Centre for Geo-Information

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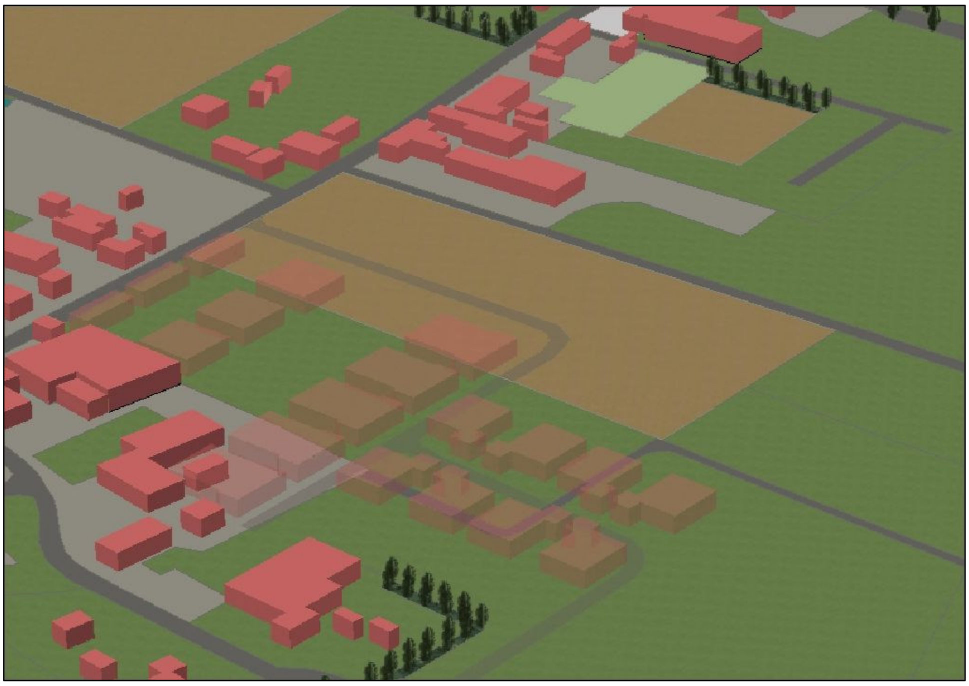
Visualization of landscape change in computerized 3D environments

W.C.J. Witte



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Visualization of landscape change in computerized 3D environments

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Foreword

Finding an interesting thesis subject was something I put much effort into, as well as into the first proposal I wrote. Nevertheless the objective of my thesis research has changed during the period I worked on it. From a more theory based research it changed to an experiment based research. Despite all the time I spent on studying theory on visualization of landscapes and spatial modelling, just a part of that knowledge is reflected in this paper. Due to this course of things, the most interesting part of this research, the test visualization itself, did not get the attention that it could have had.

I would like to thank my supervisor Ron van Lammeren for his enthusiasm and support during my research. Secondly, I would like to thank Arnold Bregt for his help and advices at the end of my research, which accelerated the finalization of this paper.

Summary

The general objective of this research is to develop and test a 3D visualization technique for the visualization of change in a landscape, showing two different situations visible in one view (ghost metaphor), in a 3D virtual GIS environment. This is done by identifying, describing and analysing methods and techniques for the visualization of changes in landscapes. The ghost metaphor is defined as the use of one view (projection surface) to show the difference between two moments in time in a 3D scene of one fixed location, viewpoint or route in a simple manner. The ghost metaphor is about landscape and landscape change. Landscape is defined as the collection of physically visual spatial phenomena in the real world. And landscape change can is defined as the change of these visual spatial phenomena. Regarding the ghost metaphor spatial phenomena can be discrete or continuous as long as they are physically visible. Spatial phenomena can be described by their spatial and non-spatial characteristics; geometry and attributes. Changes can occur in both geometry and attributes. The ghost metaphor is thought to be useful for landscape monitoring or landscape planning purpose because they are about changes in the landscape. To test if the ghost function in computer games provides a good metaphor for the visualization of landscape change a test visualization is designed. Three visualization were created and shown to 14 respondents who answered questions about the visualizations. The test visualization intended to show two different moments in time in on view. It appears that the visualization of volumetric objects like buildings and areas like roads that either appear or disappear from a landscape or scene are a suitable change to visualize 'ghostly' in a computerized 3D environment. Two techniques that can be used to visualize the appearing or disappearing objects are hatching and transparency. Transparency is the best technique for the visualization of appearing or disappearing volume objects (buildings). Hatching is the best technique for the visualization of appearing or disappearing area objects (roads). The presented visualization in this research was understandable for the majority of the people. Even though there was no legend or explanation present in the visualization about its purpose or meaning. A majority (50-92%) of the respondents described the visualizations as showing a change in the landscape. They explained the visualizations as showing current and past or future landscape elements.

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1. Introduction

1.1 Context and background

What strikes me when playing modern computer games are the realistic and detailed landscapes in which you can navigate and can sometimes manipulate. These computerized gaming environments show great similarity with the 3D landscape visualizations used for research and planning purposes. Though graphically gaming environments can often form a great contrast with the “professional” landscape visualizations. An important aspect in landscape visualizations are changes in the landscape like new buildings, changing land use, etc. Change (of objects) and time also play a very important role in computer games. Just think of the many simulation games, they vary from theme parks, to cities and complete railway systems, based on the real world to the completely imaginary. In these games many methods and techniques are used for the visualization of change. An interesting example is the “ghost function” in racing games (fig 1.1).

In a racing-game one and the same track can be driven over and over again. But each time you will drive it a little differently, you push the brake a little earlier, steer your car a little better around the corners, etc. This can be seen as a change over time. This change can be visualized by a “ghost”. While you are driving, you can see yourself driving, like you have driven, for example, your best lap. If you regard this example of the ghost function as a metaphor, it appeals to the idea to improve 3D visualizations of landscape change.

Fig. 1.1 The ghost metaphor: The car in the middle lower part of the picture is the current active car. The car in the middle is the “ghost” of the previously active car.

1.2 Problem definition

The real world is a continuously evolving three dimensional space. The landscapes in this real world are a result of human interaction and natural processes like geology and climate (fig. 1.2). The changes in these landscapes have been a subject of many research and development studies because the rate and patterns of landscape change provides information on issues like urban growth, nature development, disappearing agricultural grounds, etc.

Changes in landscapes have been a subject in social, economical and ecological studies. The ecological impact of landscape change, for example is studied by White (1997). Nassauer (1995) studied how culture changes the landscape and how culture is embodied by the landscape. Changes of the cultural landscape viewed from a landscape archaeology point of view are a subject in Lock & Harris (1998). Land degradation in the developing countries is studied by Batterbury & Bebbington (1999) and Gray (1999). Models of landscape change have been discussed by Baker (1989) and Flamm & Turner (1994). Many of the studies on landscape change focus on the human impact on the environment. Their goal is often to support decision making for policy makers and/or to encourage public participation in planning decisions.

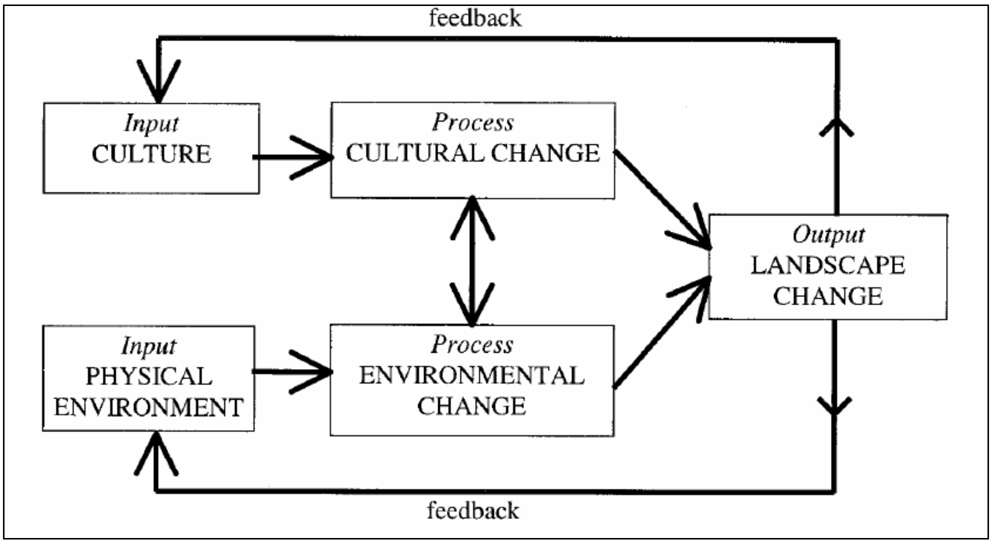

Fig. 1.2 A view on landscape change. (Dawson, 1983 p.12)

The visualization of geographical data is being assumed to stimulate thought and may reveal patterns and relationships that might otherwise remain hidden (McEachren 1995, p356. Blok, 1999). Maps for example are much used visualizations of geographical data; they are considered to be useful tools for understanding geospatial patterns and relationships (Lo, 2002). Most maps however just represent a single moment in time. But for a better understanding of changes based on geographical processes or events, the time dimension must be considered. This is expressed by Kraak (2003): “In GIS environments there is a need to deal with processes as a whole and not only with single time-slices.” For the visualization of changes, static maps can be confusing and hard to read (Iwerks & Samet, 2000). In particular the changes in the landscape can be hard to recognize (Lovett, 2002). Much used options for displaying change are animated series of static maps. In general most animation methods render spatial data in a bitmap, gif, etc. One bitmap is created for each discrete time step in a series. The bitmaps are then displayed in succession creating an animation. This is known as animated cartography (Iwerks & Samet, 2000).

The basic goal of animation is the depiction of change. Most cartographic animations depict change over time. Many examples of animations demonstrate the increasing role of dynamic cartography as a research tool (Mitas, 1997). Animation is for example used in the presentation of meteorological data in weather forecast presentations to show changes over time (Schroder, 1993) and for the visualization of urban growth (Acevedo & Masuoka, 1997). And in Kang & Servign (1999) animated cartography is used in the presentation of urban environmental soundscape information for environmental decision support.

The suitability of animations to visualize change in geo-spatial data however is not taken for granted (Emmer, 2001). Morrison et al (2000) and Kehoe et al (2001) have raised some doubts on the effectiveness of animations. “These kinds of studies have, within the cartographic community, led to an increased awareness of the fact that cartographic animations maybe should not automatically be accepted as an effective means to depict geographical change and processes over time” (Emmer, 2001). Although already some research has been carried out on the usability of cartographic animations, more research is needed (Slocum et al, 2001).

A recent and sophisticated form of landscape visualization is in Virtual Reality. Virtual Reality can be described as a virtual 3D dynamic, immersive and interactive environment. The need for 3D information is rapidly increasing in different areas of human activities, one of them being landscape planning (Zlatanova, 2002). This is illustrated by the testing and designing of all kind of Virtual Reality environments for analyzing and discussing changes in landscapes (Appleton & Lovett 2002, Lammeren 2002, Ottens 2004, Pullar 2002, Lovett & Sunneberg 2002). These 3D environments are far more difficult to handle for developers than the common used 2D GIS.

The visualscan project (Lammeren, 2004) gives an example of the problem to visualize change in geographical datasets in 3D. In this project the aim was to visualize 2D data of an application that calculates future land use classes. One option was to relate 3D objects to the 2D outcome data. The problem they hereby encountered was how to visualize the changes that occurred in the landscape. One solution that was tried was by a pair wise comparison via two windows in one screen.

As technology advances this brings new opportunities but also more problems. From the above it can be concluded that there is a need for further research on landscape visualization, especially the changes that can occur in a landscape.

To improve landscape visualizations based on the metaphor of a computer game many questions have to be answered. The visualization of landscapes and landscape change is a very broad category of visualizations. Many types of visualization exist and many techniques. So before attempting to create a visualization of landscape change based on this metaphor one has to know what is a landscape, what are landscape changes and how can they be visualized?

1.3 Research objectives

The general objective is to develop and test a 3D visualization technique for the visualization of change in a landscape, showing two different situations visible in one view (ghost metaphor), in a 3D virtual GIS environment. This will be done by identifying, describing and analysing methods and techniques for the visualization of changes in landscapes.

Hypothesis: The ghost function in computer games provides a good metaphor to visualize changes in computerized 3D landscape visualizations in one view.

To put this hypothesis to the test the following questions have to be answered.

<u>Research questions</u>:

Q1 What landscape changes are suitable for visualization of two different situations in one view?

Q2 Is it possible to implement the "ghost function" of games in a 3D computerized visualization of landscape change?

1.4 Research methods

The focus of this study is on visualizing landscape changes in a 3D virtual environment. An insight on the visualization of landscapes and landscape change is needed as well as insight in relevant visualization techniques of changes in general. To accomplish this an extensive literature review was conducted. The purpose of this literature study is to provide a theoretical basis for the implementation of the ghost metaphor (fig. 1.3). Many different landscape visualizations exist and are used, they range from 2D to 3D and from static to dynamic. Some of the most interesting landscape visualizations considering the ghost metaphor are discussed and analyzed in this paper.

In order to test if the ghost function in computer games provides a good metaphor to visualize landscape changes, a test application will be made. To come to a conceptual idea for a visualization of landscape change according to the ghost metaphor, the ghost metaphor has to be defined.

Definition of the ghost metaphor

The use of one view (projection surface) to show the difference between two moments in time in a 3D scene of one fixed location, viewpoint or route in a simple manner.

The system should be a computerized digital 3D scene representing a real world landscape.

Test visualization
The test visualization will be made in ESRI ArcScene. This software provides all the possibilities that are needed.

- Support of geographical data, point, line and polygon
- Support of 3D objects (based on point data)
- Extrusion of polygon data
- The use of transparency and hatching

Other reasons why this software is chosen are its availability, its ease to work with and that the author was already familiar with the software.

Questionnaire
To test the implementation of the ghost metaphor the test visualization will be shown to a group of people. The test visualization will be guided by a questionnaire. The goal of these questions is to find out if a visualization of old and new situations in one view is recognizable.

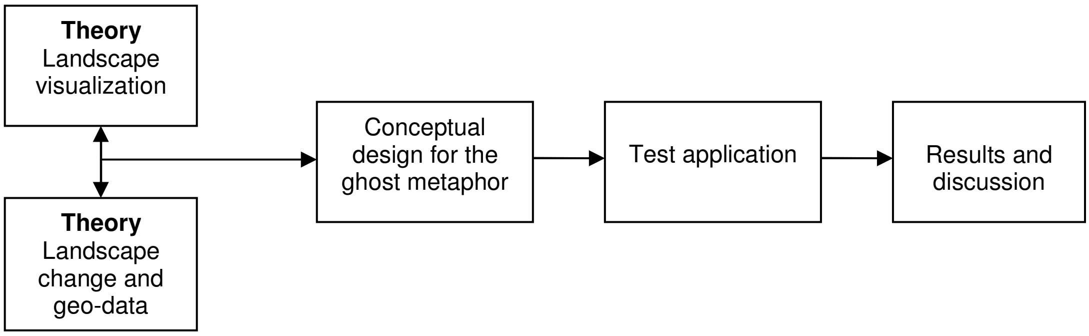

Fig 1.3 Research framework

1.5 Structure of the report

In chapter two, the modelling of the real world is described by defining what a landscape is and the changes that can occur in a landscape. It will discuss a conceptual model by discussing how landscapes and landscape changes can be represented in geo-data. In the third chapter the visualization of landscape change will be discussed. Chapter four discusses the implementation of the ghost metaphor. The test application is described and the results are discussed. The final conclusions and some recommendations follow in chapter five.

2. Geographical data and landscape change

A description of the real world is per definition an abstraction of the real world. In this chapter the modelling of the real world is described by defining an external and conceptual model (fig 2.1). The conceptual model is the representation of the external model in geo-data. A definition of landscapes is formulated and the change in landscapes is analysed. Also the perception of landscapes and spatial phenomena will be discussed. The representation of spatial phenomena and how change of landscapes is reflected in geographical data is discussed. At the end of the chapter different research fields considering changes in spatial phenomena will be discussed.

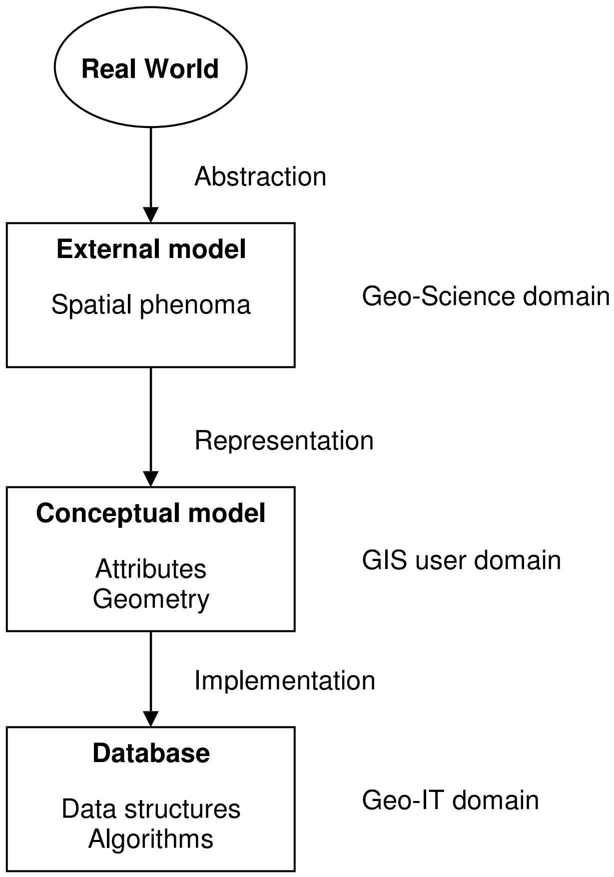

Fig. 2.1 Presentation of spatial modelling in a GI-System environment (based on Kainz, 1995).

2.1 Conceptual data model

There are two ways to describe spatial phenomena: the location-based approach and the object-based approach (Loedeman, 2004). They represent two different data structures (fig. 2.2). For reasons of simplicity in this research spatial phenomena will be discussed in an object-based approach.

The result of such a description, object or location based, is a set of tables in a digital database. A database is a collection of files of data that hold information on one type of object (Watson 2004) and ultimately a computational process. In this chapter only the conceptual level of spatial modelling will be described and not how this can be implemented in a digital database.

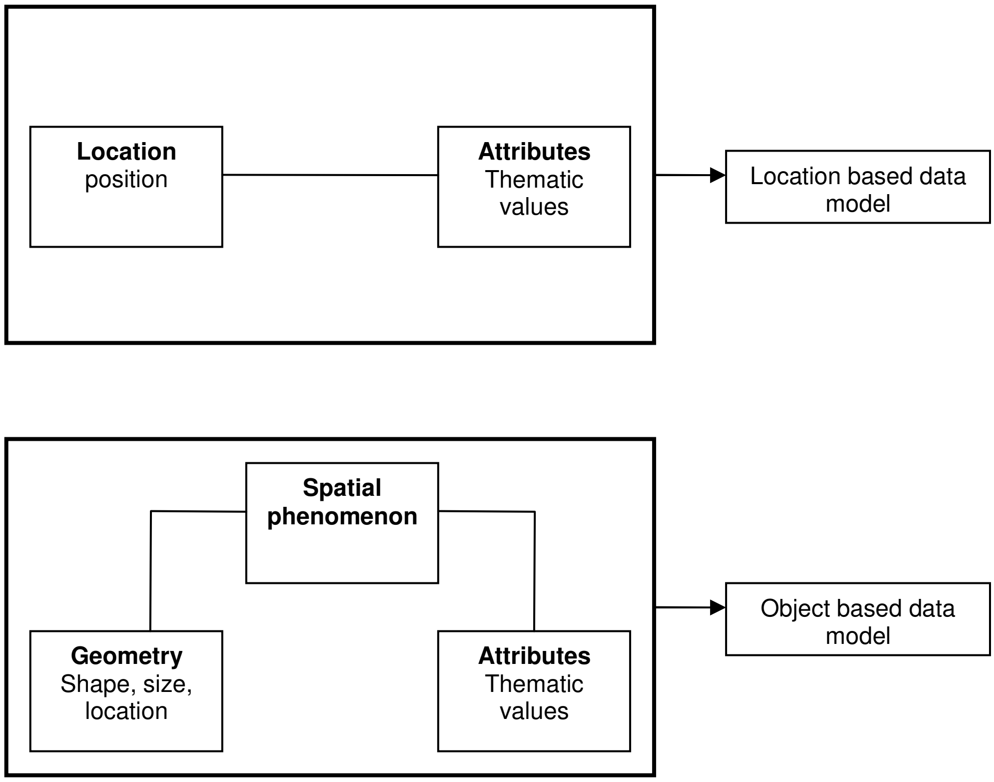

Fig. 2.2 Top: a location or object based data model; thematic attributes relate to locations. Bottom: an object based conceptual data model; spatial phenomena are described by their geometry and attributes.

2.2 Landscape definition

The hypothesis of this research states that the ghost function in computer games provides a good metaphor to visualize changes in computerized 3D landscape visualizations in one view. To be able to test this hypothesis one has to define what a landscape is.

Today's cultural-historic landscapes are a result of human interaction and natural processes like geology and climate. The landscape is built up of a-biotic, biotic and anthropogenic or cultural elements (Fig. 2.3). For the purpose of this research landscape will be defined as follows:

<u>A landscape is the collection of physically visual spatial phenomena in the real world. This is the landscape as it unfolds itself to the human eye.</u>

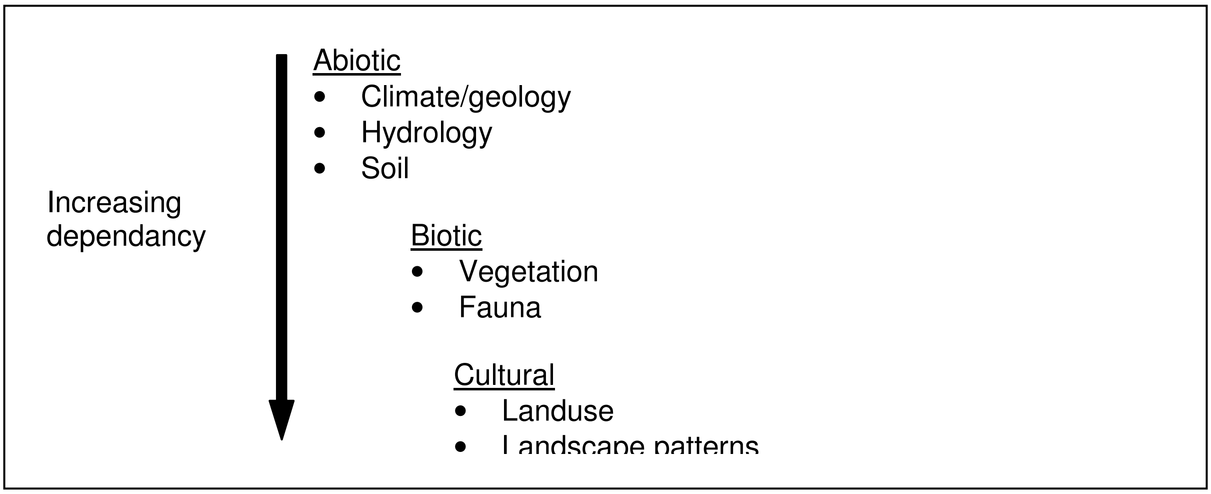

Fig. 2.3 How a landscape is built up (Mücher, 2003)

2.3 Perception

The way we perceive our environment determines what information is put in a geographical database and what a geo-visualization looks like. What defines a spatial phenomenon is dependent on how geographical objects are grouped. An urban area could be considered a spatial phenomenon. But an urban area consists of houses, roads, etc. And houses consist of walls, doors and windows which in turn can also be considered spatial phenomena. Which spatial phenomena will be described in an external model is determined by the context of the disciplinary field, such as geology, soil science or landscape planning. Examples of such phenomena are a landslide, a soil unit or a road.

Discrete or continuous

There are two different perceptions of spatial phenomena that determine how the real world can be described in an external spatial model: a discrete and a continuous perception. A continuous perception implies that a phenomenon appears everywhere and a discrete perception implies that a phenomenon is only present in some locations.

In the definition of landscape formulated in paragraph 2.1 spatial phenomena can be discrete or continuous, as long as they are physically visual. So surface temperature and annual precipitation are not included in this definition, but elevation is.

Representation of spatial phenomena

The representation of real world objects in a DBMS (Database Management System) is becoming a very important issue in modelling the real world (Zlatanova, 2002). An increasing number of DBMS support the management of real world objects (spatial phenomena). This object based approach is used by more and more applications. In general, spatial data sets are created in order to provide information for specific applications. Usually, these sets are specific representations of real world objects, which are collected by distinct organisations. Each set of objects is a selection of real world objects (only the objects of interest are modelled) and therefore subjective (the objects are represented from the point of view of the specific application). Consequently, different representations of the same real world objects can be found in a variety of data sets (fig. 2.4) (Zlatanova, 2002).

In a 2D representation of the real world three spatial entity types can be distinguished: point, line and area. The choice for a certain entity type depends on the purpose and context of a description.

Beside 2D, spatial phenomena can also be represented in 2.5D and 3D. 2.5D is a simplified 3D (x, y, z) surface representation that contains at most one depth value (z direction) for every point in the (x, y) plane. This is also known as a Digital Elevation Model (DEM). A truly 3D representation of the real world includes all represented objects in a full three dimensional manner including 3D topology. In practice this often means that the objects are CAD created and imported in a GIS and combined with a 2D (2.5D) GIS map (e.g. Verbree, 1998).

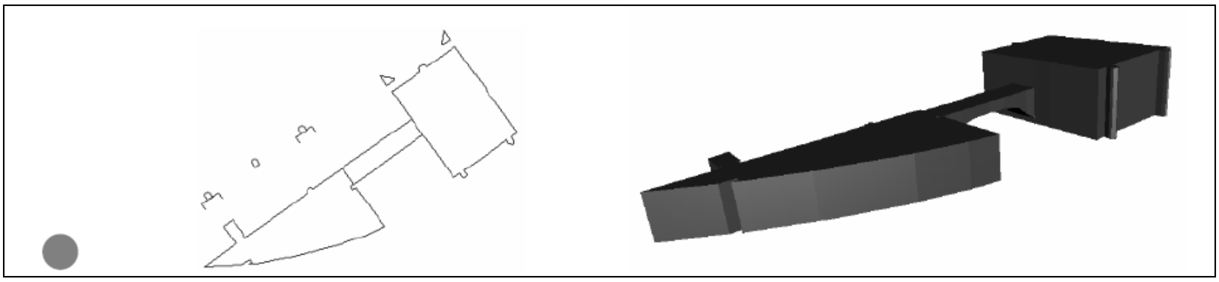

Fig. 2.4 Different representations of the same spatial phenomenon: point, area, volume (based on Zlatanova, 2004).

Geometry and attributes

Spatial phenomena can be described by their spatial and non-spatial characteristics (fig. 2.1). Geometry is used to represent the spatial characteristics of spatial phenomena. Geometry defines the measures and properties of points, lines and surfaces or in other words defines the shape size, location and topology.

The attributes of a spatial phenomenon describe the non-spatial characteristics. The attributes provide non-spatial information about the spatial phenomenon, for example the phenomenon is a tree, the attribute value can be species, health, etc.

In both 2D and 3D representation of the real world the vertical dimension can be captured but in a different manner. In a 2D representation of the real world this is done in thematic data as an attribute value like elevation. In a 3D database the elevation is a part of the geometry.

2.4 Landscape change

Landscapes are continuously evolving and thus changing. A landscape is defined as the collection of physically visual spatial phenomena in the real world. So landscape change can be defined as the change of these visual spatial phenomena. The changes in landscapes can have a human or natural cause.

Two types of landscape change with a human cause are distinguished by Wood (2001): obsolescence and dysfunction. Obsolescence and dysfunction are defined as follows.

Obsolescence: “Obsolescence, or loss of function, is associated with changing patterns of land use induced through the evolution of the economy and society.” An example is the intensification in agriculture followed by the restructuring of land parcels, loss of hedgerows, ponds and other comparable elements.
Dysfunction: “Dysfunction refers to the disruption caused by a mismatch between the type or intensity of land use and the character of the receiving landscape.” Examples are urbanization and road building which can lead to visual-, light-, and sound pollution, habitat loss and fragmentation and a reduction in biodiversity.

Change in spatial phenomena can be further defined in changes in the spatial and in the temporal domain. ‘Obsolescence’ and ‘dysfunction’ relate to a social-economical landscape view and refer to a wide variety of landscape change, which can include changes in the spatial and in the temporal domain. In the following paragraphs changes in the spatial and temporal domain will be discussed.

The spatial domain

Landscape change is defined by a change of visual spatial phenomena of that landscape. Considering the spatial domain, spatial phenomena can appear, disappear, mutate and move (fig 2.4). Changes in spatial phenomena can occur in its geometry, its attributes or both (Kraak & Ormeling, 2003).

Appearance and disappearance
Each spatial phenomenon within a system (GIS) or in the real world has a lifespan. Langran (1992) introduces the terminology of birth, death and if applicable, reincarnation (rebirth) for the existence of spatial phenomena. Appearance and disappearance are inherited aspects to that. An example is the building and demolition of a house or a road. Appearance and disappearance are changes in the geometry and topology of a spatial phenomenon.

Mutation
A spatial phenomenon can mutate in its geometry as well as in thematic sense. Change in geometry can for example be a change in boundaries like shifting borders. Change in attribute value is for example a change in land use. An example of the combination of both is urban growth, the urban boundaries expand and at the same time the land use shifts. Two subtypes of mutation of spatial phenomena can be distinguished:

- Mutation at nominal level of measurement: refers to a change in the nature or character of a phenomenon. E.g. a former church that is used as a discotheque.
- Increase or decrease: refers to a change at ordinal, interval or ratio level of measurement. E.g. the expansion of urban areas or shifting coast lines.

Movement
Refers to a change in the spatial position of a spatial phenomenon. E.g. the movement of cars, animals or a tornado. Moving phenomena represent a change in coordinates and are therefore a change in the geometry of a spatial phenomenon.

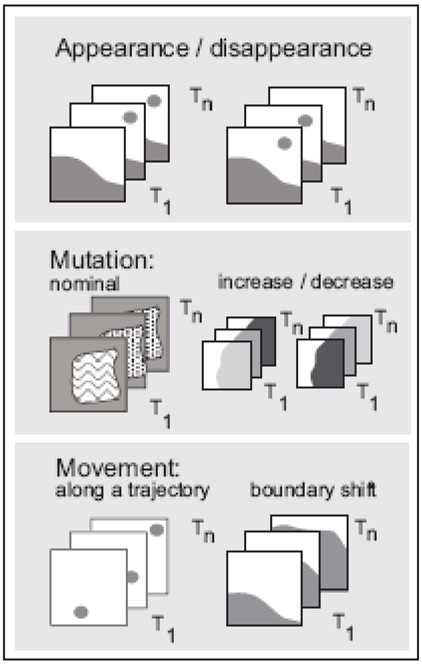

Fig 2.4 Basic characteristics of change (Blok, 1999)

The temporal domain

Time in a system of geographical data can be considered as a sequence of states punctuated by events that transform one state into the next. States have duration, and are therefore represented by time-intervals (Langran, 1992). Each object mutation is an event that produces a new object version and map state. A version or state can be seen as a line segment that represents the duration of a condition, while a mutation or event is a point that terminates that condition and begins the next.

Changes in the spatial domain have a direct parallel in time. Considering the temporal domain the following concepts can be distinguished: moment in time, pace, duration, a sequence or order and frequency.

Moment in time
Refers to the instant of time of a certain state. E.g. a top10 vector dataset of June 2005 or a remote sensing image of the centre of Amsterdam on 18 August 2005.

Pace
Refers to the rate of change over time. It can be expressed in terms such as slow/fast; or at an increasing/decreasing/constant rate of change. E.g. the rate of deforestation or a flood according to remote sensing images.

Duration
Refers to the total duration of a state of a spatial phenomenon. It can be expressed in absolute or in relative terms (respectively number of time units, and notions such as short/long). E.g. the duration of a flood (according to a definition of a flood).

Sequence or order
Refers to the order of occurrence of states. E.g. crop cycles.

Frequency
Refers to the number of times that a state is repeated. E.g. how many times do floods occur in a certain area. Or what is the frequency of the crop cycle of rice.

Spatial and temporal changes are related; if for example land use changes, this has a direct temporal dimension. Parallels in spatial and temporal constructs are shown in table 2.1.

Table 2.1 Parallels in spatial and temporal constructs (Langran, 1992)

	Space (cartographic)	**Time (cartographic)**
Overall configuration	Map	State
Configurations separated by …	Sheet lines	Events
Regular sampling units	Cells	Hours, days, decades, etc.
Meaningful units	Objects	Versions
Separators between units	Boundaries	Mutations
Size measured by ...	Length, area	Duration
Position described by ...	Coordinates	Date
Continuous neighbours ...	Adjacent objects	Previous and next version
Maximum number of neighbours	Infinite	Two

2.5 Analysing spatial phenomena

In general analysing tasks in exploring spatio-temporal data questions can be related to:

- Time;
- Location;
- Geometry;
- Topology;
- Thematic data.

Questions related to changes in the landscape specific can be classified into the following categories:

- Qualitative change, what changed?
- Quantitative change, what are the relative magnitudes of change?
- Composite change, where more than one time slice is mapped, e.g. paths, time sequences, diffusion, cycles.
- Space-time ratios to describe such space-time interactions as travel times, cognitive spaces, or rates of spatial change.

Moving objects
Most geographical objects have a fairly static location. Moving objects give rise to some additional questions. Movement of an object in this context is defined as the change of coordinate of the centre of an object in a 3D (x,y,z) system. Questions related to movement of objects can be classified into the following categories:

- Overall view: what trajectories did the objects make during the whole time span considered?
- Moment view: where was each object at a selected moment?
- Comparison: how did the positions of objects change from moment t1 to moment t2?
- Interval view: what were the routes of the objects on the interval (t1-t2)?

Monitoring and planning

Two important research fields that study changes in spatial phenomena are monitoring and planning. Monitoring can be defined as a process of measuring and comparing of time series (mostly a quantitative analysis). Planning can be defined as a designing process via mostly qualitative methods focusing on synthesis. Both have a different approach in data handling and visualization. In both research fields the time aspect of geographical data plays a key role. Monitoring is a research field that studies past and present landscapes, while planning is about implementing possible future changes in geographical data. Some reasons for the monitoring of geographical objects or in other words the landscape are (Blok, 2000):

- Warn or act otherwise in case of undesired developments, like hazard.
- Models of reality, for example to estimate effects of interference or non-interference in a development.
- Predict future developments.

Some reasons for landscape planning:

- Predict the impact of future developments (scenario planning)
- Participatory and interactive planning

2.6 Conclusions

The ghost metaphor is about landscape and landscape change. Landscape is defined as the collection of physically visual spatial phenomena in the real world. And landscape change can be defined as the change of these visual spatial phenomena. Regarding the ghost metaphor spatial phenomena can be discrete or continuous as long as they are physically visible. Spatial phenomena can be described by their spatial and non-spatial characteristics; geometry and attributes. Changes can occur in both geometry and attributes. Spatial phenomena can appear, disappear, mutate and move. In theory, all of these changes seem possible to visualize in a ghostly-manor. E.g. the appearance of buildings, the growth of a tree (mutation) or the movement of vehicles. Considering the temporal domain mainly “moment in time” and perhaps “sequence or order” call up associations with the ghost-metaphor since it is about showing two time-frames. The ghost metaphor could be useful for landscape monitoring or landscape planning purposes because they are about changes in the landscape.

3. Visualization of landscape changes

This chapter will address the representation of spatial phenomena. First the different types of visualizations will be discussed and then geo-visualization as a data presentation technique will be discussed. The fourth paragraph explores different visualization methods. In the last paragraph the perception of visual representations is discussed.

3.1 Types of visualizations

One of the basic principles of geo-information science is the division between the representation of the real world by digital geographical data and the representation of the digital geographical data (MacEachren, 1999). A geo-visualization is based on data that forms a representation of the real world. The process of abstraction and representation of the real world is discussed in chapters three and four. The implementation of the conceptual data model by putting the descriptive data in the required data structure of a digital database is a computational process.

Finally there is the user of this geo-visualization. Each visualization has got a purpose and is aiming at a certain goal. The perception of the user and the type of user will determine the success of a geo-visualization.

2D, 2.5D and 3D

The relation between the digital representation of the real world by geographical data and the representation (visualization) of geographical data is shown in figure 3.1. The first column shows the available geographical datasets that exist. The 2D, 2.5D and 3D refer to subsequently two-dimensional referenced data (2D), digital elevation models (2.5D) and three-dimensional referenced, including three-dimensional topology, as known from computer aided design software (3D). The Δt points at continuous time series that are delivered by some spatio-temporal simulation models. The second row shows the possibilities to digitally represent these geographical datasets. Two-dimensional geographical data may be visualised in a two- (2D) or a three-dimensional (3D) way. The Δt in the second row points at the animations of the visualization.

	Visual representation			
Geographical data	2D	2D + Δt	3D	3D + Δt
2D				
2D + Δt				
2.5D				
2.5D + Δt				
3D				
3D + Δt				

Fig 3.1 Relation between geographical data and the visual representation (Lammeren et al, 2004).

3.2 Geo-visualization as a data presentation technique

Time in visualizations

The time dimension is difficult to define and can only be perceived by its effects. Like space, time is a continuous phenomenon but is treated as discrete in order to measure or represent it. There is much literature on the perception of time in the field of psychology and philosophers have given much thought to the nature of time and reality. The goal of this research however is not to visualize the whole reality, but to compare (2) different situations or time frames of the same spatial area. Hence, not so important is the discussion of what is time, but more what are the effects of time. What components of time are important to represent and how should they be represented.

The following major aspects of time relevant for the visualization of change arise from literature (Dibiase et al. 1990, MacEachren, 1995):

- *Order (succession)* refers to the sequential occurrence of frames or scenes.
- *Duration* refers to several different characteristics of events:
    - Every event persists for a certain duration.
    - Events are separated by intervals that may contain other events. The length of the intervals is of significance.
    - A relatively unified series of events forms an episode that continues for a certain duration.
- *Rate of change* refers to the difference in magnitude of change per unit of time. For each sequence of frames or scenes. Rate of change can be constant or variable. No change is zero rate of change.
- *Temporal frequency* refers to the occurrence of an event or state per unit of time. Temporal frequency is a ratio of two durations. For example the time from scene to scene compared to a unit time.
- *Display date* refers to the time at which some display change is initiated. Display date can be linked to a temporal location (chronological date). In a dynamic map a feature can be turned on a certain display date, for example, the creation of a geographical object.
- *Synchronization* (phase correspondence) refers to the temporal correspondence of two or more time series. This can apply to matching dates of two or more data sets. Data sets can be in phase or out of phase.

A 2D representation of geo spatial data is a map, but when a map is a part of an animation it can be considered a frame. A frame will be defined as a static digital representation of at least one geographical object at one moment in time. A frame represents a certain state. MacEachren (1995) introduces the next four temporal entities:

- Scene: a time period with no change.
- Episode: An identifiable stage in a sequence (a coherent set of scenes).
- Time phase: an identifiable stage in a cycle.
- Event: an identifiable break point or transition between discrete scenes, episodes or phases.

These temporal entities can consist of one or multiple frames. A state, scene, episode, time phase or event can also be represented in a static digital 3D world.

With this a (full) navigational digital 3D world is meant that presents at least one geographical object at a certain moment in time. A view on this world or a `screenshot` can be defined then again as a frame.

Besides database and world time there is display time which is independent of database time. So at least three different delta T's can be distinguished:

- World time
- Database time
- Display time

So in terms of display, the number of original data frames is decisive for the overall quality of the animation: the greater the number of original data frames the better the representation of the real-world situation.

For temporal animations, a critical concern is associating a proper time with various points in the animation. Temporal animations are often difficult to understand because it is hard (with a rapidly changing display) to keep track of the match between display time and real world time. This problem might be tackled through multimodal interfaces (for example, using sound to signify position in time so that vision is free to observe changes in the phenomenon depicted) (Slocum et al. 2001).

3.3 Quality of landscape visualizations

Visualization techniques have been an important subject of discussion by many authors. Especially with the appearance of the computer age and the increasingly powerful hardware, the aim of the discussion is more and more on the 'ethics' for defensible landscape visualization (Sheppard, 2001); what and how to visualize and not what can be done with all the new techniques.

Sheppard (2001) proposes a better framework (code of ethics) for defensible landscape visualization. The reasoning for this is that a relatively small group of people rule the landscape visualizations, while these visualizations are often meant for very different reasons and for different individuals and groups. This can lead to biased visualizations of geographical data.

Kraak (2002) claims among others for alternative mapping methods. To view geospatial data sets in a number of alternative ways, e.g., using multiple representations without constraints set by traditional techniques or rules. "New methods might offer insights and will probably have more impact than traditional mapping methods." It is in this framework that the ghost metaphor fits.

3.4 Visualization methods

Time-slice snapshots

Time-slice snapshots are a space-time model with roots in traditional cartography, imitating the progressive nature of a slow-motion video (Langran, 1992). The individual time slices represented by maps describe the situation at the times of map creation (fig. 3.2). Thus the snapshots represent states rather than changes, providing no information on how to go from one state to the next. The various map series are usually many years apart, causing a very low temporal granularity. Traditionally, time-slice snapshots have been used extensively in time-series animation (e.g. Acevedo & Masuoka, 1997). This model is based on the selection of snapshots at critical times. A disadvantage is that it leads to preconceived ideas of what is critical (Hoinkes & Mitchel, 1994).

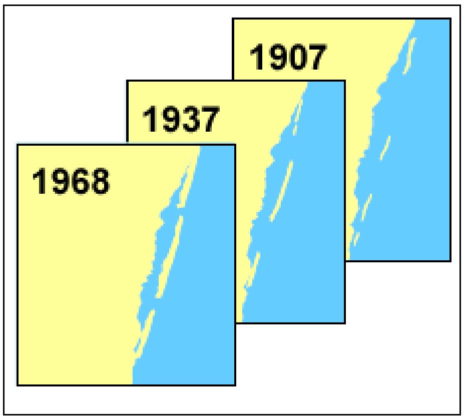

Fig. 3.2 Time-slice snapshots

Animation

In its simplest form, a cartographic animation can consist of only two maps, thus two frames. Viewed in quick succession, these maps can depict a trend or a pattern that would not be apparent if the maps were viewed individually. Creating this `pattern in space and (animation) time' is the purpose of cartographic animation, much as the purpose of a static thematic map is to create a pattern only in space (Peterson, 1999).

Cartographic animation is in fact an automated presentation of time-slice snapshots. The creation of cartographic animations takes many steps and usually takes several software packages to achieve the desired end result. Software packages like movie tools, image processing programs and custom developed software are often used (Acevedo & Masuoka, 1997). In general most animation methods render spatial data in a bitmap, gif, etc. One bitmap is created for each discrete time step in a series. The bitmaps are then displayed in succession creating an animation (Iwerks & Samet, 2000).

Use of animations:

- To visually represent simulations. For example hydrological simulations, growth simulations, economical simulations, etc.
- To represent (moving) objects. For example, police-cars, hunters, etc. Everything that can be (GPS)tracked. This can be done in real-time, but also in all different kinds of replay.

The use of drawings, models, computer presentations and maps are common use in supporting spatial planning. The fast growing possibilities of graphical imaging and more powerful hardware, spreads the use of animations to many other areas of human activity. Participatory planning can be aided by the use of visualizations and animations by giving stakeholders a better insight to the actual meaning of spatial plans. Involving stakeholders (for example citizens) in spatial planning by using visualizations and/or animations can aid the process by making the spatial meaning more concrete. High impact spatial plans on forestation and flooding areas, etc. gain in concreteness and are easier to discuss (Twist et al., 1998).

The optimal animation has to be measured in the light of the original data provided. The number of original data frames is decisive for the overall quality of the animation; as expressed before, the greater the number of original data frames the better the representation of the real-world situation (Acevedo & Masuoka 1997). The display speed for a spatio-temporal animation is decisive for the communication of changes in space and time. Following Acevedo & Masuoka (1997) the optimal display speed is dependent on human visual perception and cognition, the objectives of the animation, and the rate of change within the data. Obviously, an interactive display environment, which encourages the user to select an appropriate display speed, is preferable.

3D visualization of 2D data

The VisualScan project aimed to reconnaissance the domain of geo-visualisation in relation to the visual presentation of the RuimteScanner output data. The RuimteScanner application calculates by spatial and economic variables future land use classes. These calculations are initiatory based on a scenario modelling approach. The primary project objective, as defined by RIVM, was to find a way to visualise the RuimteScanner data in a so-called semi-realistic three-dimensional way. To do so the differences between geographical data and geographical data visualisation (geo-visualisation) are explained. Based on this explanation two VisualScan implementations have been elaborated upon: the Land Use Icon approach was one of them. The Land Use Icon approach links the RuimteScanner output data to 3D models, the so called land use icons (LUI) (fig. 3.3 & 3.4). The implementation to link, render and animate the data is based on the use of a game tool. This approach shows how a semi-realistic 3D presentation of the RuimteScanner data could be created out of grid cell data (Lammeren, 2004).

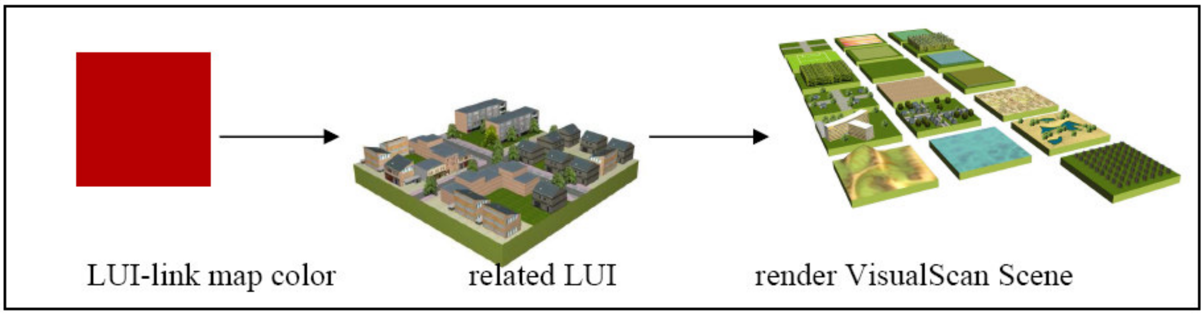

Fig 3.3 From 2D data into 3D visualisation: subsequently phases (Lammeren, 2004)

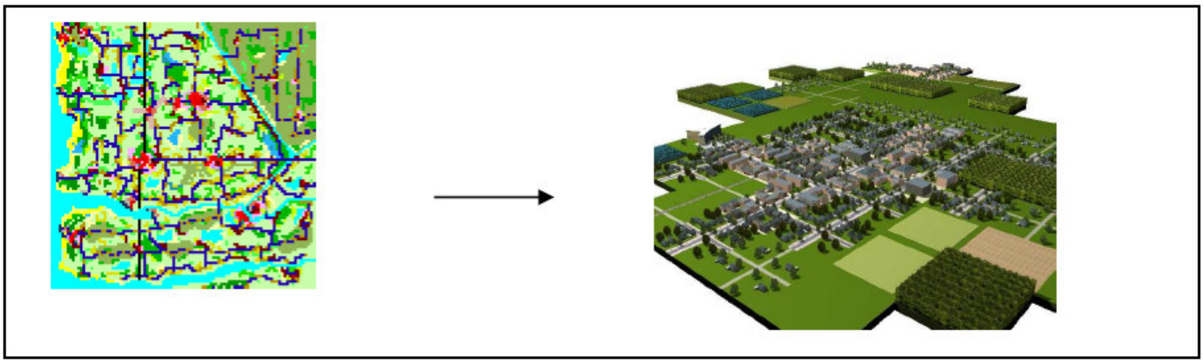

Fig. 3.4 From 2D data into a VisualScan Scene (Lammeren, 2004)

Virtual Reality

The introduction of the computer and in particular the research on flight simulators by NASA has led to contemporary visualisation possibilities. Simulators offer the user(s) a dynamic and interactive environment (sometimes called "Virtual Reality" – VR-) to perceive, to explore and to manipulate visual representations of possible, probable and real worlds. To realise such 'cyber spaces' the visualisation should be three-dimensional and be based on two- or three-dimensionally geo-referenced geodata sets (Lammeren, 2004).

Virtual reality, and in fact geo virtual reality (GeoVR) exists of several components that can be illustrated by the metaphor of the peep box (Lammeren & Hoogerwerf, 2003) (fig. 3.5). The expected importance of the GeoVR is explicitly based on interaction, simulation and feedback. These three functions offer a peep box that supports an immersive, dynamic and reflective research and communication environment.

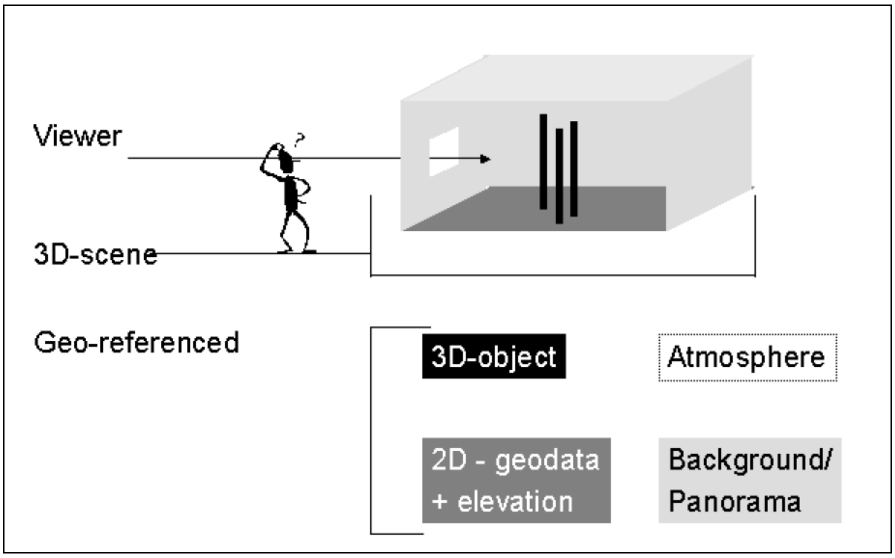

Fig. 3.5 The peep box approach of Virtual Reality (Lammeren, 2003)

3.5 Perception of visual landscape representations

Even when actual motion is smooth and continuous, people may conceive of it as composed of discrete steps (e.g. Hegarty, 1992). If motion is conceived of in discrete steps instead of continuously, then the natural way of conveying it may be to portray it in discrete steps rather than in a continuous animation. This is quite common in pictorial instructions for complex motion, such as operating a machine or assembling an object, where each step is portrayed in a separate frame and the frames ordered by the sequence of steps. For simple motion, as in the path of an object or the flow of control or electricity through a system, a single diagram can convey the path, indicated by lines and arrows. In addition to corresponding to the way people conceive of animations, these diagrammatic devices have an additional advantage: they easily allow comparison and re-inspection of the details of the actions. By contrast, animations are fleeting, they disappear, and when they can be re-inspected, they must usually be re-inspecting in motion, where it may be difficult to perceive all the minute changes simultaneously (Morrison, 2000)

The effectiveness of animation techniques to present time-series cartographic data to a user is studied in Koussoulakou & Kraak (1992). Animation can be effective for helping to detect patterns or trends over time in spatial data. The study of Iwerks & Samet (2000) concluded that animation may be able to help decrease the amount of time needed for a user to comprehend time-series spatial data and to answer questions about it compared with other methods. Disadvantages of animated visualization are the loss of ability to see everything at once and that one has to rely on spatiotemporal memory to link what we are seeing now with what took place before (MacEachren, 1995, p425). This applies to 2D as well as 3D visualizations. In addition a 3D display has the disadvantage of producing a scene we can no longer see at once. The adding of movement can also be a disadvantage. According to Bertin (1981) this is so dominating the perception that it severely limits the attention which can be given to the meaning of other variables.

3.6 Conclusions

Important to notice when relating the information of this chapter to the ghost-metaphor is that authors claim for alternative visualization methods (e.g. Kraak, 2003) and that others (e.g. Sheppard, 2001) try to set out rules for the visualization of geographical data. These together forms the framework in which the visualization of the ghost-metaphor fits.

Another interesting matter is the differing thoughts of authors about animation. By many a smooth animation is thought to be the best way to visualize spatio-temporal data (e.g. Acevedo & Masuoka, 1997). While others (Morrison, 2000) criticize the functionality of a smooth animation and point at the perception of time in discrete steps. This perception of time in discrete steps gives extra support to the design of a ghost visualization showing two frames in one view and to test how this is perceived by the human eye.

Objects can be represented in many different ways. The ghost-metaphor is about 3D scenes so 3D visual representation of objects should be used in a ghost visualization. Based on what geographical data these visual representations is not of importance.

4. Results and discussion

This chapter discusses the implementation of the ghost metaphor. The test visualization and the results of the questionnaires are presented and discussed.

4.1 Test visualization

The visualizations of the ghost metaphor can prove the readability and usability of showing the difference between two moments in time in a 3D scene. To determine what geographical data and what kind of changes are best suited for the implementation of the ghost metaphor many combinations of geographical data, types of changes and visualization techniques can be made. The ideal test application should include different visualizations of change in both geographical data components attributes and geometry. This makes it possible to test which kind of geographical data component is best suitable for the visualization of the ghost-metaphor. Different types of change in spatial attributes should be visualized if possible. Considering the time-span of this research and technical constraints a selection of geographical data and the kind of change to visualize in the test design is made.

The visualization is based on a real world case. Together with a project developer, the municipality of Heumen has planned a 5 to 7 hectare business park near the village of Overasselt. Overasselt can be described as a rural village and has approximately 2500 inhabitants. The business park is planned near the main roads to Overasselt and is considered to be the entrance of the village. A citizens workgroup wants to maintain the rural identity of the village. They would like to have a 3D computerized visualization of the business park to support the discussion of how the identity of this area can be maintained and what the new business park should look like. This visualization is based on the plans created by the project developer combined with the ideas of the workgroup. Also the municipality has stated that research on the visual impact of the new business park should be done.

The basis for the visualization is a vector dataset (top10Vector) of Overasselt and its close surroundings in the current situation. The parcels and the layout of the buildings were drawn in by hand. The buildings were extruded to create a 3D look. To create a more realistic visualization 3D trees were put in based on point data of trees and forest.

The business park is represented in the visualization as some buildings (volume) and a road (area). Two types of visualization techniques will be used to represent the buildings and the road, they are transparency and hatching (Table 4.1). In total three scenes were created (fig. 4.1, 4.2 & 4.3). The current roads and buildings will be solid and provided with a representative colour based on common map colours.

Table 4.1 Representation of the new objects in the visualizations of the ghost metaphor

	Visualization 1 (fig. 4.1)	**Visualization 2** (fig. 4.2)	**Visualization 3** (fig. 4.3)
Volume (buildings)	transparent	transparent	hatched
Area (road)	transparent	hatched	hatched

The created scenes can be shown in different ways to a viewer

- A still frame (screenshot) of a VRML world or viewpoint
- As a navigational world (e.g. VRML or ArcScene)
- A movie

For the purpose of this research a movie file (avi) was chosen. Three different visualizations where made and of each a movie was made following an identical flight path. The movie file is easily transportable, and it can be played on nearly any personal computer. Another advantage is that each viewer sees the exact same view on the scene as an identical flight path is used for each movie.

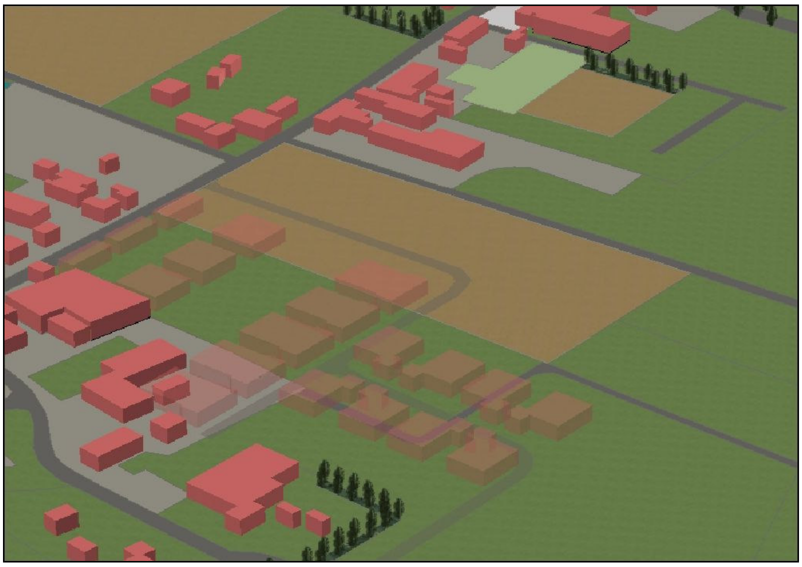

Fig. 4.1 Visualization 1

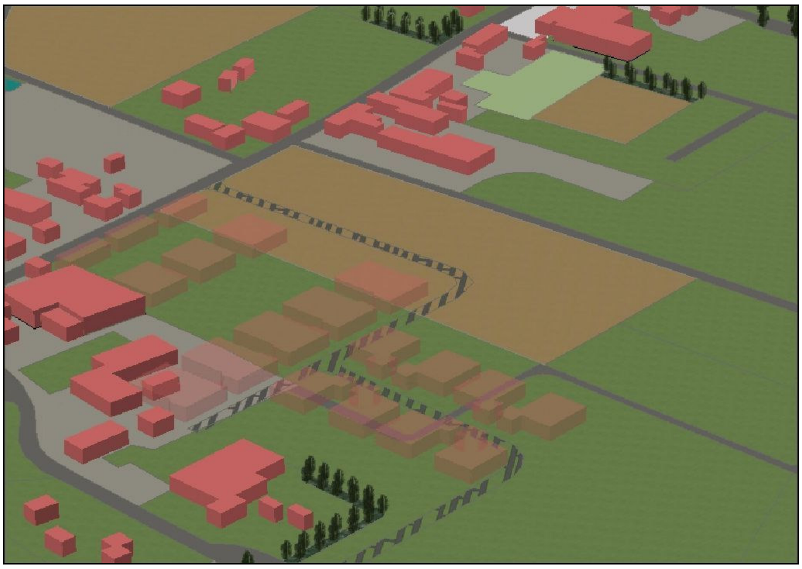

Fig. 4.2 Visualization 2

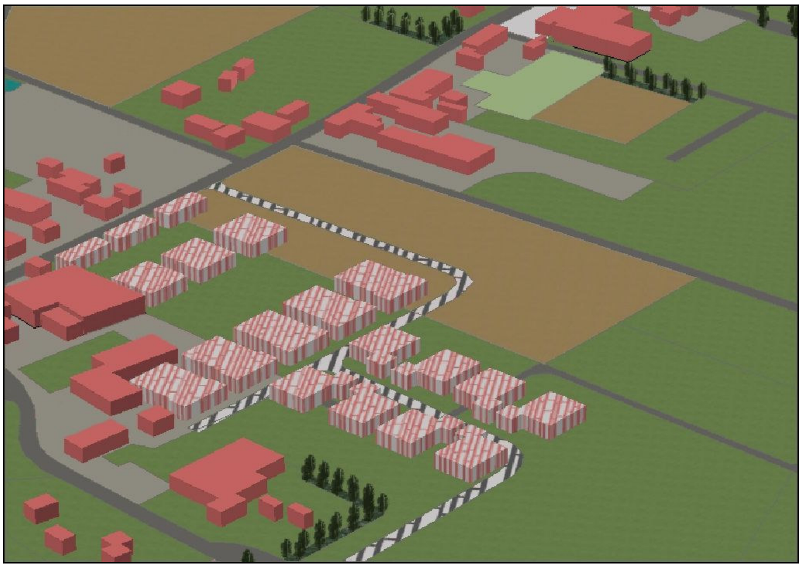

Fig. 4.3 Visualization 3

4.2 Research design

To test the visualizations on their effectiveness, that is whether a visualization of two situations in one view is readable, the movies were shown to a group of people. All test persons were shown three movies. The movies were shown in the same order as their number, so visualization 1, visualization 2, visualization 3. The respondents were placed alone in front of a PC with a 19 inch CRT monitor. The movies where shown in Windows Media Player 10 in full screen mode. After the viewing of a single movie they were asked to answer the corresponding questions. During the answering of the questions they were allowed to review the movie or parts of it. They also had the option to "pause" the movie at any given moment. The questions can be found in appendix I.

In total 14 respondents viewed the movies and answered the questions. To prevent any bias regarding landscape visualization none of the respondents had more than average knowledge, experience, or training in the field of GIS or geographical visualizations. The age of the respondents varied from 23 to 58 years.

4.3 Results

In this paragraph the results of the questionnaires are presented per visualization. The answers to the questionnaires are shown in the tables. In some tables the questions are divided into 'change related answers' and 'non change related answers'. With 'change related' it is meant: an answer that refers to a description of two moments in time, for example past, future or planned building versus existing buildings. Descriptions like 'buildings under construction' or 'newly built houses' are thus non change related answers as they describe the objects as being there at the moment. From both categories, change and non change related answers, the total is noted. Finally the results of the three visualizations will be compared.

Response on visualization 1: transparent buildings and transparent road

What do you think the visualization represents?
All respondents were able to recognize the general meaning of the scene. Most people defined the scenes as a development plan or used other terms which describe a situation of change (79%). 21% of the respondents described it as a static situation in terms like ‘a model of a village’.

Table 4.2 Question 1: What do you think the visualization represents?

Answers	**Count**	**%**
Development plan	3	21
Development of buildings	2	14
Visualization of a development plan	2	14
A 3D map of a development plan	1	7
A model of a development plan	1	7
Landscape and urban planning	1	7
An overview of urban area and expansion of urban area	1	7
A village surrounded by grasslands	1	7
A model of a village	1	7
A map of a village, shown from all directions	1	7
Total	14	**100**

Buildings (volumes)

Eleven of the respondents (79%) linked the transparent buildings to a difference in time, e.g. as buildings that have to be built or buildings that stood there in the past. From these ten people eight (57% of the total) corresponded them to future buildings and two explained them as beings either future (appearing) or past (disappeared) buildings. One respondent associated the transparent buildings with buildings that will be built or that will be removed in the future. The non-time related answers (21%) varied from just ‘buildings’ to ‘buildings that stand in the water’.

Table 4.3 Question 2: What do you think the transparent pink objects represent?

Answers	**Count**	**%**
Houses to be built	8	57
Houses to be built or that stood there in the past	2	15
Houses to be built or that will be removed	1	7
Total change related answers	11	**79**
Buildings	2	14
Buildings in the water	1	7
Total non change related answers	3	**21**

Table 4.4 Question 3: What do you think the solid pink objects represent?

Answers	**Count**	**%**
Present day houses	9	65
Buildings	3	21
Buildings that are not 'selected'	1	7
Factories	1	7
Total	14	**100**

Table 4.5 Question 4: What do you think is the difference between the solid and transparent pink objects?

Answers	**Count**	**%**
Non-transparent are present day objects, the transparent objects will be built in the future	6	43
Transparent objects do not yet exist	2	14
Existing versus non existing	2	14
Time	1	7
Transparent objects have to be built or will be removed	1	7
Total change related answers	12	**86**
Transparent objects stand in the water	1	7
Transparent objects represent sites that are not suitable for a certain purpose	1	7
Total non change related answers	2	**14**

Road (area)
Nine respondents (64%) were able to detect the transparent road. And six (43%) of them associated the transparency with the appearance or disappearance of the road. Some thought it was a piece of road that 'was not selected' or simply had no explanation for the meaning of the transparency. These were the same people who gave non time related answers about the transparent buildings.

Table 4.6 Question 5: What do you think the grey linear areas represent?

Answers	**Count**	**%**
Roads	10	72
Parcel structure	2	14
Infrastructure	1	7
Parcels, roads, ditches	1	7
Total	14	**100**

Table 4.7 Question 6: Did you see a transparent linear area, if so what do you think it represents?

Answers	**Count**	**%**
No	5	**36**
Yes, a future or planned road	6	43
Yes, roads or ditch in the future or the past	1	7
Total change related answers	7	**50**
Yes, dont know	1	7
Yes, 'non selected' roads	1	7
Total non change related answers	2	**14**
Total Yes	9	**64**

Response on visualization 2: transparent buildings and hatched road

Question 7: What do you think the visualization represents?
All but one respondent referred to their answer for the first question or gave the same answer as they gave for the first question. Only one respondent (7%) gave a different answer, he or she explained the second movie as: "Visualization following on from movie 1 showing the 'proposed modifications'."

Buildings (volumes)
86% of the respondents gave the same answers to or referred to the answers they gave to the questions about the buildings from the first visualization. The person who

thought the transparent buildings in movie 1 where 'not selected' now described them as 'buildings not fitting in some development plan'. Another respondent now describes the solid pink objects as grass lands.

Table 4.8 Question 8: What do you think the transparent pink objects represent?

Answers	Count	%
Houses to be built	8	57
Houses to be built or that stood there in the past	2	14
Houses to be built or that will be removed	1	7
Total change related answers	11	**79**
Buildings	1	7
Buildings in the water	1	7
Buildings that do not occur in a certain development plan	1	7
Total non change related answers	3	**21**

Table 4.9 Question 9: What do you think the solid pink object represent?

Answers	Count	%
Present day houses	9	64
Buildings	3	21
Buildings that do occur in a certain development plan	1	7
Grass lands	1	7
Total	14	**100**

Table 4.10 Question 10: What do you think is the difference between the solid and transparent pink objects?

Answers	Count	%
Non-transparent are present day objects, the transparent objects will be built in the future	6	43
Transparent objects do not yet exist	2	14
Existing versus non existing	2	14
Time	1	7
Transparent objects have to be build or will be removed	1	7
The changes between the current and the planned situation	1	7
Total change related answers	13	**93**
Transparent objects stand in the water	1	7
Total non change related answers	1	**7**

Road (area)

79% of the respondents corresponded the hatched road with a future road or road that was there in the past. Other respondents (14%) related the hatching to the nature of the road, like being underground or closed for certain traffic. One respondent explained the hatched area as a row of trees.

Table 4.11 Question 11: What do you think the grey linear areas represent?

Answers	Count	%
Roads	11	79
Infrastructure	1	7
Roads	1	7
Existing roads	1	7
Total	14	**100**

Table 4.12 Question 12: What do you think the shaded linear areas represent?

Answers	Count	%
A planned road	10	71
A former road or a planned road	1	7
Total change related answers	11	**79**
A road forbidden for traffic	1	7
Something underground or alternative traffic	1	7
Trees	1	7
Total non change related answers	3	**21**

Response on visualization 3: hatched buildings and hatched road

Question 13: What do you think the visualization represents?
All but one respondent referred to their answer for the first question or gave the same answer as they gave for the first question. Only one respondent (7%) gave a different answer, he or she explained the third movie as ‘a visual representation of changes in development plans’ .

Buildings (volumes)
Most respondents (57%) related the hatched buildings as buildings that will appear in the future or are planned to be built. Five respondents (36%) explained the hatched buildings as newly built buildings or under construction and the solid as “old” buildings, but both solid and hatched are there at the moment. Another person explained the hatched buildings as greenhouses. Interesting to note is the reaction of a respondent who related the transparent buildings in the other movies to buildings in the water. This respondent explains the hatched buildings as future buildings.

Table 4.13 Question 14: What do you think the shaded objects represent?

Answers	Count	%
Planned buildings	7	50
Total change related answers	7	**50**
Newly built houses	3	21
Buildings under construction	2	14
Greenhouses	1	7
Buildings	1	7
Total non change related answers	7	**50**

Table 4.14 Question 15: What do you think the non-shaded pink objects represent?

Answers	Count	%
Existing buildings	12	86
Buildings	2	14
Total	14	**100**

Table 4.15 Question 16: What do you think is the difference between the shaded and non-shaded pink objects?

Answers	**Count**	**%**
Existing versus future	4	29
The hatched objects do not yet exist	3	29
Difference in time	1	7
Total change related answers	8	**57**
The hatched objects are under construction	2	14
The hatched objects are younger	2	7
The hatched objects represent a change	1	7
Use of different building materials or type of building	1	7
Total non change related answers	6	**43**

Road (area)

Most respondents (57%) explain the hatched road as a road that will be built in the future. The other 43% of the respondents related the hatching to the nature of the roads in the same way as for the hatched buildings. They explained it as ‘road under construction’ (29%) or a ‘new type of road’ (7%).

Table 4.16 Question 17: What do you think the grey linear areas represent?

Answers	**Count**	**%**
Roads	12	86
Existing roads	2	14
Total	14	**100**

Table 4.17 Question 18: What do you think the shaded linear areas represent?

Answers	**Count**	**%**
Planned road	10	71
Total change related answers	10	**71**
Newly built road	2	14
Roads used for agricultural purpose	1	7
A not yet existing form of infrastructure	1	7
Total non change related answers	4	**29**

Comparison of the visualizations

When comparing the answers that the respondents gave to the different visualizations the following remarks can be made.

General

For all of the three visualizations the majority of the respondents (50-93%) describe the different visualization techniques used for the same type of objects (e.g. transparent versus solid buildings) as some sort of change (Table 4.18).

Each visualization had the same questions linked to it: one question about the general meaning of the visualization, three questions about the buildings and two about the roads. Most people gave the same answer to each similar question, but some did not. This inconsistency is illustrated by the fact that according to the answers on question 4 (table 4.5), two people did not relate the difference between transparent and solid objects to some sort of change. But according to question 10 (table 4.10), only one person did not relate the difference between transparent and solid objects to a change in time. While these are the exact same questions about the exact same objects.

In the first two visualizations the percentage of change related answers to explain the difference between the transparent and non transparent buildings is higher than the change related answers for the roads. Only in the third visualization do a higher percentage of people give a change related answer to explain the difference of visualization of the roads.

Two types of objects are shown in all three visualizations: solid pink buildings and grey roads. Each time a visualization is watched the same question is asked about these objects (Table 4.4, 4.6, 4.9, 4.11, 4.14, 4.16) . The number of different answers to describe these objects decrease towards the end of the test. In the first visualization four different explanations were given for the buildings (solid pink) and also four for the roads. In the last visualization for both only two different explanations are given.

Table 4.18 The total of change and non change related answer per visualization per object.

	Visualization 1 (fig. 4.1)		**Visualization 2** (fig. 4.2)		**Visualization 3** (fig. 4.3)	
Question	4 (tab. 4.5)	6 (tab. 4.7)	10 (tab. 4.10)	12 (tab. 4.12)	16 (tab. 4.15)	18 (tab 4.17)
Object	Volume (buildings)	Area (road)	Volume (buildings)	Area (road)	Volume (buildings)	Area (road)
Change related answers (%)	86	50	93	79	57	71
Non change related answers (%)	14	14	7	21	43	29

Buildings
In response to the first two movies an almost equal majority (86-93%) explain the difference between transparent and solid buildings as some sort of change in time like the appearance or disappearance of a building. The third visualization shows the buildings as hatched objects, then only 57% of the respondents give a change related explanation for the difference between the hatched and solid buildings.

Roads
The hatched roads (visualization 2 & 3) clearly have the highest percentage of change related explanations. The transparent roads in the first visualization were not detected by 36% of the respondents and therefore only 64% of the respondents gave an explanation for the transparent road.

4.4 Discussion

The questionnaires related to the three visualizations showed that the ghost metaphor can work in a visualization of changes in a landscape. Interesting to note is how different techniques for showing old or new objects in a landscape can 'work' or 'not work' depending on the viewer.

Twelve out of fourteen (86%) respondents related the transparent volume objects (buildings) in the first visualization to a difference in time or as a change, two (14%) respondents did not make that association at all. Interesting is that one of these respondents did have this association as the objects (buildings) were hatched in the last visualization. There were two respondents who showed the opposite reaction. They related the transparency to the appearance or disappearance of a building, but they explained the hatching as 'buildings under construction', so as a different type of building.

Some specific effects about the use of transparency and hatching can be discovered in the results. Transparency seems a good technique to represent volumetric objects that appear or disappear, hatching is less successful to do this. The new roads (2D areas) seem to be best represented by hatching, the use of transparency seems no alternative in the visualizations because 36% of the respondents did not even see the transparent road. When hatching is used to represent the future road 79-86% explain this as a planned or former road. The effective use of hatching can perhaps be explained by the use of hatching in 2D visualizations like planning maps of development plans, where future landscape features are often displayed as hatched areas.

The ghost metaphor does probably not offer the best opportunity for displaying space-time patterns. An animation is far more suitable, because herein aspects such as duration and rate of change can be depicted. Cyclic patterns and frequency cannot be visualized using the 'two moments of time in one view' approach. The advantage of a ghost visualization, over an animation is that the information does not disappear, but can be visualized constantly. In a ghost visualization a direct visual insight can be given of where changes took or will take place.

This study investigates human perception when using transparency in 3D computer graphics environments. Transparency has been discussed as a variable for the visualization of 2D data on maps. MacEachren (1995, p437) mentions transparency as a sub variable of clarity. This variable was not tested but is assumed to be most useful for representation of uncertainty: "They may prove to be most practical in an interactive setting in which an analyst is able to toggle them on and off when needed." (MacEachren, 1995, p437). However this assumption was made for visualization in 2D, one could say this study partly underlines this assumption for a 3D visualization, as some of the respondents referred to the transparent buildings as 'planned buildings'. This description relates to a certain degree of uncertainty. The majority of the respondents however related the transparency, especially for the buildings (volumes) to a time relation.

The test movies and the questionnaires used in this research were able to give some information on how people perceive transparent and hatched objects in a landscape visualization. It also proves that the ghost metaphor is a possible visualization technique in landscape visualization. By no means however does this test show the true possible effect and usability of transparency and hatching in landscape visualization; it only gives an indication. The use of several movies and the use of a questionnaire has a certain impact on the results of this test. Some of the respondents tried to see relations between the different movies, so the order in which they are shown can be of importance to the answers people give. Also the content of the movies plays a role for the conclusions that are made on the effect of transparency and hatching. No movie for example was shown in which both hatched, transparent and solid buildings were depicted. Also the questionnaire itself influenced the respondents, because the movies changed and the questions per movie mostly did not, so that many of the respondents thought they were giving the wrong answers. The conclusions of this research are only valid for the presented information in the movies. Which means only for a specific landscape change. Many other types of landscape change exist as described in this paper.

5 Conclusions and recommendations

5.1 Conclusions

The general objective of this research was to develop and test a 3D visualization technique for the visualization of change in a landscape, showing two different situations visible in one view (ghost metaphor), in a 3D virtual GIS environment. The following conclusions can be made.

It seems the use of transparency is a good technique to visualize future or past buildings in a computerized 3D landscape visualization. **The hypothesis of this research "The ghost function in computer games provides a good metaphor to visualize changes in computerized 3D landscape visualizations in one view", can be stated true.** This statement is further defined by answering the research questions.

What landscape changes are suitable for visualization of two different situations in one view?
It appears that the visualization of volumetric objects like buildings and areas like roads that either appear or disappear from a landscape or scene are a suitable change to visualize 'ghostly' in a computerized 3D environment. Two techniques that can be used to visualize the appearing or disappearing objects are hatching and transparency. Transparency is the best technique for the visualization of appearing or disappearing volume objects (buildings). Hatching is the best technique for the visualization of appearing or disappearing area objects (roads).

Is it possible to implement the "ghost function" of games in a 3D computerized visualization of landscape change?
The presented visualization in this research was understandable for the majority of the people, even though there was no legend or explanation present in the visualization about its purpose or meaning. The test visualization intended to show two different moments in time in on view. A majority (50-92%) of the respondents described the visualizations as showing a change in the landscape. They explained the visualizations as showing current and past or future landscape elements.

5.2 Recommendations

As the ghost metaphor is about trying different visualization techniques to represent old or new objects it is interesting to do a research in software. This research is based on how changes are represented in racing games. Change of objects and time play a very important role in computer games. Just think of the many simulation games, they vary from theme parks, to cities, to railways. It would be very interesting to see what and how changes over time are represented in these computer games and see how these techniques could improve or enrich landscape visualization.

An important subject of this research was landscape change and how it can be visualized. The final application and the questionnaire were merely a way to prove, if at least under certain circumstances a ghost visualization is realisable. A very interesting subject is the perception of people considering visualizations. From my own observation there seemed to be clear relation between the respondents' age, gender and background and how they perceived the movies and answered the questions. For example, one elder respondent clearly got confused by the visualization. Some questions were not answered or with ‘no idea’, while most of the young respondents had absolutely no problem to recognize what was shown in the visualizations. Further research could be aimed at this subject, as it would contribute to the insight of how landscape visualizations should look and for what purpose they can be best used.

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