the scale reduction has no effect in the probability calculation of Shannon entropy.

Table 3. 3: Information Intensity of Housing data

Classification	Thematic Information	Geometric Information	**Total**
Netherlands	0.34 bits	21.6 bits	21.94 bits
Belgium	0 bits	21.6 bits	21.6 bits
United Kingdom	0 bits	21.6 bits	21.6 bits

Geometric information is calculated as the sum of information intensity of area and length value of each record.

Table 3. 4: Information Intensity of Road data

Classification	Thematic Information	Geometric Information	**Total**
Netherlands	2.48 bits	11.49 bits	13.97 bits
Belgium	2.40 bits	11.21 bits	13.61 bits
United Kingdom	1.99 bits	8.57 bits	10.56 bits

Geometric information is the information intensity calculated from length value of each record.

Table 3. 5: Information Intensity of Land cover data

Classification	Thematic Information	Geometric Information	**Total**
Netherlands	2.72 bits	20.97 bits	23.69 bits
Belgium	1.56 bits	7.32 bits	8.88 bits
United Kingdom	1.40 bits	6.93 bits	8.83 bits

Geometric information is calculated as the sum of information intensity of area and length value of each record.

Table 3. 6: Total Information Intensity of the Achterhoek Visualisation

Classification	**Total**
Netherlands	59.6 bits
Belgium	44.09 bits
United Kingdom	40.99 bits

Total equals to the sum of the total information intensity of each data type.

The total information intensity of the geo-data is different from the total information intensity of the 2D visualizations for each classification. Belgium's and United Kingdom's official legend does not have 'Arable land', 'Pasture', and 'Poplar' land cover. In addition 'Sand' and 'Heath' land cover types are not available in UK official legend. In the same way, in the road classification, Belgium's official legend does not have 'Cycle track' and 'Foot path' and UK's official legend does not include 'Paved road'. Concerning the housing data, Belgium's and UK's official legend does not have 'Storage tank'.

Table 3.3, 3.4 and 3.5 indicate that, the difference in number of thematic classes for the same geo-data extends to noticeable difference in thematic and geometric information intensity.

3.7 Conclusions and Discussion

Shannon's information theory is used to measure information intensity from the Achterhoek data and its 2D maps of different classification. Shannon interprets information content in terms of *bits.* The theory is based on assumption of equal probability and occurrence of events which is not always true in case of spatial data.

Due to the attribute transformation involved in the data conversion and the different classification standards used, information intensity of the geo-data is different from the information intensity of its 2D maps. The different classification standards have different thematic classes which lead to different thematic and geometric information intensity. For instance, Netherlands classification has two thematic classes of the housing data whereas; Belgium and UK classification has only one type. For Belgium and UK classification, the probability of all the houses to fail in the category of one type of thematic class is one.

The result '0 bits' may seems unusual or meaningless however; information content can also be explained in terms of variance. Miller (1956) stated that "*When we have a large variance, we are very ignorant about what is going to happen. If we are very ignorant, then when we make the observation it gives us a lot of information. On the other hand, if the variance is very small, we know in advance how our observation must come out, so we get little information from making the observation*". When it comes to geo-visualisation, feature or object with one type of thematic class has zero thematic information.

The entropy calculation is based on the number of thematic classes particularly for the thematic information. Thus, the same geo-data can have different information intensity based on the type of cartographic transformation used and classification standard. Based on this justification, one can conclude that information intensity of a 2D visualisation varies depending on its content generalization. In other words, the different cartographic processes involved in the data conversion have a direct effect on information intensity.

Concerning the geometric information, this thesis decided to use same probability calculation for the metric attributes regardless of their measurement scale (see equation [4] and [5]). If Pelaez (2000) information calculation [2] were used, the land cover data will have the same geometric information in all the three classifications despite the different number of thematic classes.

For instance, the land cover data has 13, 9 and 6 thematic classes based on Netherlands, Belgium and United Kingdom classification standard respectively (see Table 3.2). However, in all the three cases, water is the smallest landscape feature and deciduous forest is the largest landscape feature. If we consider the range in the geometric information calculation the land cover data will have same range value and same geometric information. Nevertheless this can not true because the data has different thematic classes. The same thing is true for the road data.

In addition to the above limitation, information calculation based on range values can not represent the information intensity of the entire dataset.

Chapter 4: Measuring Information Intensity from 3D Geo-visualisation

4.1 Introduction

This chapter starts with an overview of the difference between 2D and 3D presentation. Then it discusses related topics to the appearance of a scene such as graphic variable, scale and level of detail. Finally, it attempts to measure information intensity of 3D geo-visualisation based on Shannon entropy.

4.2 3D Geo-visualisation

There are different ways of presenting the real world. 2D and 3D geo-visualisation are the main categories of visual representation. As it was mentioned in the first chapter, a geo-visualisation can be defined as a three dimensional representation of geographically referenced data (Hoogerwerf, 2005).This particular definition of geo-visualisation best fits to 3D geo-visualisation.

2D maps represent geographic phenomena and spatial features of the earth always as a flat plain. When it comes to features with the third dimension i.e. height, it is very difficult to understand 2D maps. On the contrary, 3D maps represent geographic phenomena in a more naturalistic way to the real life situation. 3D maps are expected easy to understand and interpret (Kraak, 2002a).

Before the development of interactive geo-visualisation in GIS, static (print) maps were the most commonly used tools by researchers to explore and analyze geospatial data (Kraak, 2002b). However, from the 1990s on ward advancements in computer and related technologies made the transition from static to interactive maps successful. When compared to 2D environments, 3D environments offer more realism, perspective view, better understanding and higher degree of freedom for users' interaction (Lammeren et al., 2004). There are number of ways to view 3D scenes. In general terms, we can classify it as passive or still and active or flying, walking through for instance by VRML, ArcScene or Google Earth. The still 3D scene in turn can be viewed in a number of ways: birds' eye view, frog view, human view, etc depending on its projection.

Viewers may select different viewpoints to explore a scene based on their purpose of visualisation. Viewpoint in this context refers to the relative position of a viewer or camera to a scene. This variety of viewing has direct effect on the amount of information obtained from a scene because it determines the number of visible objects and details. For example, a still scene with perspective projection will significantly influence the perception of the visualised objects, because some objects are partly covered by others. Number of research works has been conducted on determining the best viewpoints (Vazquez et al., 2003; Sbert et al., 2005).

4.3 Graphic Variables

Visual variables play an important role in the representation as well as in the perception and understanding of information in both 2D and 3D visualisation. Wunsche (2004) indicated that visual attributes connect the two steps of visualisation process i.e. encoding and decoding. According to (MacEachren et al., 1992) definition of geo-visualisation, the power of human visualisation is associated with the appearance of a representation.

Hardisty et al. (2001) described visual variables as the fundamental building blocks of 3D scenes. Bertin visual variables include size, shape, colour, texture/grain, location and orientation (Hardisty et al, 2001; Heaberling, 2002). The importance of visual variables in a scene is depicted in different ways. Heaberling (2002) indicated a group of parameters called graphic aspects influences the appearance of objects in 2D or 3D maps. The graphic aspects are grouped in three: modelling, symbolization and visualisation and each of them include one or more visual variables. A 3D scene can be described by three elements: the scene composition, light sources, and camera or eye view (Hardisty et al., 2001). Furthermore, the visual appearance of a scene can also be explained in terms of visual variables. Hardisty (2001) divided the visual variables in to two categories:

- ‘Tactual’ properties
- ‘Purely Visual’ properties

4.3.1‘Tactual’ properties

The Tactual properties of visual variables refer to objects detected by feeling such as shape, size, location and orientation. It is obvious that in the domain of visualisation there is no room for non-visual senses. This chapter is not interested on such properties are not of interest in this chapter.

- Shape: objects in a 3D scene can have different shapes; simple to complex based on the number of faces involved.
- Size: refers to the relative difference between objects in a scene
- Location: refers to the exact position of objects and features of a 3D scene on Earth

- Orientation: represents the rotation of objects around x, y and z-axis.

4.3.2‘Visual’ properties

As the word *visual* indicates, these purely visual properties are only identified by visualizing. The purely visual elements of a 3D scene include colour, visual texture, transparency and reflectance.

- Colour: is qualitative visual variable used to represent objects of different thematic class.
- Texture: is the most important variable that gives realistic effect to features and objects.
- Transparency and Reflectance: even if Bertin did not mention these two variables in his discussion, they are the special aspects of visual variables that play important role in the visibility of a display.

Each graphical object and their visual attributes of a 3D scene represent information. In this regard, related works show that visual attributes have different information content. Wunsche (2004) classified visual attributes based on their *information dimension* and *spatial requirement. Information dimension* refers to the number of dimensions inherent in the visual attribute *and spatial requirement* refers the smallest unit of space needed to identify a piece of information .This paper is interested on the information content of each visual variable. The following table by Wunsche shows the classification of visual variables.

Table 4. 1: Classification of common visual attributes

	Information dimension	Information accuracy	Spatial Requirement (dimension)	Information content	Information density
Position on scale	1-3	High	Low(0)	High	High
Length	1	High	Medium(1)	Medium	Low
3D Direction	2	Medium	Medium(1)	Medium	Medium
Area	1	Medium	Medium(2)	Low-Medium	Low
Volume	1	Medium	High(3)	Low-Medium	Very Low
Shape	> =3	Low-Medium	High(3)	Medium-High	Medium-High
Texture	>=3	Low-Medium	Medium (1-3)	Medium-High	Medium-High
Colour	2	Low	Low (>=0)	Medium	High

Source: Wunsche 2004

Information content is Information accuracy multiplied by Information dimension and Information density is Information content divided by spatial requirement.

Wunsche used subjective ranking as high, medium, low and very low to compare the information accuracy, spatial requirement, information content and density of each visual attributes. He also used objective description in terms of number of dimensions needed for information dimension and spatial requirement (Wunsche, 2004).

4.4 Scale and Level of detail

The word 'scale' in the domain of geo-information science is one of the most ambiguous words. "*Scale is used to refer both to the magnitude of a study (e.g., its geographic extent) and also to the degree of detail (e.g., its level of geographic resolutions)*" (Goodchild and Quattrochi, 1997, p.1). According to Montello and Golledge (1999), scale has multiple meanings such as absolute size, relative size, resolution, granularity, and detail. As it was mentioned in paragraph 3.2.1, in digital representations, the traditional cartographic definition of scale loses its meaning because users have the option to zoom in and out. "*In a truly scalable 3D environment, as a general rule, there are always multiple resolutions or representations per 3D view*" (Nebiker, 2003). In interactive 3D geo-visualisation, the notion scale is replaced by the notion level of detail (LOD). Number of applications requires graphical presentations of varying scale. Scale is one of the factors that determines information intensity or level of detail of both 2D and 3D presentations (Kraak, 2002). It is obvious that zooming in offers the opportunity of visualizing objects or part of a scene at closer distance. On the other hand, the extent of the displaying screen hinders the possibility of visualizing the entire scene in detail.

4.5 Case Study

4.5.1 Method

This chapter compares information intensity of different 3D visualisation based on Shannon entropy. The Achterhoek dataset and DEM of same extent with 5 meter resolution are used. There are different transformations of geo-data into 3D scenes:

1. simple extrusion of features with height from the geo-data (2D + Extrude)
2. drape 2D representations on DEM of the same extent (2D + DEM)
3. drape 2D and extrude features height (2D + DEM + Extrude)
4. use 3D textured objects instead of simple extrusion (2D + DEM + 3D Objects)

Information intensity of a 3D scene varies with the type of transformation method used because each method provides different level of detail. Choosing an appropriate transformation method is not always simple task. It depends on the required level of detail and application of 3D visualisation. Even thought it is not the intension of this chapter to provide detailed explanation of each method, it points out the basic differences. In general, method 3 gives better 3D visualisation effect than method 2 and 1. Method 4 presents objects and features with closer detail like their appearance in the real world. On the other hand, the fourth method requires greater storage space to import image files to texture each feature. Moreover, using 3D textured objects often takes longer time to render the scene. For these reasons, the fourth method is not included in the 3D scenes construction. For comparison purpose, this case study employs the second and third method of transformation in combination.

4.5.2 Procedure

Two types of transformation methods are used to create the different 3D scenes. The first method (method 2) draped the 2D map of the Achterhoek on the DEM to derive surface height for landscape features. The second method (method 3) is same as the first method but features like buildings and forest are extruded with assumed heights. Such an extrusion changes feature appearance such as line features to vertical walls and polygon features to 3D blocks. ArcMap and ArcScene of the ESRI ArcGIS 9.2 have been used to present the 2D and 3D scenes respectively. Official legends with patterns generate errors when displayed in a 3D scene. In such cases, plain colours are used to solve the problem.

In addition, the 3D scenes have different viewpoints, graphic detail and viewing parameter such as zoom factor. In this thesis context, graphical detail refers to features' appearance on a scene such as texture, extrusion etc.

Table 4.2 shows the different combination of methods, viewpoints and zoom factors used in the 3D constructions.

Table 4. 2: Methods combination

3D Scenes	Method 2	Method 3
Perspective view	1.a	1.b
Section view	2.a	2.b
Zoom	Distant view	Closer view

The first column indicates the different view types used to create the 3D scenes. In scene 1.a and 1.b, the observer and target have different surface height, i.e. Z value whereas 2.a and 2.b have same Z value for observer and target. The first row shows the transformation method. Method 3 extrudes features with assumed height. For instance, the housing data has two thematic classes: Building/house and Storage tank. They are given 10 meter and 15 meter assumed height respectively. Similarly, from the land cover data there are three types of forests: Conifer, Deciduous and Mixed with 26, 23, and 18 meter. The last row indicates relative distance of the observer. Scene 1.b and 2.b have relatively closer view than scene 1.a and 2.a.

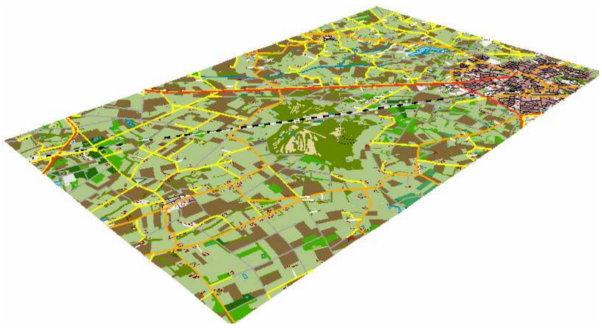
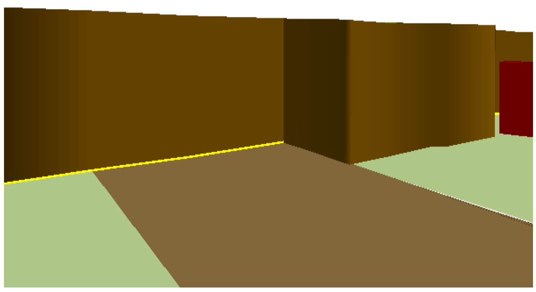
3D scenes with out extrusion	**3D scenes with extrusion**
 **1. a**	 **1. b**
2. a	 **2. b**

Figure 4. 1: Geo-visualisations used in the cast study

4.6 Results of case study

This sub chapter presents the information intensity of the different 3D scenes. The assessment focuses on thematic, geometric and topologic information intensity of the different 3D scenes.

4.6.1 Thematic Information

The same intensity calculation is used based on the number of thematic classes. The visible landscape features of the still 3D scenes are counted using the selection tool. From thematic point of view, scene 1.a has the same number to thematic classes as 2D geo-visualisation.

Table 4. 3: Thematic Information

3D Still Scenes	Land cover	Road	Houses	**Total**
1.a	2.72 bits	2.48 bits	0.34 bits	5.54 bits
1.b	2.12 bits	1.91 bits	0.08 bits	4.11 bits
2.a	0 bits	0 bits	0 bits	0 bits
2.b	1.46 bits	0 bits	0 bits	1.46 bits

4.6.2 Geometric Information

Objects in 3D visualisation are subjected to metric distortion .Due to this metric distortion the geometric information of 3D visualisation is different from 2D visualisation. The transformation of the geo-data to 3D visualisation and draping of the 2D map on DEM are the two reasons for metric distortion. The metric distortion includes reshaping of features, different outline, etc. Such distortion results change to the area and perimeter of features.

Unlike the 2D geo-visualisation, 3D scenes have additional surface height information (DEM) to the geometric information. Further more, scene 1.b and 2.b has assumed height information of extruded features. Features height information can be quantified with same Shannon entropy calculation. The calculation is same as geometric information calculation mentioned in chapter three. In real life situation each house and tree has unique height value like the area and perimeter values. However in this case study features are given assumed height based on their thematic classes. In other words features from the same thematic class have same height value. Thus the probability is calculated:

$$P_i = \frac{\mathrm{Hn}}{H} \qquad [14]$$

Where, P is the probability, Hn height of n^{th} feature and H is the sum of height of n features available on the 3D still scene.

Table 4. 4: Geometric Information Associated with Features Height

3D Still Scenes	Forests	Houses	**Total**
1.b	7.45 bits	7.70 bits	15.15 bits
2.b	1.58 bits	0 bits	1.58 bits

4.6.3 Topologic Information

Since it is difficult to quantify topologic information at this thesis level, this chapter gives only qualitative description. Landscape features in scene 1.a has similar spatial relation like the 2D maps such as left, right, near etc. Since scene, 1.a has no extruded features and significant surface height variation; it does not have the expected 3D spatial relations such as behind, in front of, etc.

For scene 2.a, it is difficult to tell about its topologic information. On the other hand, scene 1.b and 2.b have a clear 3D spatial relation. For instance, one can see houses under the trees, roads crossing behind the forest, etc.

4.7 Conclusions and Discussion

In addition to geo-data conversion, transformation methods, viewpoints and zooming factor result different information intensity of 3D visualisation. Particularly, viewpoint and zooming factor decides the number of visible objects in a given 3D scene. The different methods of geo-data transformations to 3D visualisations also determine the graphic detail of geo-visualisation. For instance, buildings and forests have different graphic detail in scene 1.a and 1.b because of the transformation method. In scene 1.a, buildings and forest features appeared as flat polygons. Whereas, in scene 1.b, the same landscape features appeared as blocks with the third dimension (see Figure 4.1). This third dimension adds to the geometric information intensity of scene 1.b (Table 4.4).

Intensity calculations of the case study confirm that 3D scenes with higher number of visible objects and graphic details exhibit high information intensity than 3D scenes with lesser number of visible objects and graphic details (see Table 4.3).

Compared to 2D visualisation of the same geo-data, results of this chapter show the thematic information intensity of 3D visualisation is the same as its corresponding 2D visualisation. See the thematic information of scene 1.a from table 4.3. In this case, even the colours used in the 3D scenes are still the same as 2D maps i.e. no texture used. However, with the change of view type and zoom factor, information intensity of 3D visualization changes.

The geometric and topologic information of a 3D visualisation is quite different from a 2D visualisation. In the 3D scenes, one can see that features are reshaped i.e. different outline, different area. In addition, one can also identify new topologies. For instance, the clear 2D relations such as left, right, on, near, etc are replaced by new relations such as behind, before, under, above, etc.

This chapter draws the following conclusion. The number of visible objects of a 3D scene and their graphic detail determines information intensity of visualization. It is true that zooming in provides more detail and realistic view. However, the extent of the displaying screen limits the number of visible objects of the scene and results low information intensity.

Chapter 5: Information Intensity in relation to user Perception

5.1 Introduction

As it was mentioned in chapter 3, this chapter discusses the third level of information intensity of 3D geo-visualization in relation to users' perception. It also attempts to answer the fourth research question.

5.2 Human perception

A number of authors Dastani (2002), Wunsche (2004), Tory and Moller (2004) emphasised human perception plays enormous role in determining users' interaction and interpretation of 3D visualisation. This signifies that people interact with a given 3D visualisation based on their "*stock of knowledge*".

Perception is defined as "*a cognitive process that is involved with detection and interpretation of sensory information*" (Lloyd, 1997, p.5). Human perception is wide topic that can not be covered in a single chapter. As a result, this chapter limits itself to visual perception only. Visual perception itself is complicated issue because it has subjective nature. "…, *different people may have different perceptions of the same picture, depending on physiology (colour blindness and other visual impairments, for instance) but also depending on prior experience and what they are 'looking for'*" (Reuter et al., 1990). There are also non-human factors that affect human visual perception: lighting conditions, visual acuity, surrounding items, colour and scale (Tory and Moller, 2004). Furthermore, presenting 3D information on 2D media poses perceptual challenge for users.

In this thesis, prior knowledge has two perspectives. The first one refers to familiarity with different visualisation techniques or generally users with GIS background. The second perspective is familiarity of users with the geo-data or visual representation of the geo-data. The degree of familiarity may range from viewing a still visualisation to more interactive visualisation. Some users may have detailed knowledge about the geo-data, via a more extensive mental map, and its visualisation to the extent of actual field visit of the represented area. As a result, a 3D scene gives different information for different viewers based on their perception and prior knowledge. In other words, the same 3D scene can have different information intensity in the viewers mind. Nevertheless, it is hard to quantify what is in viewers mind at least in this thesis. This chapter specifically focuses on the latter context of prior knowledge; familiarity with geo-visualisations and interaction.

5.3 Visual Interactions

Number of factors determines users' interaction with 3D visualisation: users' interest, purpose of interaction, perception, etc. It is obvious that different users interact to the same 3D scenes differently. Those with prior knowledge of that particular 3D scene use their prior knowledge or experience to guide their way of interaction. Verbree et al. (1999) categorized interaction with scene in to three:

- Orientation and navigation
- Selection and query
- Manipulation and analysis

The first type of interaction is the most common and simple one. Users can walk through the 3D scenes and change their viewpoints. The second type of interaction involves selecting different geo-data and deriving information from objects. The third type of interaction is more complex than the first two. It includes GIS operations like, buffer, overlay, etc to create a subset data from the already existing.

5.4 Methodology

The intention of this chapter is to find out the effect of users' 'stock of knowledge' on their visual perception and interaction. It is also interested to find out what will happen to the information intensity of a 3D scene in time of interaction. In order to achieve these objectives, this chapter uses web-based questionnaire on selected reference groups. The results will be analysed using simple statistical descriptions such as tables and more frequently charts. Finally conclusions will be drawn based on the questionnaire response.

The proposed methodology also includes sketching a mental map. Students were asked to sketch up their mental map of the Achterhoek after their field visit. This helps to measure the starting level or stock of knowledge of each respondent about the study area.

Participants of the reference group are MGI students (programme 2006-2008). The total number of MGI students is 29. Since the number is manageable, all the 29 students are included in web-based questionnaire. The groups are purposefully selected in advance for two reasons: The first reason, they have more or less the same prior knowledge of different visualization techniques; mainly GIS tools. The second reason is students have been to the village of Groenlo in the Achterhoek as part of GRS-31809 course work. The Achterhoek is the study area, which is used in previous chapters and this chapter too.

Figure 5. 1: Study Area

The red line indicates the excursion route and the green line indicates the extent of the area used for the 3D scenes of the questionnaire.

5.4.1 Questionnaire Construction

Web-based questionnaire is advantageous in terms of accessibility and saving time. Furthermore, it has the advantage of automatically saving responses to database (.mdb) by linking the web page with Microsoft Access.

The questionnaire used in this thesis has three parts. The first part has general memory recall questions about landscape features in the Achterhoek. Except the first one all the memory recall questions are open-ended questions that enable the respondents to express their visual perception freely. The questionnaire is designed to include questions about the thematic, metric and topology of the Achterhoek. This helps to compare respondents' visual perception.

1.1 How many times have you been in the Achterhoek?

A. 1-2 B. 2-5 C. More than 5

1.2 Which landscape feature you remember first?

1.3 Which landscape feature has the largest size?

1.4 What is the highest landscape feature you observed?

1.5 Which landscape features are crowd together to one area? List two features

1.6 Which landscape features are scattered in the area? List two features

1.7 Which landscape features come together or are related? For example, houses along the road. List at least three such relations that you remember.

Figure 5. 2: Part I of the Questionnaire

The second part has instant view questions. The questions are based on the 3D scenes of Achterhoek (the 3D scenes used for each questions can be seen from Appendix 2).

2.1 Which of the following three scenes is the correct one if scene 1 is viewed from point P?

2.2 Which of the following four 3D still scenes gives you the best readable information about Achterhoek landscape features?

2.3 Which landscape feature do you see first from the 3D still scene?

2.4 Which of the following 3D still scenes representation do you prefer most?

Figure 5. 3: Part II of Questionnaire

The first two parts of questionnaire were available on web on June 8, 2007 starting from 10.30A.M.

In the third part of the questionnaire it was intended to include simple and common type of interaction such as zooming, panning, 3D-rotation, and navigating through the 3D scene of the Achterhoek with the reference groups. The ArcScene documents were available on web. Instruction and related questions about the scene interaction were prepared on hard copy to be hand out for the reference groups (Appendix 3). However, it could not be implemented as intended for there is no enough response from respondents.*

5.4.2 3D Scene Construction

The 3D scenes used for the web-questionnaire are constructed from the Achterhoek dataset. The scenes are prepared with ESRI ArcScene. Different scenes are used for each question in part II of the questionnaire (See Appendix 2).

The first question has three still 3D scenes of different viewpoints Respondents are expected to use their prior knowledge of the area and visual perception to select the correct scene from these three scenes. The second question has four scenes with different viewpoint and resolution. The third question has only one 3D still scene in perspective projection. Respondents were provided with list of landscape features to select from. The fourth question has two 3D scenes; one with out extruded features and one with extruded features.

* The reference groups were informed about the third part of the questionnaire in person and through email but none of them appeared on the specified date and time.

5.5 Results of Mental Maps

Before filling out the questionnaire, participants of the reference groups were asked to draw their mental map of the Achterhoek. The mental maps were collected from all the 29 respondents to see their perception about the Achterhoek. Respondents tried to put their perception in both text and drawing formats. Even though the mental maps are different in their appearance most of them have common things. Respondents gave attention to similar landscape features such as hills, swampy areas, canals, typical houses of the area, etc. Sample of the respondents' mental map are included (Appendix 6).

5.6 Results of Questionnaire

This sub-chapter presents the results of part one and two of the questionnaire. The responses are collected on 11th of June, 2007. From 29 MGI respondents, it is only 41% who submitted their response. The responses are less than expected. For that reason results of the analysis may not be completely representative. The results obtained from the questionnaire are analyzed in Microsoft Excel using simple charts.

5.6.1 Respondents' Prior knowledge

Thought the respondents have same GIS background, their prior knowledge of the Achterhoek area is different. All the reference groups have been to the Achterhoek one to two times as part of their course work. However, 42% of the respondents have already visited the area more than two times prior to the field excursion.

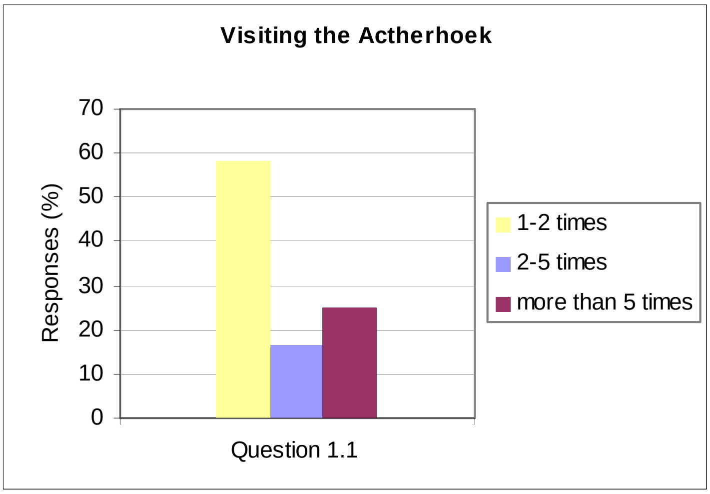


Figure 5. 4: Frequency of visiting the Achterhoek (%).

5.6.2 Respondents' Visual perception

In the first part of the questionnaire, questions 1.2 to 1.7 are particularly designed to find out respondents' immediate visual perception of the real situation in the field. In general, respondents have varying visual perception of the natural scene i.e. the Achterhoek area. Both the respondents' mental map and their response to the memory recall questions support the point (See Appendix 5).There can be many reasons for the different visual perceptions. What the respondents were looking for in time of field excursion or what (Healey et al., 1999 as cited in Wunsche, 2004) calls, as "*attentional focus*" and different prior knowledge of the area can be the responsible factors.

The effect of users' perception on information intensity of 3D scenes can be seen from the result analysis of question 2.2. Respondents were provided with four 3D scenes of same area but different view. The respondents ranked the scenes according to their information content and readability as follows:

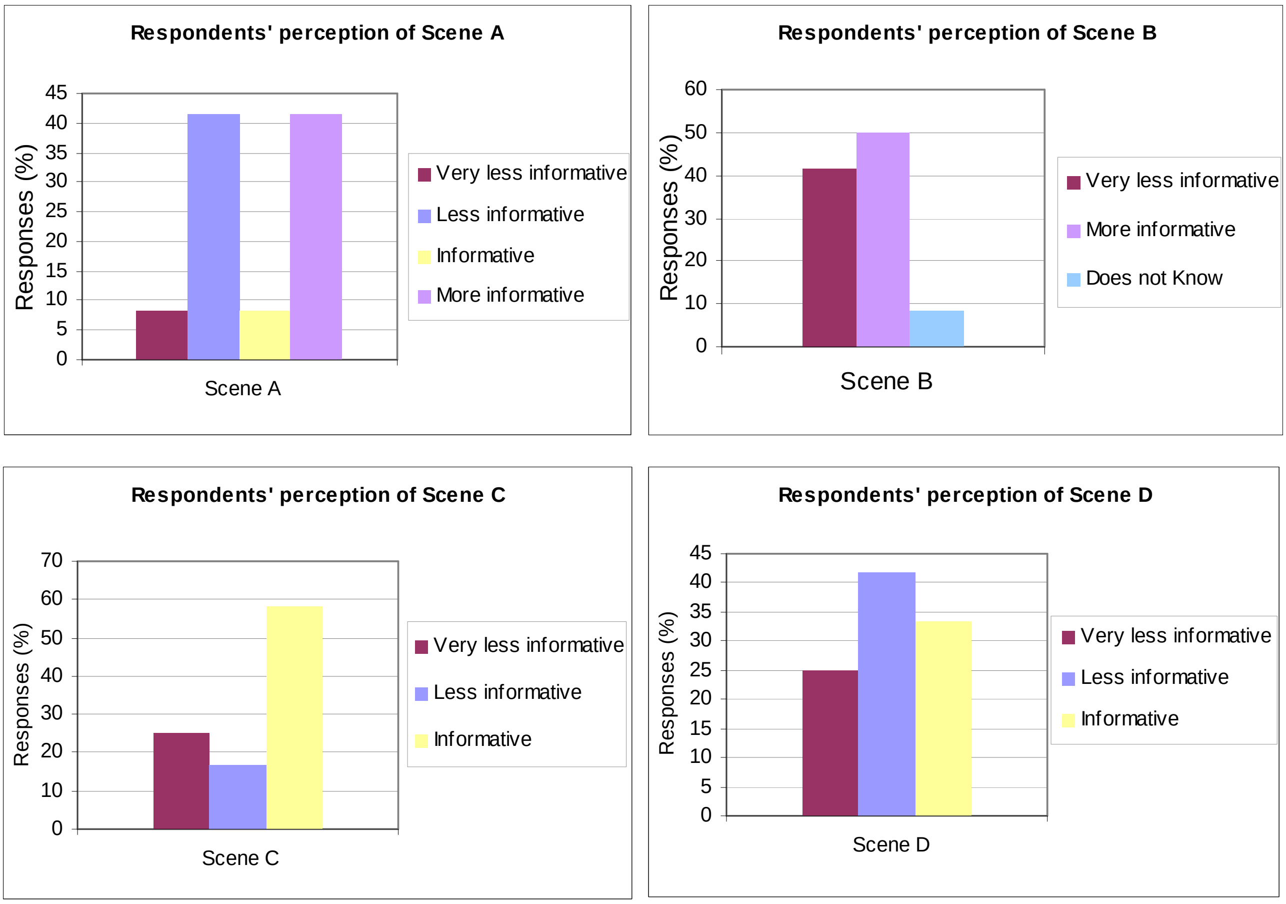


Figure 5. 5: Response to question 2.2 (%).

On the other hand, majority of the respondents have more or less similar perception of the 3D representation of the Achterhoek. Respondent were asked the same question in the first and second part of the questionnaire i.e. which landscape feature they see first. In question 1.2, respondents were not provided with 3D scene. In question 2.3, respondents were provided with 3D still scene of the Achterhoek. When the responses to both questions are compared, in general responses to question 1.2 have significant variation than responses to question 2.3. This could be due to the nature of questions. Question 1.2 is open-ended question and the respondents are free to give any answer. Question 2.3 gives list of landscape features to choose from.

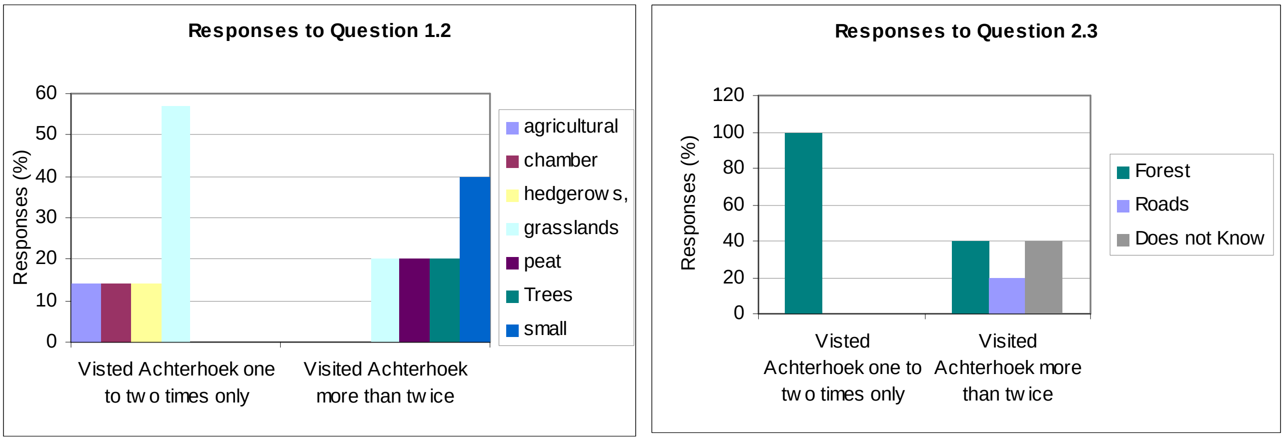


Figure 5. 6: Response to questions 1.2and 2.3(%).

In question 2.4, respondents were given two 3D still scenes. Scene A has relatively higher level of detail than scene B. Scene A has extruded forests and houses with assumed height where as scene B has no extrusion. Respondents were asked to select the representation which they prefer most. Out of the total respondents, 75% selected scene A. This is also another indication that the respondents have more or less similar perception to the 3D scene of the Achterhoek. Moreover, this contributes to the idea of Appleton (2003) that higher level of detail helps users to easily relate their visual perception of the 3D representations with the corresponding reality.

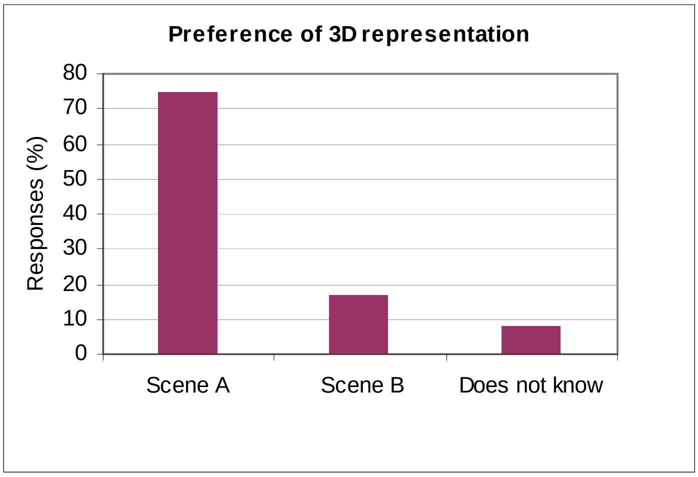


Figure 5. 7: Responses to question 2.4 (%).

5.7 Conclusion and Discussion

This chapter has discussed about prior knowledge and visual perception of participants. As shown in the result part respondents have different prior knowledge and visual perception.

Prior knowledge in general and familiarity to the study area in particular guides once visual perception. It is also expected that users' prior knowledge determines the information content of the scene in the users mind. In other words, users may think that a given 3D scene has less information if they are already familiar to the scene or to the area which is represented on the scene.

The responses to question 1.1 indicated that 42% of the respondents are already familiar to the Achterhoek .This is expected to influence their perception about the Achterhoek than the rest of the respondents who have been to the area once only.

This thesis expected that respondents who are more familiar to the Achterhoek will have similar perception than those who are less familiar. Concerning this expectation, responses to question 1.1 and 1.2 are compared. The result of the comparison indicate that, contrary to what is expected, results of 2.3 shows those respondents who visited the Achterhoek one to two times have similar response to question 2.3 .Whereas, those who visited more than twice have different answer to the same question 2.3 (Figure 5.6).

Result of question 2.4 shows, the respondents has similar perception to the 3D scene of the Achterhoek. As it was mentioned in chapter 4, the third dimension gives additional information to the geometry of the landscape features .For instance, building and forest features are more visible in scene A than scene B (see Appendix 2).

Chapter 6: Conclusions, Discussion and Recommendation

This chapter addresses the following issues: general conclusions about this thesis, discussions of main results and final recommendations about information intensity of 3D geo-visualisation.

6.1 Conclusions

This thesis is more of a reconnaissance work. Questions about information intensity of 3D geo-visualisation were asked, namely what does information intensity mean, has information intensity to deal with data conversion to 3D visualisation, and graphic detail and what will happen to information intensity at the time of users' interaction. Different methodologies were employed to answer these questions.

Based on literature search on related disciplines, this thesis came to the conclusion that information intensity can be defined in two levels. These are information intensity of the geo-data and information intensity of the visualised geo-data. Geo-data offers a certain amount of intrinsic information. From this perspective information intensity of geo-data can be defined as the total amount of information contained by geo-data. It is known that geo-data has to pass through a certain steps of transformation before it is visualised. In the process of transformation some data will be selected and converted in to visual forms for visualisation purpose. From geo-visualisation perspective, information intensity denotes to the amount or degree of visual forms of the geo-data showed on the scene. The amount of visual forms presented on a scene depends on the type of transformation used. The analysis of the results in chapter 3 signifies that before the conversion, Achterhoek data has total information of 59.7 bits (Table 3.1). However, the information content is quite different when transformed to different visualisations according to the classification standard of three European countries (See Table 3.6).

In addition to data conversion, it appeared that information intensity has relation with the graphical detail of 3D geo-visualisation. The case study in chapter 4 shows that 3D scenes of same geo-data have different information intensity for the reason that they have different graphic detail. To vary the graphic detail of the scenes, different methods of 3D scene construction, viewpoints and zoom factors were used.

6.2 Discussion

In this thesis, information intensity is defined based on the different contexts of information in different disciplines. Literature search on related disciplines such as GIS, Cartography, Visualisation, Information Science and Psychology is used to define information. Saracevic (1999) levels of understanding information and Buckland (1991) principal use of information are the basic concepts used in this thesis. Saracevic and Buckland perceived information in three levels: information as signal, mind-text interaction, context and information as thing, knowledge, and process respectively.

This thesis associated the two scholars' perception with the three parts of visualisation process namely data, visualisation and users' perception (Tory and Moller, 2004). In other words, the information content of the geo-data used in this thesis is considered as the first level of information i.e. as signal or thing, information content of the corresponding geo-visualisation as second level information and the third level of information deals with users' perception and interaction with geo-visualisation.

Shannon's information calculation is used to measure information intensity of the geo-data and the visualisations of this data in case study. Even though Shannon is the first scholar to be mentioned regarding information quantification, there are number of scholars (Sukhov, 1967 and Neumann, 1987 in Li, 2002) who are pioneers to apply Shannon's communication theory to Cartographic communication. As discussed in chapter 3, Li's approach is map driven approach mainly focused on symbols. He calculates thematic, metric and topologic information content of maps based on the number of symbols. On the contrary this thesis approach is geo-data driven. Therefore, Li's approach could not be applicable for datasets like the Achterhoek where there is no empty space between features of the data.

It should be clear that quantifying information intensity is not the main target of this thesis. However, measuring information intensity from the geo-data and geo-visualisation is necessary to answer the second research question. The result analysis of chapter 3 proves that each dataset of the Achterhoek and the visualisations have different thematic classes as a result of the different classification standards used. This in turn led to different thematic information content of the visualisations (see subchapter 3.5).

The visualisation process has subsequent stages of data transformation to visual forms and visual forms to graphical representation (Wunsche, 2004). Moreover, as it was discussed in chapter 3, there are number of factors that determine data transformation to visualisation such as; required scale, purpose of visualization, classification standards of different countries and mapping agencies etc (Monmonier, 1993; Morehouse, 1995; Joăo, 1998). These factors together with the subsequent transformation stages play important role in deciding the number of visual forms displayed on screen or any format for visualisation.

It is known that geo-data by itself contains a certain amount of information. The conversion of geo-data into graphical representation implies that part of the geo-data is selected and converted to visual attributes. Converting the original data to visual forms involves change to the semantic and geometric aspect of the data; features of the data may be reshaped or aggregated depending on the type of classification used. As a result, the information content of the geo-data and the visual representation will no longer be the same. Visualisations with more number of visual forms/graphics of geo-data will have high information intensity than visualisations with less number of visual forms.

A literature by Stamps (2003) gives explanation that can support this argument. Stamps specifies that Shannon's information entropy is the best measure of visual diversity. He demonstrated that, "*Entropy is zero if everything is the same and entropy is maximized if each thing is different. Because total sameness is uniformity, and each thing being unique is the maximum possible amount of diversity…* ". The same logical explanation of Stamp can be applied to thematic information content of geo-visualisations. Visualisations with different thematic classes have higher information content than visualisations with same thematic classes.

Another case study is used to check whether information intensity has anything to deal with graphic detail of objects in the 3D geo-visualisation or not. In chapter 4 it was underlined that graphic variables play significant role in the appearance of 3D geo-visualisation (Hardisty et al., 2001; Heaberling, 2002).

Geo-visualisations can have different graphic details, viewpoint and scale based on the required purpose. In the case study four 3D scenes of the Achterhoek are used. The scenes are purposefully made to vary in their graphic detail using different viewpoint and resolution. In this thesis, information intensity calculation depends on the number of thematic objects displayed on the scene. The visibility of these objects in turn depends on the viewpoint and zoom factor selected for that specific scene.

Vazquez (2003) in his concept of *viewpoint entropy* explained it in detail that the amount of information captured from a scene is dependent on viewpoint selected. It is obvious that perspective view offers the possibility of viewing the entire scene which gives high information intensity. On the contrary, section view hinders entire view resulting low information intensity. In section view, small objects are hidden by large and tall objects of the scene (see figure 4.1). As a result 3D scenes of the same extent but different viewpoints have different information intensity.

Verbree et al (1999), Koua and Kraak (2004) indicated zooming in and out helps to adjust the level of detail and enhances exploration of geo-visualisation. Google Earth and other visualisation soft wares show that zooming in offers more detail about the different objects in the scene. On the other hand, the displaying window/screen limits the overview or number of visible objects which in turn decreases information intensity of the scene.

Lack of response to the third part of questionnaire limited this thesis not to discuss the fourth research question. It suggests further research is necessary to give complete answer to the question.

6.3 Recommendations

Information Intensity is one of the four “I” factors that are decisive in the designing of geo-visualisation. Nowadays, in different professions, important decisions are made based on geo-visualisation. Thus, it is advisable to check the information intensity of a geo-visualisation before using it for decision making purpose. Like Immersion and Interactivity, Information Intensity of geo-visualisation also deserves great deal of attention. Moreover, knowing the “prior knowledge” of users in advance helps to decide on the amount of information of a given geo-visualisation.

The result of this MSc thesis is partial due to limited responses from the reference group and lack of literatures on information intensity. Therefore, the topic needs further exploration to have detailed and complete understanding of information intensity of 3D geo-visualisation.

Especially the third level of information intensity needs detailed investigation. The approach used to find out about the third level of information intensity can be more helpful with large sample groups. To improve this work, this thesis suggests repeating measuring the third level of information intensity. Form the methodological perspective, it also suggests to consider sample groups from different field of study or specialisations. Regarding the third part of the questionnaire, this thesis recommends using two groups; one group with prior knowledge of the geo-data or visualisation of the geo-data and another group with no prior knowledge.

References

Al-Kodmany, K. (1999). Using visualization techniques for enhancing public participation in planning and design: process, implementation, and evaluation, *Landscape and urban planning* 45: 37-45.

Appleton, K. and Lovett, A. (2005). GIS-based visualisation of development proposals: reactions from planning and related professionals, *Computers, Environment and Urban Systems* 29: 321-339.

Appleton, K., Lovett, A., et al. (2002). Rural landscape visualisation from GIS databases: a comparison of approaches, options and problems, *Computers, Environment and Urban Systems* 26: 141-162.

Bourne, L.E., Dominowski, R.L., et al. (1986). Cognitive Process, Englewood cliffs, New Jersey.

Buckland, M.K. (1991a). Information and Information Systems. Westport, CT, USA Greenwood Publishing Group Inc.

Buckland, M.K (1991b). Information as thing, *Journal of the American Society for Information Science* 42: 351-360.

Burdea, G. and Coiffet, P. (2003). Virtual Reality Technology, Hoboken, New Jersey, John Wiley & Sons, Inc.

Colman, A.M. (2002). A Dictionary of Psychology, Oxford University Press.

Danahy, J. (1999). Visualization Data Needs in Urban Environmental Planning and Design, *Photogrammetric Week* 99: 351-365.

Dastani, M. (2002). The Role of Visual Perception in Data Visualization, *Journal of Visual Languages and Computing* 13: 601-622.

Davis, B.E. (2001). GIS: A Visual Approach, OnWord Press.

Davis, C. and Laender, A. (1999). Multiple representations in GIS: materialization through map generalization, geometric and spatial analysis operations, in: *Proceedings of the 7th ACM international symposium on Advances in geographic information systems*, Kansas City, Missouri, United States, ACM Press New York, NY, USA.

Ebanks, B., Sahoo, P., et al. (1998). Characterizations of Information Measures, World Scientific.

Fisher, P. and Unwin, D. (2002). Virtual Reality in Geography: An Introduction, in: Fisher, P and Unwin, D. (Ed.), *Virtual Reality in Geography*, London, Taylor & Francis: 1-4.

Forberg, A. and Mayer, H. (2002). Generalization of 3D Building Data Based on Scale-Space, *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science* 34(4): 225-230.

Gershon, N. and Eick, S.G. (1998). Guest Editors' Introduction: Information Visualization. The Next Frontier, *Journal of Intelligent Information Systems,* Springer 11: 199-204.

Goodchild, M. and Quattrochi, D. (1997). Introduction: Scale, Multiscaling, Remote Sensing and GIS, in: Goodchild, M and Quattrochi, D. (Ed.), *Scale in Remote Sensing and GIS,* New York, Lewis: 1-12.

Haeberling, C. (2002). 3D Map Presentation–A Systematic Evaluation of Important Graphic Aspects, in: *Proceedings of the ICA Mountain Cartography Workshop*, Timberline Lodge, Mt.Hood, Oregon, International Cartographic Association.

Hardisty, F., MacEachren, A., et al. (2001). Cartographic Animation in Three Dimensions: Experimenting with the Scene Graph, *20th International Cartographic Conference*, Beijing, China, August 6-10.

Heim, M. (1998). Virtual Realism, Oxford University Press, New York.

Hilgard, E. and Atkinson, R. (1975). Introduction to Psychology. New York, Harcourt Brace Jovanovich, Inc.

Hoogerwerf, T. (2005). Geo-visualization approaches, Wageningen, the Netherlands, Wageningen University.

Jiang, B. (1996). Fuzzy Overlay Analysis and Visualization in Geographic Information Systems, PhD thesis, Department of Geoinformatics, International Institute for Aerospace Survey and Earth Sciences. Enschede, The Netherlands, Utrecht University.

Joăo, E.M. (1998). Causes and Consequences of Map Generalization, CRC Press, London.

Keates, J.S. (1989). Cartographic Design and Production, England, Longman Group UK Limited.

Koua, E.L. and Kraak, M. (2004). Alternative Visualization of Large Geospatial Datasets, *The Cartographic Journal* 41(3): 217-228.

Kraak, M. (2002 a). Some Aspects of Geo-visualisation, *Geoinformatics* 5(8): 26-37.

Kraak, M. (2002b). Geo-visualisation illustrated, *ISPRS Journal of Photogrammetry and Remote Sensing* 57: 309-399.

Kraak, M. J. and Ormeling, F. J (2003). Cartography: Visualization of Geospatial Data, Harlow: Pearson Education.

Kulhavy, R. and Stock, W. (1996). How Cognitive Maps are Learned and Remembered, *Annals of the Association of American Geographers* 86(1): 123-145.

Kullback, S. (1997). Information Theory and Statistics, Mineola, New York, Dover Publications, Inc.

Lammeren, R. van, A.Ligtenberg, J. Serpa, J. Abreu, I. Plezier (2007), Geo-visualisation: the e-interaction factor of spatial planning. In: Brink, A., R. van Lammeren, R. van de Velde, S. Däne, Geo-visualisation for participatory planning in Europe, (2007), Mansholt publication series - volume 3, Wageningen. (Available by September 2007).

Lammeren, R.v., Momot, A., et al. (2004). Visual Scan, 3D visualizations of 2D Scenarios, Wageningen, Netherlands, Wageningen University and Research centre, CGI report 2004-09.

Li, C., Chen, J., et al. (1999). A raster-based method for computing Voronoi diagrams of spatial objects using dynamic distance transformation, *Geographical Information Science* 13(3): 209-225.

Li, Z. and Huang, P. (2002). Quantitative measures for spatial information of maps, *Geographical Information Science* 16(7): 699-709.

Lloyd, R.E. (1997). Spatial Cognition: Geographic Environments, Kluwer Academic Publishers.

MacEachren, A.M. (1995). How Maps Work: Representation, Visualization, and Design, Guilford Press, New York.

MacEachren, A., Wachowicz, M., Edsall, R., Haug, D., Masters, R. (1999).Constructing knowledge from multivariate spatiotemporal data: integrating geographical visualization with knowledge discovery in database methods, *International Journal of Geographical Information Science* 13(4): 311-334.

MacEachren, A.M., Edsall, R., et al. (1999). Virtual Environments for Geographic Visualization; Potentials and challenges, in: *Proceedings of the 1999 workshop on new paradigms in information visualization and manipulation in conjunction with the eighth ACM international conference on Information and knowledge management*, 35-40, ACM Press New York, NY, USA.

Mahmoud, A.H: Can Virtual Reality Simulation Techniques Reshape the Future of Environmental Simulations? Retrieved January 18, 2007, from http://www.casa.ucl.ac.uk/planning/articles41/vrsim.htm

Miller, G.A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information, *The Psychological Review* 63: 81-97.

Milosz, M. (2006). Usability of 3D Geo-Visualization in Participatory Spatial Planning; spatial orientation in 3D geo-visualization, Master's thesis Centre for Geo-Information, Wageningen University.

Monmonier, M. (1993). Mapping It Out: Expository Cartography for the Humanities and Social Sciences, London, University of Chicago.

Monmonier, M. (1996). How to Lie with Maps, Chicago, London, The university of Chicago press.

Montello, D.R and Golledge, R (1999): Scale and Detail in the Cognition of Geographic Information, Work shop report, University of California, Santa Barbara. Retrieved April 20, 2007, from http://www.ncgia.ucsb.edu/Publications/Varenius_Reports/Scale_and_Detail_in_Cognition.pdf

Morehouse, S. (1995). GIS-based map compilation and generalization, in: Muller, J.C., Lagrange, J. P., et al. (Ed.), *GIS and Generalization; Methodology and Practice Issues*, Taylor & Francis: 21-24.

Nebiker, S. (2003). Support for visualisation and animation in a scalable 3D GIS environment: motivation, concepts and implementation, in: *Proceedings of ISPRS Commission V Working Group 6, Workshop on Visualisation and Animation of Reality-based 3D Models*, Engadin, Switzerland.

Pelaez, J. and Flowers, W. (2000). Information Content Measure of Visual Displays, *IEEE Symposium*, Salt Lake City, UT, USA.

Pickles, J. (1995). Representations in an Electronic Age: Geography, GIS and Democracy, in Pickles, J. (Ed.), Ground *Truth: The Social Implications of Geographic Information Systems*, Guilford Press, New York.

Reuter, L., Tukey, P., et al. (1990). Human perception and visualisation, in *Proceedings of the 1st conference on Visualization '90*, San Francisco, California IEEE Computer Society Press.

Saracevic, T. (1999). Information Science, *Journal of the American Society for Information Science* 50(12): 1051-1063.

Sbert, M., Plemenos, D., et al. (2005). Viewpoint Quality: Measures and Applications, in: Neumann, L., Sbert, M., et al. (Ed.), *Computational Aesthetics in Graphics, Visualisation and Imaging*, The Eurographics Association.

Schroeder, P.C. (2003). Spatial Aspects of Metaphors for Information: Implications for Polycentric System Design, PhD thesis, Spatial Information Science and Engineering, The University of Maine.

Shannon, C.E. and Weaver, W. (1949). The Mathematical Theory of Communication, University of Illinois.

Shiode, N. (2001). 3D urban models: recent developments in the digital modeling of urban environments in three-dimensions, *GeoJournal* 52:263-269.

Soanes, C. and Stevenson, A. (2004). Concise Oxford English dictionary New York, Oxford University Press.

Stamps, A.E. (2003). Advances in visual diversity and entropy, *Environmental and Planning B: Planning and Design* 30(3): 449-463.

Stoter, J., and Zlatanova, S. (2003). 3D GIS, where are we standing?, *ISPRS Joint Workshop on Spatial, Temporal and Multi-Dimensional Data Modeling and Analysis*, Quebec City, Canada, Section GIS technology, Delft University of Technology, The Netherlands

Timpf, S. and Franck, A. (1995). A multi-scale DAG for cartographic objects, Auto-Carto 12, Charlotte, NC ACM/ASPRS.

Tobler, W.R. (1979). A transformational view of cartography, *The American Cartographer* 6(2): 101-106.

Tory, M. and Moller, T. (2004). Human Factors in Visualisation Research, *IEEE Transactions on Visualisation and Compute Graphics* 10(1): 1-13.

Vazquel, P., Feixas, M., et al. (2003). Automatic View Selection Using Viewpoint Entropy and its Application to Image-Based Modeling, *Computer Graphics forum* 2(4): 689–700

Verbree, E., van Maren, G., et al. (1999). Interaction in virtual world views: Linking 3D GIS with VR, *Geographical Information Science* 13(4): 385-396.

Wachowicz, M., Bulens, J., et al. (2002). GeoVR construction and use: The seven factors, *5th AGILE Conference on Geographic Information Science*, Palma (Balearic Islands, Spain), April 25th-27th.

Worboys, M. and Duckham, M. (2004). GIS: A Computing Perspective, CRC Press, Boca Raton, FL, USA.

Wunshce, B. (2004). A survey, classification and analysis of perceptual concepts and their application for the effective visualisation of complex information, in: *Proceedings of the 2004 Australasian symposium on Information Visualisation* (35):17-24, Christchurch, New Zealand, Australian Computer Society, Inc.

Yun, L., Yufen, C., et al. (2004). Cognition theory-based research on adaptive user interface for geo-visualization system, in: *Proceedings of the Geoinformatics 12th International Conference*, 7-9, University of Gävle, Sweden.

(2000). Ordnance Survey, National Mapping Agency of Great Britain. Retrieved March 22, 2007, from http://www.ordnancesurvey.co.uk/oswebsite/products/50kraster/pdf/d01070a.pdf

(2006). Top 50-topographic map 1:50000, National Geographic Institute. Retrieved March 20, 2007, from www.ngi.be/Common/leg50/50000NL.htm#top

Appendices

Appendix 1: Official Legends of 1:50000 topographic maps

Belgium

Figure1. Legends of land features and built up area

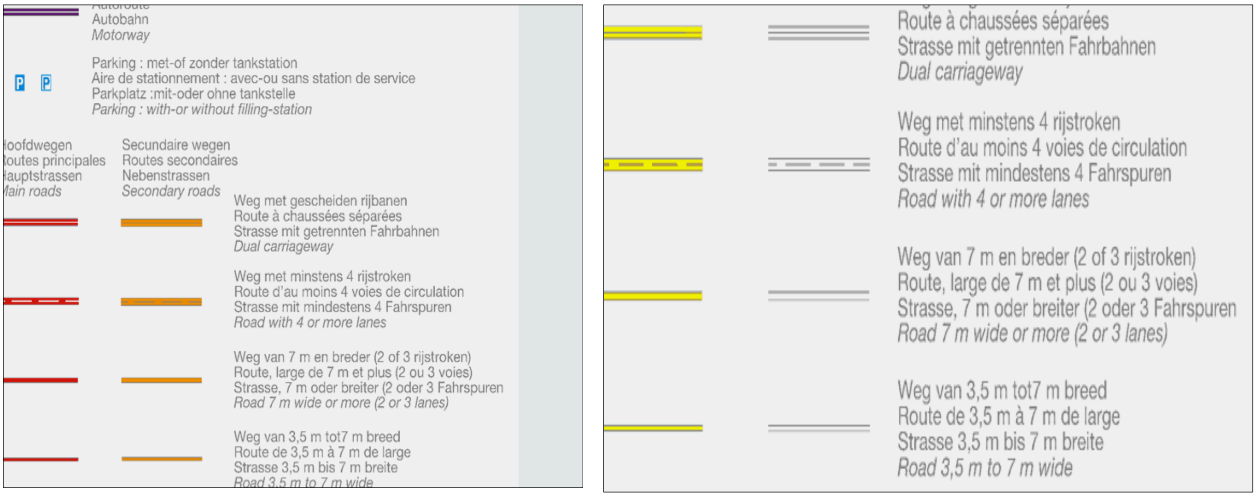


Figure2. Legend of road

Netherlands

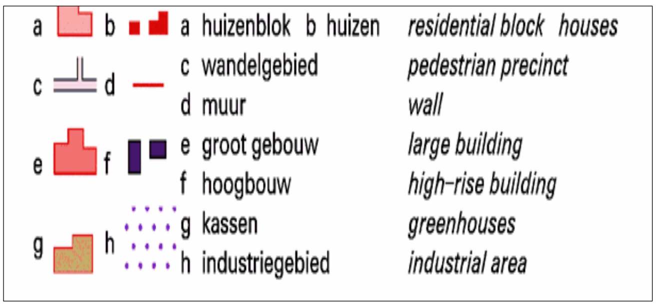
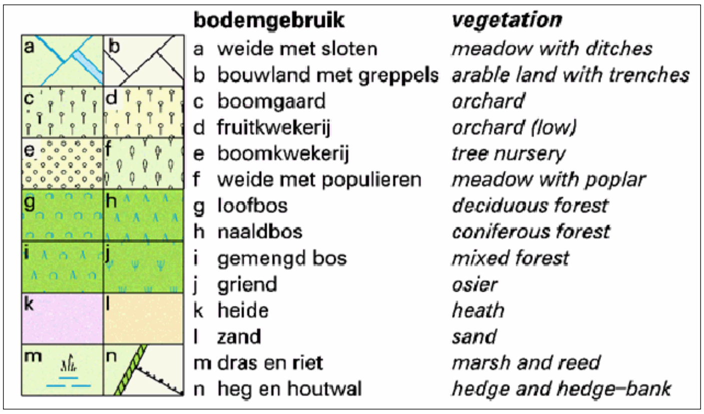


Figure3. Legend of built-up area and houses



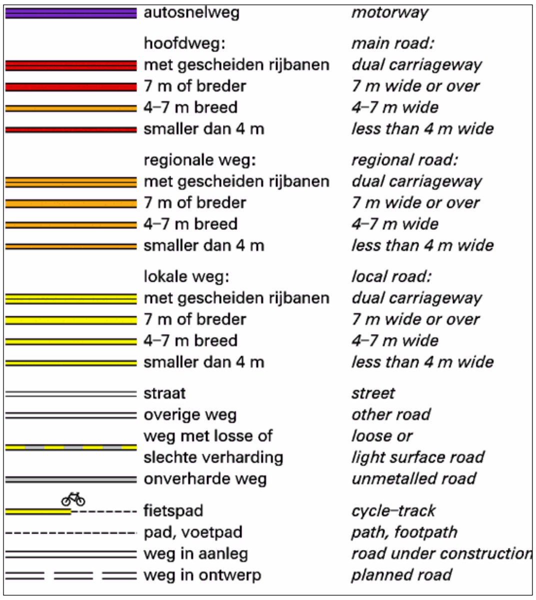
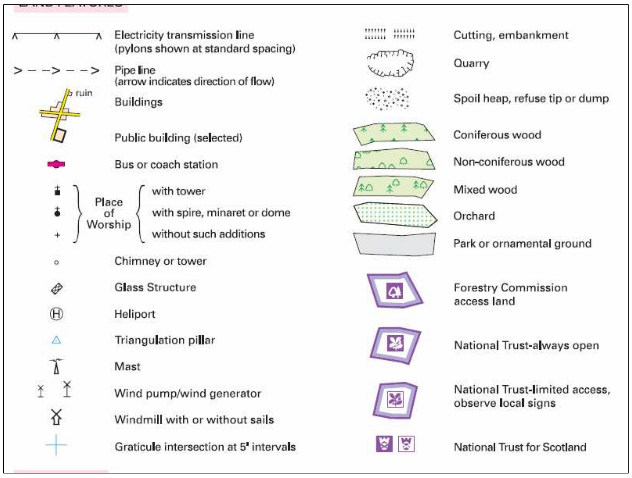


Figure4. Legends of land features and road

United Kingdom



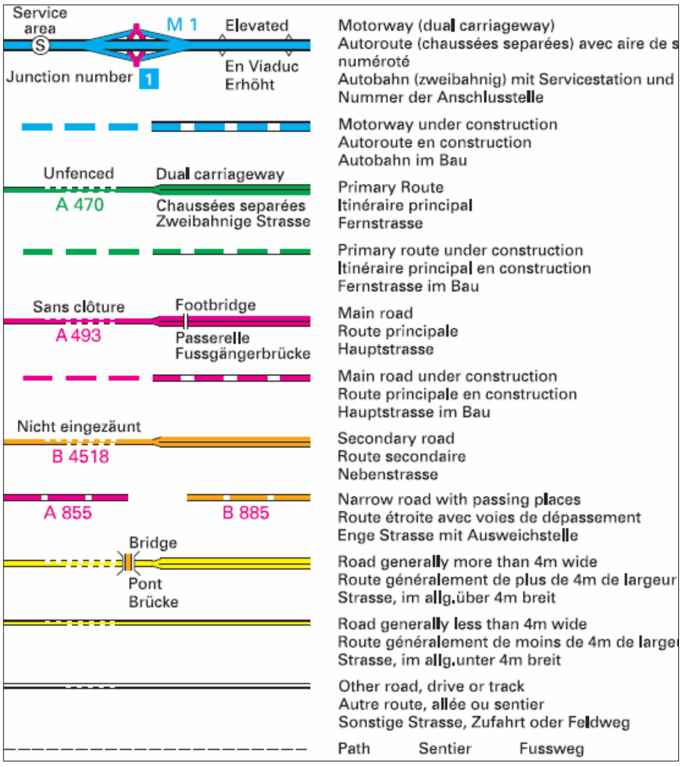


Figure5. Legends of land features and road

Appendix 2: Part I and II of questionnaire

Introduction

This questionnaire is part of MSc thesis. The purpose is to find out how information intensity of a 3D visualization is influenced by users' 'stock of knowledge' and visual perceptions. The questions are based on your field visit of the village of Groenlo in the Achterhoek. The questionnaire has two parts:

Part I: Memory Recall

Part I has seven questions. The questions mainly focus on what you remember about the landscape features from the filed visit. In this context landscape features refers to land cover types such as meadow, built up area, etc. and features such as forests, houses, rail way, etc. Please type your answer on the space provided. You have time limit of 10 minutes to give your answers.

1.1 How many times have you been in the Achterhoek?

A. 1-2 B. 2-5 C. More than 5

1.2 Which landscape feature you remember first?

1.3 Which landscape feature has the largest size?

1.4 What is the highest landscape feature you observed?

1.5 Which landscape features are crowd together to one area? List two features

1.6 Which landscape features are scattered in the area? List two features

1.7 Which landscape features come together? For example, houses along the road. List at least three such relations that you remember.

Part II: **Instant View**

Part II consists of four questions. The questions are based on 3D scenes of different perspective of the same area. Below you see two figures. Figure 1 has a green rectangle, which indicates the extent of area used in the 3D scenes of this questionnaire. The red line indicates the GRS-31809 excursion route. Figure 2 shows the classification of landscape features and legends used. Watch the map and legend for half a minute.

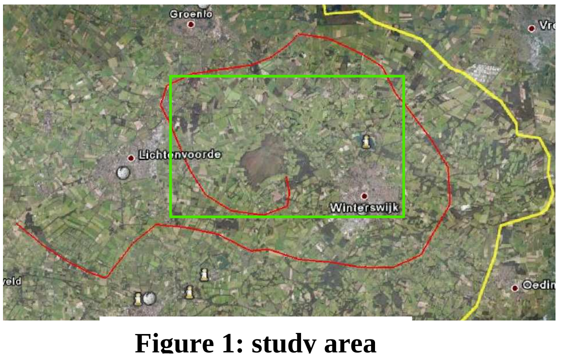


Figure 1: study area

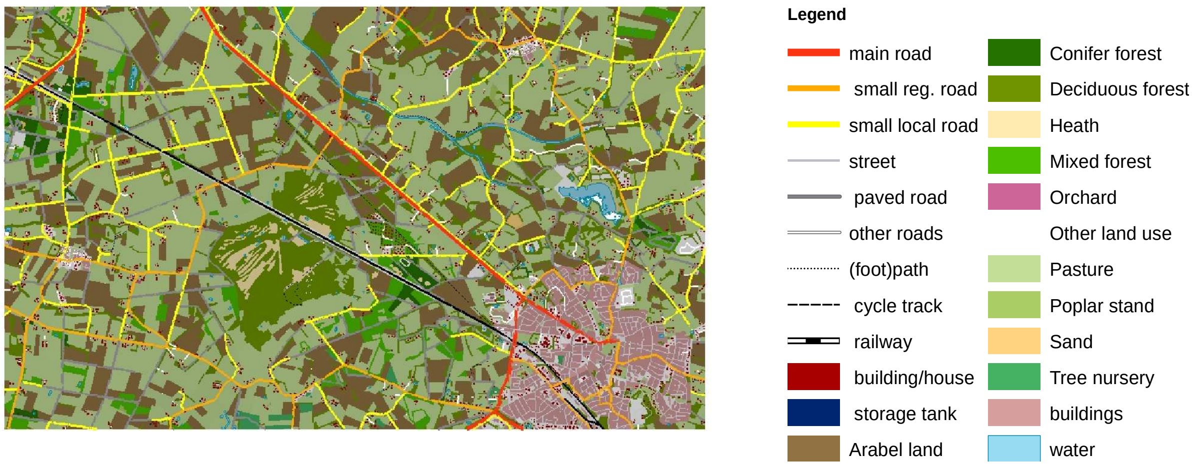
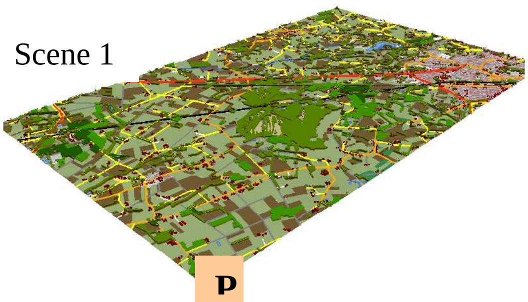


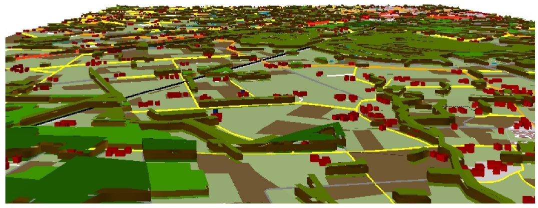
Figure 2: classification

2.1 Which of the following three scenes is the correct one if scene 1 is viewed from point **P**? You have time limit of 10 seconds.

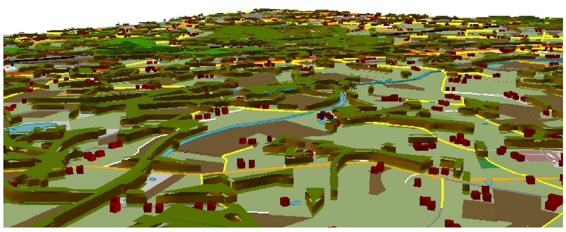
Scene 1



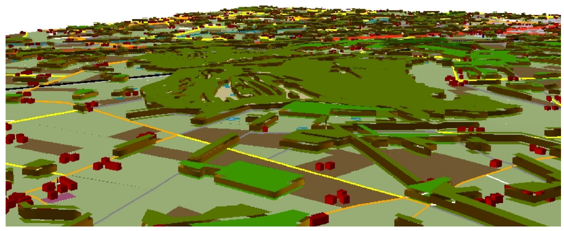
A



B



C



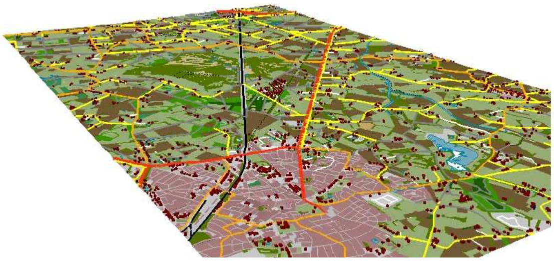
2.2 Which of the following four 3D still scenes gives you the best readable information about Achterhoek landscape features? Rank the scenes as 1, 2, 3, and 4. Number 1 stands for the lowest information and number 4 stands for the highest information.

You have time limit of 45 seconds.

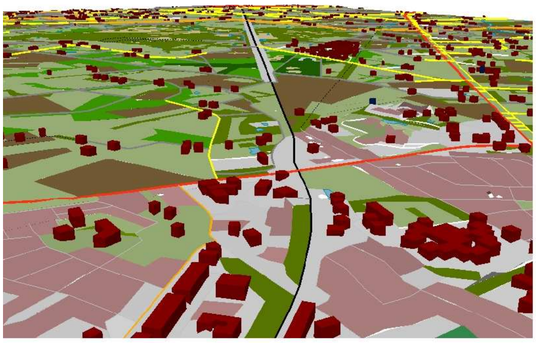
A

B

C

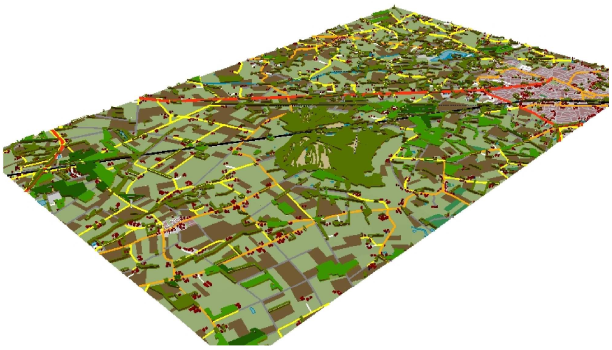


D



2.3 In the following 3D still scene, which feature do you see first?

You have time limit of 10 seconds.

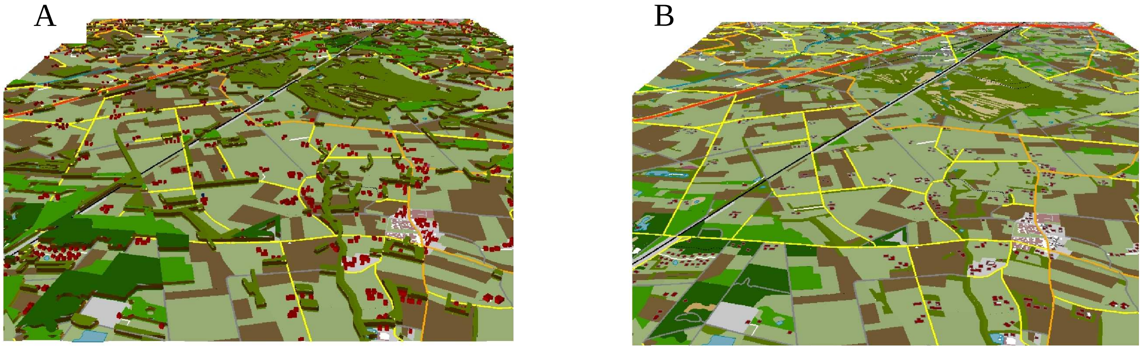


A. Forest
B. Houses
C. River
D. Roads
E. Rail way
F. Pasture
G. Arable land
H. Built up area

2.4 Which of the following 3D still scenes representation do you prefer most?

You have time limit of 5 seconds.

A B



Appendix 3: Part III questionnaire

Part III

Introduction

This thesis test is part of MSc thesis. The intention is to find what will happen to the information intensity of a 3D visualization at the moment of interaction. The test consists of four questions. Before answering the questions you are going to make simple interaction with the 3D scene of the Achterhoek. First read the instruction very carefully!

Instruction

URL: http://webgrs.wur.nl/cgi/projects/achterhoek

Please go to the link and save the data to your computer. Open the ArcScene program from you computer. After opening the ArcScene software, click on the open file and go to the folder where you saved the data and click on **Achterhoek_2.sxd** ArcScene document. Now you can start to explore the scene by zoom in and out, panning or walk through using the different tools of navigation in the ArcScene. You can do this for maximum of 5 minutes, after that you can start answering the questions in their respective order i.e. 1 to 4. You are also allowed to make changes to your answers.

After you practice the navigation tools you may start to read and answer the questions. You have time limit of 15 minutes.

!! Please note that you are not allowed to use the attribute tables to answer the questions!!

Select one answer (A, B, C or D)

1. How many forest blocks do you see as you move from the left down corner of the scene to the right up corner diagonally? ....
   A. 10-20 B. 20-40 C. More than 40
2. How many roads (all types) cross the rail way? ....
   A. 1-5 B. 5-10 C. 10-15 D. 15-20
3. How many water features do you see near the built up areas? ....
   A. 10-20 B. 20-30 C. 30-40 D. 40-50
4. Do you think this visual interaction gave you better information than the 3D still scene of Achterhoek you saw last time? A. Yes B. No C. Not sure

Appendix 4: Respondents' visual perception

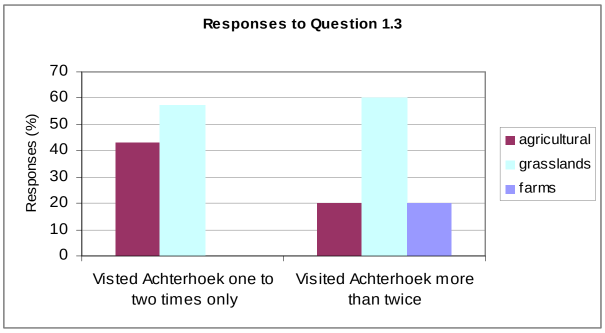


Figure 6 Responses to question 1.3 (%).

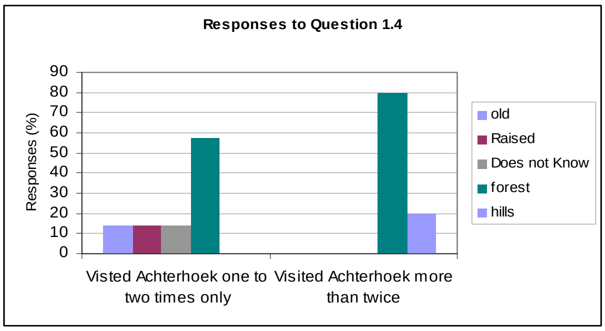


Figure 7 Responses to question 1.4 (%).

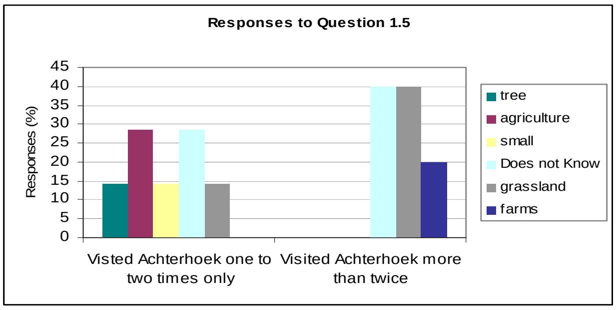


Figure 8 Responses to question 1.5 (%).

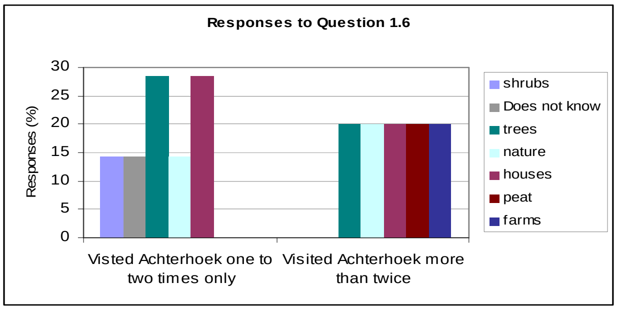


Figure 9 Responses to question 1.6(%).

Table 1: Response to Question 1.7

Respondents who visited Achterhoek one to two times	Response to Question 1.7	No of Respondents	(%)
	Sauvage ,human, tourism	1	8
	farms	1	8
	Tree rows	1	8
	forest, trees ,grass	1	8
	house, road, canal	1	8
	houses, trees	2	17
Respondents who visited Achterhoek more than twice			
	peat, meadows, forest	1	8
	heather, forest	1	8
	Agriculture, vegetation, nature	1	8
	hedgerows, house, grass	1	8
	crop, forest	1	8
Total		**12**	**100**

Appendix 5: List of abbreviations

2D = Two Dimensional

3D = Three Dimensional

GIS = Geographic Information Science

OED = Oxford English Dictionary

VE = Virtual Environment

VR = Virtual Reality