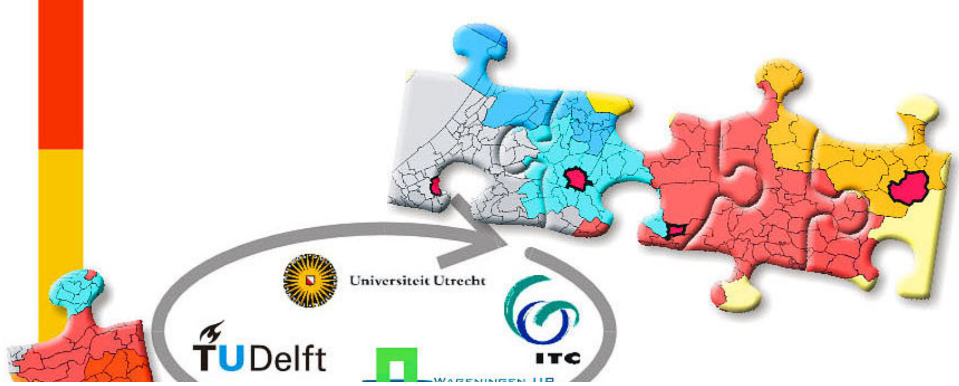
GIMA

Geographical Information Management and Applications

Functionalities of geo-virtual environments to visualize urban projects



Functionalities of Geo-VE to visualize Urban Projects

Mahmud Shahrear Kibria
Geographical Information Management & Applications (GIMA)
Research conducted at OTB, TU Delft
Email: m.s.kibria@tudelft.nl

Supervisor
Dr. Dipl.-Ing. Sisi Zlatanova
GISt, OTB TU Delft
Jaffalaan 9, 2628 BX Delft
Email: s.zlatanova@tudelft.nl

Supervisor
Dr. Ir. M.J. van Dorst
Technical Environmental Design
Department of Urbanism, TU Delft
Berlageweg 1
Email: M.J.vanDorst@tudelft.nl

Supervisor
Dr. L.C.M Itard
Sustainable and Healthy Housing
OTB, TU Delft
Jaffalaan 9, 2628 BX Delft
Email: L.C.M.Itard@tudelft.nl

Reviewer
Ir. John Stuiver
GIS Support and Education
Room C308a, Gaia, Building 101
Email: john.stuiver@wur.nl

Professor
Dr. Peter van Oosterom
Professor of GIS-technology
GISt, OTB TUDelft
Jaffalaan 9, 2628 BX Delft
P.v.Oosterom@otb.tudelft.nl

"There is a fundamental law about the creation of complexity …(which) states simply this: all the well-ordered systems that we know in the world, all those anyway that we view as highly successful, are generated structures, not fabricated structures."

Architect and Philosopher Christopher Alexander
The Nature of Order, Book 2: The Process of Creating Life.

Received	Dr. Zlatanova	Dr. Itard	Dr. Machiel	Ir. Stuiver	Dr. Oosterom	Date
Draft 1.1	X	X	X			13/1/08
Draft 1.2	X	X	X	X		22/1/08
Draft 1.3	x	x	x	x	x	10/02/08
Final	x	x	x	x	x	15/02/08

Acknowledgment

In 2007, I had a constructive talk with Dr. Sisi, Zlatanova on the use of new media like Google Earth as an interaction tool. She was enthusiastic about new research frontiers for the use of such environments in the planning process of urban projects. This thesis is dedicated to Dr. Sisi Zlatanova for her tremendous effort and time spent on the research. Without her advice and active participation, the thesis would have not become reality.

I would like to thank Dr. Laure Itard and Dr. Machiel van Dorst for their input in this thesis. The periodical SUA (Sustainable Urban Areas) meetings have produced fruit and provided valuable input. I would like to thank Dr. Professor Peter van Oosterom for arranging everything at OTB, TU Delft.

I would like to express gratitude to Ir. John Stuiver for his efforts as the reviewer. Finally I would like to dedicate the thesis to motherly Susan van der Brugge and my mother Lutfun Nahar for their patience.

The thesis is written in *t*hird person from here on.

Mahmud Shahrear Kibria

MSc. Student
GIMA (Geographical Information Management and Application)
OTB, TU Delft
10th of February, 2008.

Table of Content

List of Tables

List of Figures

Abbreviations

AR	Augmented Reality
BOOM	Binocular Omni Orientation Monitor
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual environment
CityGML	City Geographic Markup Language
COLLADA	COLLAborative Design Activity
CRT	Cathode Ray Tube
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DSS	Decision Support Systems
FOV	Field of View
GE	Google Earth
GIMA	Geographical Management & Application
GIS	Geographic Information System
GML	Geography Markup Language
GUI	Graphic User Interface
G-VR	Geo-Virtual Reality
HCI	Human Computer Interaction
KML	Keyhole Markup Language
LOD	Level of Detail/Definition
MV	Model View
OGC	Open Geospatial Consortium
PPS	Public Participation System
PSS	Planning Support System
PV	Plan View
RE	Requirement Engineering
VE	Virtual environments
VR	Virtual Reality
VRML	Virtual Reality Markup Language
WV	World View
X3D	Extensible 3D

List of Annexes

PROPOSAL AND METHODOLOGY

CHAPTER 1

Abstract

This Master of Science thesis states the taxonomy of functionalities and the visual materials of geo-virtual environments for the visualization of urban projects. The core of this visualization thesis is based on a requirement analysis process using the software approach of Requirement Engineering. It contains two important aspects. The requirement analysis part of the thesis identifies the functionalities that can be used in visual interaction between actors in the planning process. The second aspect of the thesis investigates the use of visual materials in geo-virtual environments to visualize the different planning phases of urban development. The relationship between the urban planning phases and the use of multi-dimensionality, realism and Levels of Detail (LoD) in models has been established here. Through observation, the thesis has analyzed the relationship between the use of visual materials and the human perception to understand them. Moreover, it has stated a process to create 3D base models on the basis of geo-data through widely used GIS software.

The thesis elaborates the functionality domains of geo-virtual environments through the introduction of the construction, capabilities, experiencing, controlling, use, exploration and components functionalities. This taxonomy is achieved through the analysis of requirements of specific Dutch municipalities. These functionalities can be used for collaborative design process by the municipalities and facilitate visual interaction with actors like citizens. Based on the requirement analysis, the thesis sheds light on the knowledge-gap with regards to the classification of functionalities and visual materials. It uses scientific methods, provides results, extensively analyzes the outcome and states the core findings at the end.

1 Empirical Motivation

The initial motivation of this Master of Science thesis comes from the research done by Riedijk et al (2006) and Hoogerwerf et al (2006) in their quest to analyze the impact of digitalization of spatial plans in the planning process. There is an ongoing research program at Delft University of Technology on Sustainable Urban Areas (SUA) where the research institute OTB, Architecture, Civil Engineering and TBM faculties of TU Delft are investigating the usability of new interaction tools for sustainable urban development. This Master in Science thesis is a part of the SUA project. In the Netherlands, there is a growing demand for interaction between the actors involved in urban renewal and design (Adriaens et al, 2005). Visualization functionalities can facilitate the actors to understand and interact in the design process. Such interaction can play a pivotal role in diminishing the risks of making irreversible mistakes.

There have been many cases of building virtual city models using CAD, GIS systems and visualizing these 3D city models in virtual reality in the last few years (Batty M, 2000). In the last decade, there have been 3D applications for visualization in virtual environments to support collaborative urban planning (Gaborit & Howard, 2004). Such urban city models can be useful to combine the existing situation with the proposed design and verify the problems that might occur as the urban design process moves forward. If 3D models are visualized in geo-VE various users can navigate, explore, and manipulate the information and interact with the models. While the existing buildings in the city can be made in various semi-automatic processes, newly designed areas can be added to such city models. This process makes the design interactive and realistic in the space-time continuum. Such virtual environment can be used as an interaction tool for the designers in the municipalities to communicate with other actors.

In the Netherlands, the municipality of Rotterdam has a recent pilot project to visualize urban projects in Internet based virtual environments by implementing international standards (CityGML, KML and X3D, etc). Municipalities of Helmond, Apeldoorn and Tilburg have already implemented Internet based virtual environments for disseminating 3D models and spatial plans for the citizens. Amsterdam city is now available in 3D in Google Earth and Second Life. With the availability of data, advances of technology and the availability of fast Internet, certainly more will follow. The main reason for this is the growing necessity to use 3D virtual models for various cross-domain applications. This is beneficial as the same virtual models can be used in multiple purposes like urban cadastral management, registration, spatial planning, urban design, architecture visualization and interaction for urban renewal projects. Furthermore, the virtual models can be used for tourism, to communicate with the citizens (and other actors), medium for spatial analysis, disaster management, gaming, etc.

The thesis consists of theoretical, practical and evaluative work. The objective of this thesis is to investigate the functionalities for the geo-virtual environments to visualize spatial plans, urban design and architecture and how these functionalities can help urban designers and decision makers in the municipality interact with specifically the citizens. Multiple Dutch municipalities participated in this thesis. The thesis addresses functionalities of geo-virtual environments as interaction tools for municipalities to interactively visualize urban projects in the various development stages.

There have been various studies pointing out that collaboration and interaction with the citizens make way for better acceptance of design in urban and spatial planning. This acceptance of design by the citizen can lead to sustainable urban development ('*duurzame stedenbouw*'). Internet based virtual environments can play a vital role in reaching out to the mass public for interaction in the municipality development projects.

Geo-VE contains 3D scenes that are made of visual materials. Visual materials for the Internet based VR can be described by modeling languages as X3D, VRML, KML, CityGML, etc. The introduction of virtual reality modeling language VRML in 1993 was a turning point for 3D visualization environments. In 2001, the standardization of Internet based 3D modeling language like X3D provides advanced functionalities of visualization and considered as the next generation VRML. The recent success of Google Earth has brought such visualization environments to the public doorstep. The OGC draft specification for thematic description data format CityGML can be used for 3D visualization on the Internet and for dissemination of spatial attribute information. Having a defined thematic structure, CityGML describes how real world 3D objects like buildings, trees, cities etc are organized in the virtual world in various 'Levels of Detail (LoD)'. There has been little but none investigation on what kind of knowledge and information is perceived through visualization of different LoD scenic models in various urban design phases. This thesis is the attempt to fill this knowledge gap. The taxonomy of functionalities and visual materials of geo-virtual environments proposed in this thesis has the potential to extend knowledge on the method of information visualization for the municipalities in the Netherlands.

1.1 Thesis and report structure

This thesis contains eight chapters as follows:

- **Chapter 1** defines the project proposal and core research question in cooperation with the supervisors and the municipalities.
- **Chapter 2** defines the research methodology using Requirement Engineering (RE) process model.
- **Chapter 3** deals with background study and definitions of urban planning, visualization components, geo-VE etc. It states the actors, the present scenario, the different phases of design and the use of geo-VE for interaction, etc.
- **Chapter 4** summarizes the theories behind the functionalities of geo-VE.
- **Chapter 5** identifies the visual materials that can be used to represent real world urban objects in the virtual world. Special emphasis is given to CityGML LoD functionality.
- **Chapter 6** builds the conceptual hypothesis for the validation survey and lists two taxonomy charts of the thesis. Chapter 6 defines how Requirement Engineering is applied leading to the validation process.
- **Chapter 7** shows the results of the two validation surveys. It leads to a specification list of functionalities and how visual materials can be used in geo-VE.
- **Chapter 8** contains discussion reflecting the process, findings, knowledge gained and defends if the objective of the thesis is met and the core research question answered.

1.2 Problem statement and research questions

The research questions and scope of the project are formulated in accordance with the supervisors. They are investigated in the realm of requirement analysis and capture for Dutch municipalities to interact with actors. The research questions that are evolved from the project proposal are stated below:

Core research question

What kinds of visualization functionalities are needed and **how** can visual materials be used in geo-virtual environments for the municipalities to interact with actors in different phases of urban planning projects?

By dissecting the core question the secondary questions are formulated in the sequence as follows:

1. Who are the actors of urban design and planning?
2. What are the phases that can be identified in the Dutch context of urban design and planning?
3. What are the functionalities of geo-VE needed to interactively visualize urban projects for the Dutch Municipalities?
4. What are the visual materials of geo-VE to represent urban projects?
5. How can visual materials in geo-VE be used to represent the different design phases?
6. What functionalities does the existing geo-VE provide for such visualization?

Objectives of research

The concept of the research objective revolves around the realm of interaction through geo-virtual environments. It takes into consideration two aspects of visualization in geo-VE. This thesis has two folded objectives:

To investigate ***what*** *functionalities of geo-virtual environments are required to visualize urban projects*

To investigate ***how*** *visual materials of geo-virtual environments can be used in urban planning phases*

1.3 Scope and limitation

1 As this thesis deals with how the users react to the geo-referenced 3D Computer Generated Imagery (CGI), it makes the thesis fall in the domain of user-centered Human Computer Interaction (HCI) (Haklay, 2002). The 3D models used in this thesis are made with geo-data and geo-referenced using GIS technology.

2 The method how to use geo-virtual environments to support decision-making and boost public participation is beyond the scope of this thesis. The thesis shall fully omit the design and testing of geo-VE as Decision Support System (DSS), Planning Support System (PSS) & Public Participation System (PPS) in urban planning.

3 The thesis does not discuss VE as a design tool for the urban planners but as a new media to visually interact with actors, like citizens, housing agencies, etc.

4 It is assumed that 3D spatial information is disseminated from a central database from which different design solutions are presented to the actors on the virtual environments. This thesis will not emphasize on the system architecture of the VE but the functionalities and visual interaction. The CityGML LoD for representing urban objects is highlighted.

5 The results of this thesis are based on expert opinion from the municipalities and housing agencies. The thesis consist of extensive requirement analysis of different functionalities design professionals need from geo-VE and the functionalities they want to provide for external actors like citizens. The (few) housing agencies that participated in this thesis provided the information on their requirement on functionalities.

6 This thesis concentrates only on Virtual Reality and excludes Augmented Reality and Augmented Virtuality. It focuses on visual means and excludes special hepatic, tactile and other possibilities for immersion.

CHAPTER 2

2 Defining the research methodology in Requirement Engineering

2.1.1 Requirement and functionality

A requirement is a condition or capability needed by a user to solve a problem or achieve an objective. The requirements are properties that a system has in order to succeed in the environment where it will be used (Goguen, 1996). Reeve and Petch (1999) describe this process of capture of user need through the means of interviews, questionnaires, observation of the work process, analysis of data-flows and relations and demands. Requirements are the functional and non-functional needs of the system. Software that is related to Human Computer Interaction (HCI) is often created using user centered design methodologies (Hix and Hartson, 1993, Nielsen, 1993) focusing on the interface.

Functionality means the quality or state of being functional, especially the particular set of functions or capabilities associated with computer software and hardware. It derives from Latin *'functio'* meaning to perform. IBM defines functionality as the sum or any aspect of what a product, such as a software application or computing device, can do for a user. The functionalities of a product are used to identify features and capabilities the product should contain. Functionality of geo-VE refers to the tasks that the system should perform to interact in communicating design. The process of requirement capture in this thesis indicates the identification of geo-VE functionalities.

2.1.2 Requirement Engineering (RE)

Requirement Engineering (RE) is used effectively in this regard in the software industry. Requirement Engineering introduces engineering principles into the practice of traditional information systems. The basic difference between System Requirement Engineering and Software Requirement Engineering is how these two deals with the end user. The former focuses on the user requirements of the system and the second one deals with the requirements of the software for performed tasks. This thesis takes software Requirement Engineering path. There are no real thumb rules for the phases of RE in literature, however Houdek and Pohl (2000) have identified the following activities of RE:

Requirements elicitation or capture
Eliciting requirements is the task of communicating with customers and users to determine what the requirements are of the users. Analysts can employ several techniques to elicit the requirements from the customer. Historically, this has included such things as holding interviews or holding focus groups (requirement workshop, working-group) and creating requirements lists.

Elicitation is named in various terms like requirement acquisition, requirement capture or requirement discovery. More modern elicitation techniques include making a prototype scenario, prototype models and test cases. Interview states a subjective opinion and insight and help target the end user group. It gives initial input. Kotonya and Sommerville (1998) suggest that interview is not always adequate to gather enough information for elicitation. In most cases there is a need to understand the work process of the end user to deliver a system that can fulfill the needs of the system. This process is called the ethnographical study. In case where the system users do not have any knowledge on the topic, it might be necessary to educate them through workshops.

Requirement Analysis
Analyzing requirements deals with determining whether the stated requirements are unclear, incomplete, unstructured, ambiguous, or contradictory, and then resolving these issues. Validation of requirements aims to check if the requirements accurately represent the need of the system (Kotonya and Sommerville, 1998). Validation can be conducted by a field survey. All software has some 'standard features'. It is necessary to mention them in the specification document, but they are not validated.

Requirement analysis has three phases such as: a. evaluation, b. negotiation and c. prioritization. In the evaluation phase the requirements are structured and analyzed. Negotiation is the process of discussing with the technical expert users, which leads to the requirement functionalities that satisfies the user groups. Prioritization identifies the functionalities according to priority.

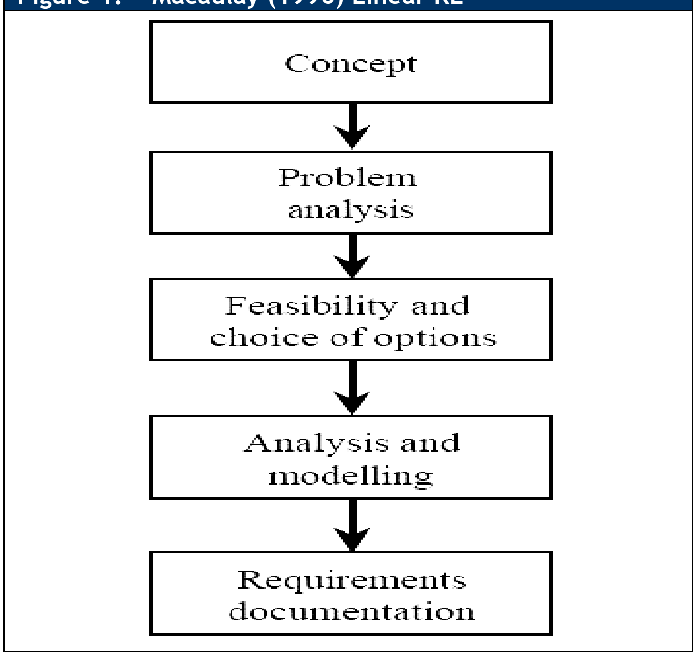
Requirements documentation and specification
This part has two subsets as requirement documentation and system specification. The requirements are structured and specifications for the software are made. The specification document can contain requirement prioritization as described.

2.1.3 The three RE process models in literature

The activities as mentioned above facilitate Requirement Engineers to capture requirements. Before defining the methodology of this thesis, three widely accepted RE process models are discussed to deduce the thesis methodology. They are such:

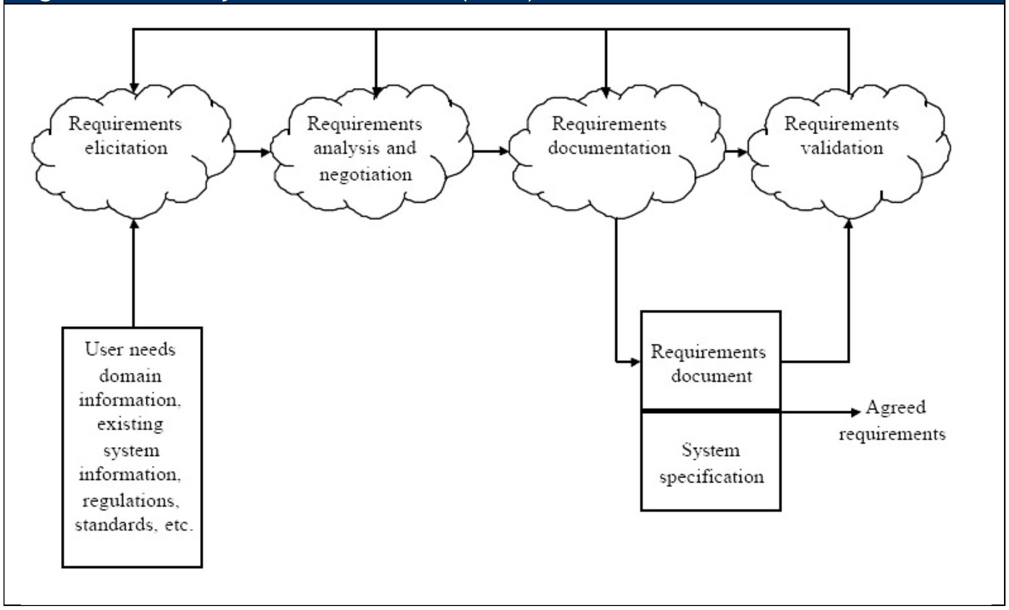
Pure Linear RE Process Model of Macaulay (1996)
The first Linear RE Process Model is that of Macaulay (1996). It is a purely linear RE process model (Figure 1) that does not indicate any overlapping or iteration. But the RE activities in this methodology is similar to that of that of Kotonya and Somerville (1998)'s model. This RE process model is system dependent and several variations of this model exist. It is successful when the work process is already known and not frequently altered.

Figure 1: Macaulay (1996) Linear RE



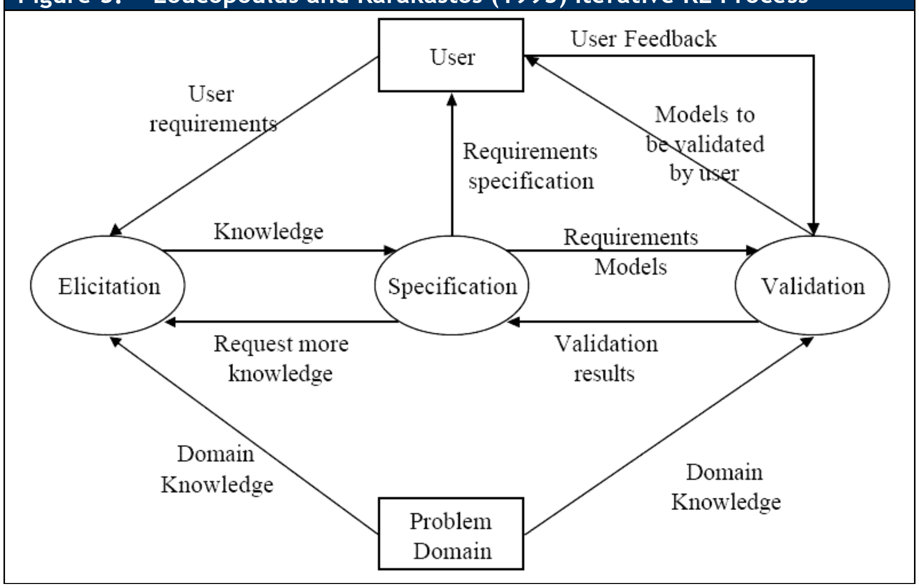
Linear Iterative RE Process Model of Kotonya and Sommerville (1998)
The RE process is often depicted as a linear, incremental model. The Kotyona and Sommerville Linear Iterative RE Process Model (1998) contains the common RE activities such as elicitation, analysis, requirement documentation and requirement validation that follow a linear pattern (Figure 2). But it also suggests that the linear RE process model has also iterations between the various above-mentioned activities.

Figure 2: Kotonya and Sommerville (1998) Linear Iterative RE Process Model



Pure Iterative RE Process Model of Loucopoulus and Karakastos (1995)
While most of the literatures depict the RE process as linear, Loucopoulus and Karakastos (1995) has defined an iterative model (Figure 3). This model depicts that the RE processes and activities are iterative. This model suggests that there are iterative relationships between requirement elicitation, specification and the validation. The problem domain is constant but the rest of the activities can be variable.

Figure 3: Loucopoulus and Karakastos (1995) Iterative RE Process



Theories prove that it is not possible to construct a single model to represent the different RE processes in a single company (Matrin, Aurum et al, 2002). Many projects use RE activities in ad hoc manner (Lowe and Ekund 2001) adapting them to fit the project. The purely linear model is not always successful in representation as iteration of activities may be necessary. But the iteration models are poor in showing the progression of RE activities in time (Martin, Aurum et al 2002). In most RE Process Models are adjusted to the project needs.

2.1.4 Research methodology in Linear Iterative RE process model

The thesis is about requirement analysis of geo-VE for Dutch municipalities to visually interact with actors like citizens and housing agencies. It follows a linear RE process model with slight iteration as seen in Figure 4. The software approach taken lists the functionalities of geo-VE. RE allows a systematic approach of engineering method for requirement analysis for software. As geo-VE is a specific kind of software, requirement engineering is an appropriate method to extract the required functionalities of geo-VE. The functionalities of the geo-VE capture process has some characteristics that lead to the use of RE to define the methodology. It includes the activities like information elicitation, functionality capture and analysis, validation process through field surveys and workshops and finally documentation of specification documents, etc.

Requirement elicitation is the information acquisition process. It is done through scientific literature study, observing VR systems and interviewing the municipalities. It was necessary to follow time constraints. The ethnographical study at the municipalities leads to the definition of end users and planning phases. This phase is synonymous to requirement elicitation. Slight iteration happens to be natural phenomenon for this project. An extensive theoretical study forms the core for functionalities of geo-virtual environments. These functionalities are then reviewed and restructured using deducing criteria through interview inputs. When the information gathered seemed inadequate, there were iterative activities necessary like re-interviewing.

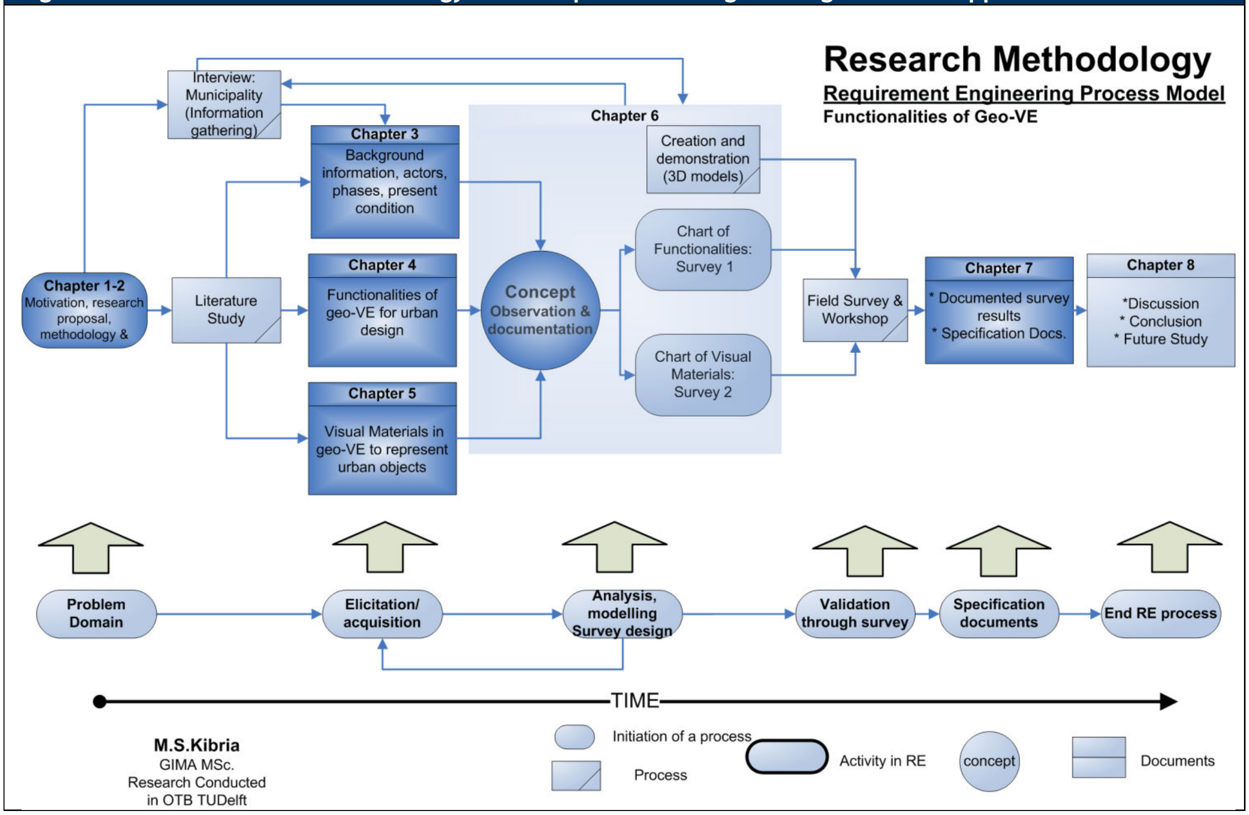
The literature study helped to classify the general functionalities of geo-VE and identify the visual materials of geo-VE. Google Earth, Cebra's VirtuoCity, LandXplorer CityGML viewer and the Bitmanagement plug-in for Internet explorer are four VR viewers that are explored. This forms the basis of the elicitation phase. During this time contacts with the municipalities helped to understand which of these geo-VE are feasible, what kind of datasets are available, etc.

Firstly the thesis has documented the different functionality domains of geo-VE in taxonomic charts. In the conceptual part of the thesis these domains are classified into the 'Chart of Functionalities (Hierarchical)' through observation and analysis. Secondly, the thesis has defined visual artifacts or materials of the 3D scene of geo-VE. It has investigated to see how urban 2D/3D objects can be represented using a wide-ranging parameters like reality axis, dimensionality and LoD. This part of the elicitation phase is to investigate the relationship between visual materials in various LoD and the planning phases. CityGML is the only 3D data format that defines LoD functionality not in the relationship to distance and zoom functionality, but for storage and use in multi-purpose applications. The thesis has investigated if the LoDs models are applicable in the different planning phases. This leads to defining the 'Chart of Visual Materials'. In ArcGIS environment 3D models are created, combined with CAD models and demonstrated for the municipalities.

Analysis and validation questionnaire design: Interviews conducted at municipality of Rotterdam, Den Haag, Delft and Oldebroek and observation from the two charts led to the generation of two validation questionnaires (Survey 1 and Survey 2). They helped to acquire information on actors, design phases, geo-data etc. The first one helped to list what the required functionalities are and the second helped to list how visual materials in various dimensionality, realism and LoD represent the different planning phases. Some of the functionalities are negotiated and they are just listed in the final specification. In the analysis part of the RE process model, test questionnaires were created. The conceptual part of the thesis (Chapter 6) elaborates the RE analysis phase in detail.

Validation process is conducted by field survey (conducted at individual municipalities) and a workshop (at OTB TU Delft). In either case it was necessary to explain the topic in detail before the users were able to validate the functionalities that are required for interaction. Prototype models are used during the field survey and workshop. Firstly the survey questionnaires were sent electronically. Unfortunately as the users do not have background knowledge on the requirements, the results were not acceptable. Therefore an alternative path has been taken. The researcher decided to conduct the validation through direct field survey, by demonstrating 3D virtual models and functionalities, talking about the functionality domains and then validating the functionalities through one to one contact. No large-scale statistical data was possible to extract from field survey. With the direct participation of the SUA team, on 30th November 2007 a workshop has been held in OTB. The participants came from wide ranging municipalities like Amsterdam, Groningen, Landgraaf and Rotterdam. Social housing agencies like BOW, Vestia Delft, etc participated in the workshop. The results of the field survey are combined with the workshop leading to statistical results.

Figure 4: The research methodology as in Requirement Engineering Software Approach



Validation results and Specification documents are discussed and made from the outcome of survey 1 and survey 2. They reflect the requirement of municipalities. Specification documents for the two survey questionnaires are listed as an end product of the RE software model. The functionalities are documented in the prioritization method ending the RE model.

Discussion on the results

Finally a broad discussion on findings and opinion of the researcher on the type of functionalities and visual materials of geo-VE to visualize urban projects using requirement analysis. The reflection on the research questions leads to the end of the thesis.

BACKGROUND AND ETHNOGRAPHY
CHAPTER 3

3 Background study on urban planning and 3D visualization

The chapter contains the background study of the thesis. It defines urban planning in the context of visualization. It also contains the results of the ethnographical study of the requirement engineering process leading to the identification of the actors, the planning phases and type of interaction tool that are presently used by the Dutch municipalities.

3.1 Urban planning and 3D visualization

Urban planning is the planning sector for shaping and organizing the real world objects such as buildings, roads, trees, etc in the built environment. It defines the limits, boundaries and constraints for the individual city-dwellers for conducting spatial activities inside the urban environment. The basic task of the urban planner is to provide a sustainable built environment that can sufficiently meet the needs of the citizens in their daily interactions with the urban environment. It is a complex decision making process where there are always relations between various tasks done by various actors. In urban design projects such groups have often-conflicting expectations and backgrounds. It is a process involving multi actors having various needs and aspirations. It follows gradual development phases. According to Lynch & Hack (1984), the definition of urban planning as follows:

> 'Urban planning is concerned with assembling and shaping the urban- i.e., local or municipal- environment by deciding about the composition and configuration of geographical objects in the space-time continuum.'

Urban design acts as the interface process of design between urban planning and architecture. It is the design and arrangement for the urban forms and urban environment keeping continuity through the whole process of urban planning. It deals with the shape and form of the objects of the urban environment and the space that is created by these geographical objects. It is the central part of urban planning that relates to 'physical arrangements of buildings and streets to functional organization which in turn reflects the social and economic structure which makes the built environment function or dysfunction' (Batty, 2000). There is a strong relationship between urban design and 3D geo-visualization. Some researchers have studied how visualization can be used in design processes (work of Camillo S, 1965, De Vries, 1998, Al-Khodmany, 2001, Whyte, 2002) through the use of hand-drawn sketches, 3D CAD, GIS and VR.

3.1.1 Visualization and geo-visualization

Visualization is a term that is applied to the field of computer graphics that addresses both the analytical and communication domains of any representation. Visualization is the process of displaying and depicting in order for the user to see, perceive and analyze information. Visualization is the process of creating and viewing graphical images of data with the aim of increasing human understanding. It is based on the fact that humans are able to reason and learn effectively in a visual setting than when using only textual and numerical data (Tufte, 1990; 1997). Visualization is related to human vision and is nothing but an illusion of an object, activity or event.

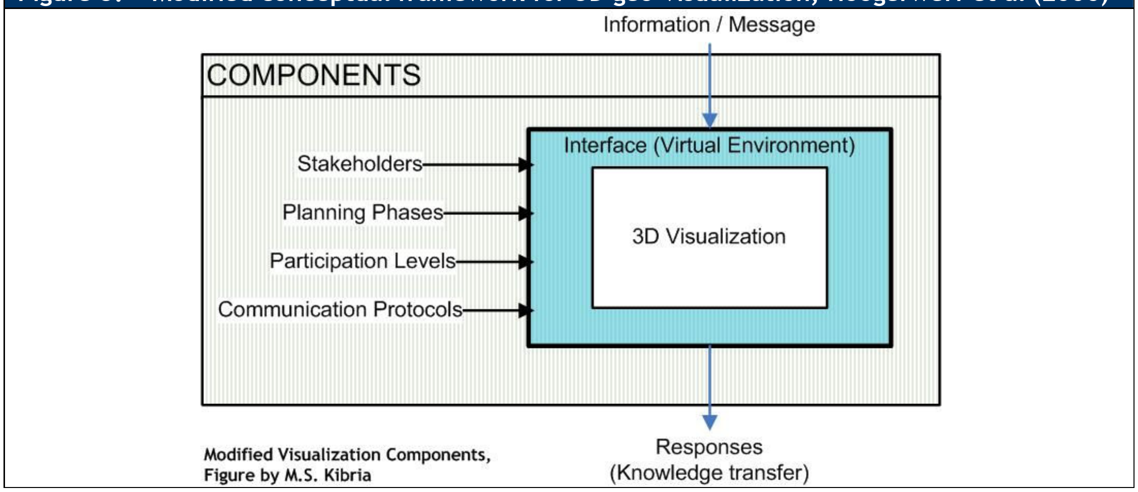
Geo-visualization refers to the visual representation of data for the purposes of spatial analysis. Geo-visualization has been defined by (MacEachren and Kraak 2001) as 'the integration of visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis and GIS, which all together provides theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data'. Maps and other linked graphics play a key role in the process of visualization. 3D visualization is a 'highly multidisciplinary science, using components of GIS, VR and HCI' (Nielsen, 2004). 3D geo-visualization revolves around virtual reality technology that is based on geographic information.

According to Ferries and Leglise (2007), there is a new co-operation between geography, urban planning and architecture. They argued that spatial planning follows a chain where the boundaries of geography, city planning and architecture are merging and the tools, interfaces and techniques these professional fields require need to be revised and adjusted. In many cases the process of urban planning uses geo-referenced images, GIS datasets for analysis in the design process. Virtual city models that are used in interaction for urban planning process can be created on the basis of GIS data. Due to such developments the 'geo' element cannot be seen as separate from the context of urban planning.

3.1.2 Components of 3D visualization for planning process

Hoogerwerf et al (2006) [also cited in Riedijk et al, 2006] have pointed out the components of 3D geo-visualization in the realm of generic spatial planning process. They have identified six components consisting of *actors (stakeholders)*, *planning phases*, *participation level*, *communication protocol*, *interface* and *3D visualization* as seen in Figure 5.

Figure 5: Modified conceptual framework for 3D geo-visualization, Hoogerwerf et al (2006)



According to the authors, 3D geo-visualization in spatial planning consists of multiple *actors* who interact with each other through visualization in different *planning phases*. The authors have defined that 3D visualization should interpret the preferences of the various involved *actors*. In the different *spatial planning phases*, the storage and retrieval of multiple design scenarios should be possible from a centralized database in multiple scales (level of detail). 3D visualization should support the maximum *participation* of the actors. Through the *communication protocol*, 3D visualization evolves in same-time same-place (like meeting or *gespreksavond*) or different-time different-place scenarios (like Internet, chat, weblogs, interactive websites with maps, multi-user 3D virtual reality, etc). 3D visualization should be supported in a single electronic environment, which the authors called the *interface* component. In the context of this thesis the geo-virtual environments (geo-VE) are synonymous to interface component. The *interface* for 3D visualization should allow maximized engagement of actors and be open to all user groups through the Internet. These six components can be applied to all kinds of spatial planning practices (for example, urban planning) for 3D geo-visualization.

3.2 The actors in urban design and planning in the Netherlands

As a part of the requirement engineering process the researcher spent some time interviewing the design officials at four Dutch municipalities such as Rotterdam, Den Haag, Delft and Oldebroek. This is part of the ethnographical study. The interviews conducted at the four Dutch municipalities revealed that there are at least seven common interest groups or actors that can be identified in urban design and renewal. These actors can be classified according to their professional background related to design as Table 1:

Table1:Actors in urban design and planning in the Netherlands

	Category	The actors
1	Design Professionals	Urban planners in Municipality urban planning department (MUDP)
		Private architecture and urban design firms
		Welstandscommissie (technical experts on design quality)
		Social housing agencies
2	Non-design Professionals	The municipality [local council (*gemeenteraad*) and the mayor & aldermen]
		The citizens
		Related technical consultants (internal departments, construction firms, project developers, etc)

3.2.1 Relationships between actors in urban design and planning

In a process related design, as urban planning, it is not possible to remove the relations from the actors. The relationships that can be primarily identified from interviews can be seen in Table 2.

Table2:The relationships in urban design and planning

	The relations between actors
1	Urban planners working for the Municipality interacting with the Municipality bodies.
2	Urban planners working for the Municipality interacting with the general public.
3	The municipality interacting with the citizens.
4	Architecture and urban planning firms and social housings agencies working for clients [1]
5	Technical consultants regulating architectural standards (for example *Welstandscommissie*[2])
6	The clients demand for information from an urban project.
7	The citizen's demand for information from an urban project.

3.2.2 End users identification

In the given time frame, it was not possible to investigate the requirements of geo-VE from the standpoint of all the seven actors. Within the scope of this thesis the municipalities and housing agencies participated in the field survey and workshop. Functionalities of geo-VE in this thesis are seen as the interaction functions that the municipalities, social housing agencies and citizens (according to the municipalities) require for communicating with each other.

3.3 The phases of urban design & planning in the Netherlands

The ethnographical study of the requirement engineering process model has identified the spatial planning phases in the Netherlands. The interviews conducted at the Dutch municipalities revealed how the design process in the municipality comes into reality in gradual stages. The process follows strict building laws and high standards (for example, *Wet Ruimtelijke Ordening* WRO, 2005) through frequent supervision of a supervising committee called the '*welstandscommissie*'. Spatial planning in the Dutch municipalities goes through defining a study area for development and setting up goals and objectives for different phases. But sometimes the terminology for these planning phases varies from municipality to municipality. (See Annex 1 for detail of planning phases).

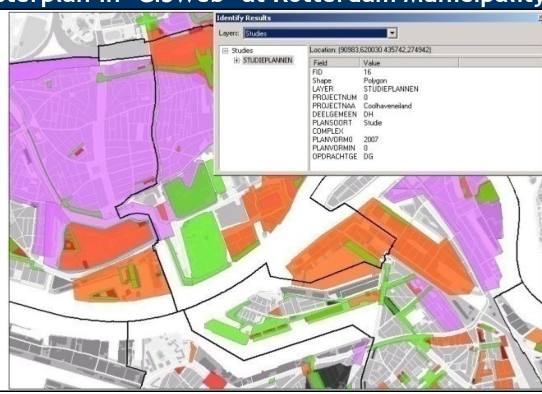
[1] The term 'client' needs clarification. When the municipality makes the land-use plans of an area, it proceeds further on developing urban plans. These urban plans can be made by the urban planners inside the Municipality or delegated to private design firms. For detailed architectural planning phase the design is delegated to external design firms. In this case the municipality can be 'client' for the architecture and urban design firms.

[2] Since the 1st of January 2003, there is a new building law named the '*woningwet*' in the Netherlands demanding that the municipalities find norms to follow strict criteria for creating sound architecture. This is achieved by the creation of an independent technical body or the '*welstandscommissie*'. The '*welstandscommissie*' is made up of architects and urban planners and regulates architecture quality as a watchdog for municipality urban projects.

The *structuurplan* is the spatial plan that outlines the broader general urban development policy of a study area. This can contain the whole municipality or a part of it. The *thematisch plan* is the spatial plan that points out the development policy of a study area and specifies the land use (example, parks, greenery, traffic, transportation-network). It covers usually the whole municipality and sometimes a larger area (regional plans). In the Netherlands, there are some design phases like the (re)development plan that outlines the land use plan alternation and the rearrangement and composition of existing buildings and public spatial entities.

Zoning plan (*bestemmingsplan)* is a juridical binding spatial plan of a geographical entity for permissible land use. It covers parts of the urban municipality varying from a large city-district to single building block. The zoning plan specifies the rules and regulations on what can be built in a specific land and the type of functions and height that are allowed. For the realization of any spatial plan, the first step is to create the base of further development through zoning plans. From 2007, these plans have to be inter-exchanged in Geography Markup Language (GML) format under the DURP (*Digitaal Uitwisselbare Ruimtelijke Plannen*) regulations. GML can be in 2D and 3D. This is an initiative of having all 2D maps/plans[3] in common digital format so that they can be exchanged between different entities. This DURP project aims to make zoning plans simpler to manage for various stakeholders.

Figure 6: Bouwplangebied, Bestemmingsplan and Masterplan in 'GISWeb' at Rotterdam Municipality



The process of spatial planning has to fulfill the needs of various actors and has to deal with different levels of detail. There are many intermediary study phases in between zoning plan (*bestemmingsplan*) and master plan. In the Rotterdam municipality the initiation begins with the defining the areas of development as *bouwplangebieden*. While continuing through such phases the zoning plan (*bestemmingsplan*) phase comes into reality. Once a certain area of development is marked out in a lateral phase the master plan of the study area are made. Figure 6 illustrates how multi-criteria analysis on 2D net-based GISWeb at Rotterdam municipality to generate a master plan.

The master plan has to fit into the restrictions set up in the *bestemmingsplan*. In the municipality of Rotterdam this process works in egg-chicken loop scenario. Sometimes the master plans and urban plans are firstly created and incorporated in the *bestemmingsplan*. It may happen that in some planning stages coincide. The order of planning is a not perfectly linear and top down process (e.g. the land use plan may precede or follow the architectural design). It can happen that the implementation of the design phase is not conducted at the municipality and outsourced to design firms. The type of ownership of land determines if the design is done at the municipality or developed by external parties. In many cases municipalities outsource certain design tasks, like making zoning plan (*bestemmingsplan*) or urban design plan (*stedenbouwkundig plan*), etc.

[3] Until now there is no widely accepted standard for the exchange of 3D information in the Netherlands, but within Europe the countries in Scandinavia (Denmark & Norway) have began to standardize 3D spatial information in IFC format. There has been work on converting the IFC format to CityGML in Germany.

The urban design plan (*stedenbouwkundig plan)* is the detailed plan worked out from the master plan and points out what will actually happen in the urban settings with specific definitions to building types, heights, roads, paths and parks, etc. When the urban plan is finalized, the urban planners have the architectural quality of the area. They are not responsible to complete the detailing of the building project but to transfer their aspiration of the design to the architects. This phase is called the *beeldkwaliteitsplan* or architectonic quality plan. In most cases, the conception and legal procedure of *beeldkwaliteitsplan* coincides with the zoning plan (*bestemmingsplan)*. The local council (*gemeenteraad*) must approve it before the next phase can commence and can be a milestone in the design process. Therefore, a specific standardized representation for this phase is necessary. It provides the legal basis for supervision from the *welstandscommissie* for sound architecture before the architectural design actually begins. Based on the *beeldkwaliteitsplan* of an area architects finish the final design. Once the design is finalized the building footprints of finalized design are incorporated in the *bestemmingsplan*. By observation of the design the process at Dutch municipalities, the following design phases in urban planning can be identified:

- **Initiation design phases** (visionary plan/structure plan/city vision & plan/ redevelopment plan/built up areas, *Programma van Eisen*, etc)
- **Zoning plan** (*bestemmingsplan*), land-use plan
- **Master plan** (*Masterplan*)
- **Urban plan** (*Stedenbouwkundig plan*)
- **SPvE phase** (*Stedenbouwkundig Programma van Eisen*)
- **Architectonic quality plan** (*Beeldkwaliteitsplan*)
- **Temporary and definitive (architectural) design** (*Voorlopig en definitief ontwerp*)

From the discussion it becomes obvious that the phases of urban planning follow a complex hierarchy. Certain planning phases can be related to the development of a design or it can be used for the process of obtaining permission to commence a follow-up spatial planning phase. Traditionally, to interact with external actors in the design and planning phases, the urban planners and architects in the Netherlands use 2D paper maps, CAD drawings, graphical images, textual/oral information and physical 3D models. Often these visual artifacts are used in isolation from the larger portion of the general public. This has made interaction and collaboration in design difficult.

Most municipalities have websites for dissemination of static spatial plans. Email and municipality websites are manners to reach the mass public but they are neither dynamic nor interactive. Only recently the larger municipalities like Rotterdam have plans for interactive digital maps for the public in Web Map Services (WMS) (‘*Rotterdam in Kaart’* project). Even though *‘gespreksavond’* or meetings are very vital for feedback and input for the municipalities in urban planning process from the citizens, informing large scale people is impossible through such meetings. Therefore many municipalities seek new medium of collaboration like geo-VE. Annex 2 elaborates a detail discussion on the present form of visual interaction at the Dutch municipalities.

3.4 Definition of geo-virtual environments (geo-VE)

It is difficult to define the term 'virtual environment' (Zlatanova et al, 2007). According to Batty (1998) virtual environment 'has no formal definition'. The basic difference between a 3D model and a virtual 3D scene is the difference in interactivity. The virtual environments are dynamic and interactive where the user can demand information and receive feedback on 3D data that represents the reality. It can be said that a virtual environment is an expansion of a multimedia system into a multi-sensory system to allow for simulated real world representation. They are nothing but the representation of the real world in the virtual world with the help of multidimensional visual materials within limited boundaries. Virtual Reality (VR) is defined as a media with three characteristics: user interactive, spatial and real-time, where action feedback is given without delay (Whyte, 2002). From these two definitions the common assumptions that can be identified are that geo-VE has ability of interactivity in real time and has the capability of simulation for spatial analysis.

Geo-virtual environments can enable spatial computation through specific functionalities. Simulation helps the viewer to interpret spatial plans but also perform analysis. Spatial computation for geo-VE can include, shade shadow, sun path, visibility and wind flow analysis, etc. Furthermore computation like noise and air pollution for newly designed urban areas can be simulated in geo-VE. In specific buildings design safe route calculation can be a requirement. Furthermore, the user can demand to seek an object based on an attribute of the data. From the GIS point of view geo-visualization and virtual environments are inter-related. Geo-VE is the means to the handling of data like integrating, storing, accessing, analyzing and viewing through a wide range of functionalities.

From a wide range of perspectives, the so-called definitions of virtual environments talk of dynamic movements, navigation, interaction feedback, simulation, immersion in a 3D space. The thesis defines geo-VE as such:

Definition of geo-VE:
Geo-virtual environment is a spatially referenced digital world that comprises of visual (and non-visual) objects in an immersive 3D scene to represent and mimic reality. Geo-VE comprises of dynamic, interactive and simulative functionalities.

Batty (1998) divided virtual environments as 'real' and 'fictional'. Real world are based on geographical real world and fictional world are based on fantasy (for example games). Furthermore, the interface of geo-VE can be based on single or multiple users. Based on the task they perform, Batty (1998) has put an effort to make distinction of virtual environments for 'information and advice', 'for science and analysis' and finally 'for design'. In this thesis the geo-VE is seen in the context of interaction through information, advice and design of urban planning process.

3.4.1 Virtual environments on the Web: 5 stages of development to full interactivity

The virtual environments on the web for effective visualization for collaborative design process went through five distinct stages as seen in Table 3 (Rockwell, 1997). This leads to full interactive visualization environments on the Internet. With the advances in Internet and open standards for 3D data (launch of VRML2 and W3D's virtual reality language X3D, August 7, 2001) and its use in design process suggests the development somewhere in the 3rd and 4th level. Figure 7 shows the development stages of VE. Only 3 of the Dutch Municipalities (Helmond, Apeldoorn and Tilburg) have implemented the 4th level of virtual environments for collaborative urban design process.

Table3: The 5 stages of development for virtual environments

	Stage of Evolution	Description	Use in Collaborative Design
1st	HTML Web Site	Textual communication medium used.	Weak in collaborative design practice as information is available only in text and images.
2nd	HTML Site with Chat	Textual communication is used. Feedback is possible	Medium level of interaction and ability to communicate in real time.
3rd	Avatar based GUI	Organized interaction, person-to-person communication is possible.	Strong abilities in collaborative education/design processes based on expensive proprietary software for Military/Organizations, etc.
4th	Avatar based 3D GUI using Open Standards	Seamless inter-connection and sharing of knowledge	Very strong in web based interactive collaborative design/education arenas using open standards.
5th	Avatar based 3D GUI in Open Standards and real time audio synchronization	Seamless inter-connection between communities	Very strong in user interaction through real time information, augmented reality, real time audio, etc enhances the design/education process.

Figure 7: Stages of development of virtual environments

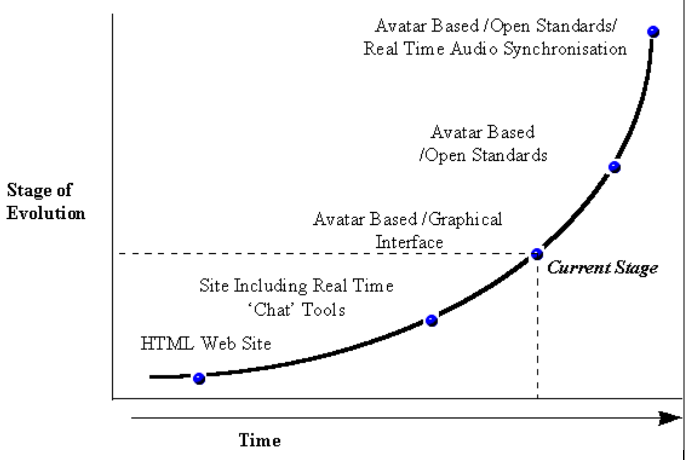


Figure 8: TU Delft on Google Earth, Netherlands

3.4.2 New trends: Virtual worlds and VirtuoCity

Since 2004, 'state of the art' 3D visualization environments have emerged that contain photo-realistic satellite images. These virtual environments consist of geo-referenced data and are not avatar based. They can contain 2D vector maps, 3D models and constitute to most of the functionalities of any virtual environment. Examples of such virtual systems are the virtual earth viewers like Google Earth, MSN's Virtual Earth 3D, World Wind, etc. Some of these systems use open standards. It is rather difficult to put them in evolution process as described in Rockwell (1997)'s categorization. Figure 8 visualizes TU Delft campus in Google Earth. Since 2006, interactive virtual cities are beginning to surface in the Netherlands. For example, the Eindhoven based ICT Company, Cebra is a forerunner in this regard. It has created three geo-referenced cities of the Netherlands and won international recognition for virtual software design for multi-user collaborative urban planning. Based on acquired 3D models, GIS-data (GBK), laser-scan height models and Cyclomedia panoramic images virtual cities of Apeldoorn, Tilburg and Helmond have been constructed. The success of *Virtueel Tilburg* has listed the company as a forerunner to construct collaborative virtual cities for many municipalities in Netherlands. Tele Atlas has been developing photorealistic 3D virtual cities of the Netherlands mostly for car navigation.

ELICITATION: FUNCTIONALITIES
CHAPTER 4

4 The functionalities of geo-VE for urban design and planning

This is the first chapter of elicitation phase of the requirement engineering process model. Work from a wide range of scientific literature study and application software is analyzed to document the functionality domains of this chapter. The classification of the functionality domains for geo-VE can be used as software specifications to compare the application of different VR software for the Dutch municipalities. The functionality domains that are listed in this chapter include construction, capabilities, experiencing, controlling, exploring and components of geo-VE.

4.1 Functionalities regarding components of geo-VE

The philosophical insight of the functionalities of virtual environments comes from the imaginative metaphors of Lewis Carroll (1832-1898)'s "Through the Looking Glass". The geo-VE is made of components that enable specific functionalities as seen in Table 4:

Table4: Components of the 3D Scene in Virtual Environments

Entity	Description
Boundary	Virtual environments have limited spatial boundaries (box, hemisphere, etc) usually modeled in the 3D scene
Atmosphere	It can have an atmospheric impression (fog, dusk, sunny day, blue sky, night, dawn, snow, rain, etc.)
Proportionate objects	The 2D/3D objects, place-mark, images, signs texts etc are in proportion to each other. These objects are geographically referenced in the geo-VE.
Geometries	The 2D/3D objects can be of simple/complex geometries with or without textures. Can be static (building blocks) and dynamic (moving objects, avatars).
Background	The 3D objects may or may not have a background, which can be a 2D plan/map or satellite image or DEM/DTM. A raster map or image can be draped on the DTM
Lights and Camera	Geo-VE can have camera settings and specific lighting criteria (ambient, point, directional, spot, intensity, color). They can have lighting that corresponds to the time of the day and season.
Visual properties	Bertin (1983) has identified the visual variables for class maps. The visual properties are color, object identifier (icon, markers) shape, lighting, brightness, surface reflectance, scale, legend transparency and occlusion.
Shading and rendering	The shades/shadows can be turned on or out. The 3D objects have to be rendered (wireframe, flat, gouraud, textured, hidden line and surface etc).
Visibility	The distance to which is the visual objects in the 3D scene visible
Referencing	Geo-VE have data that are geo-referenced
Layering	May or not have multi-layers of objects
Controls	In desktop visualization there are always modes of control. Desktop visualization environments are mostly keyboard, mouse and joystick based.
Collision & Gravity	Dynamic objects in the 3D can collide with each other. In a 3D scene with avatars there can be a feeling of gravity.
Elaboration and Multiple windows	There can be external windows, pointers, and clickable objects leading to extra information for exploration. Hyperlinks and coordinated windows are essential for the exploring, explanation and elaboration functionalities of geo-VE.
Analysis tools	Geo-VE models can be used for visualization can be used for analysis of spatial phenomenon. In specific cases the virtual city models can be used for shade-shadow, sun-path, wind analysis. They can be used for noise and air pollution mapping in 3D, getting directional routes, disaster management, etc.

4.2 Functionalities regarding construction and capabilities

Sneiderman (1998) and Heim (1998), Lammeren and Hoogerwerf (2003) have identified the basic capabilities of geo-virtual environments. The construction of the 3D scene is inseparable to the scale and resolution of the 3D data (mentioned as an I-Factor: Information Intensity or LoD by Heim (1998) and Wachowicz (2002). The construction issues are related to the control, experience, exploration and interactive tools, object preparation like 3D formats, data sources and database types, etc. The capabilities of the geo-VE are related to how the system is constructed. All virtual environments have the following capabilities:

a. Interfacing

This functionality of the geo-virtual environment helps the user to interact with the virtual scene. The digital viewer 2D/3D can be supplied with functionalities to interact with the environment, models and information.

b. Data-fusion and Integration

Data-fusion and integration is closely related to the construction of the 3D scene. The virtual environment consists of various datasets. Some of these datasets are geo-referenced in 2D, 2.5D or in full 3D including Digital Elevation Models (DEM) and Digital Terrain Models (DTM). All these different types of data are integrated in the 3D scene, through a process called data-fusion. Modeling is an important issue in data-fusion and integration. The existing city can be constructed in 3D using various modeling techniques and newly designed buildings can be inserted and merged with the existing model through a data integration process. Thus when users enter the geo-VE, they see the existing city and newly proposed design in the urban setting.

c. Representation

The representation functionality defines the color, texture, shape, and geometry of the objects in the 3D scene. Representation deals with the visual content of the geo-visualization environment. Representation in the virtual environments can be visual, hepatic, tactile, etc. But only pure visualization domain of interaction is investigated in this thesis.

Multiple representations of objects/materials in 3D scene

Representation of a geometrical model from the same source can be many folds. Generic design software (like SketchUp) provides the representation as in the Table 5:

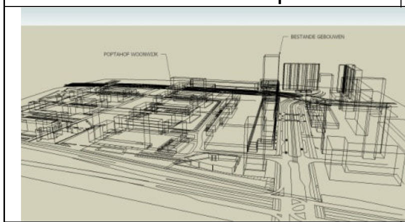
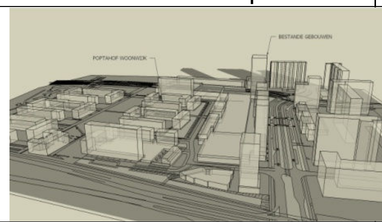
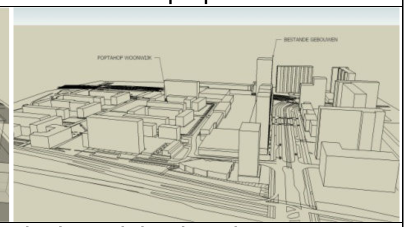
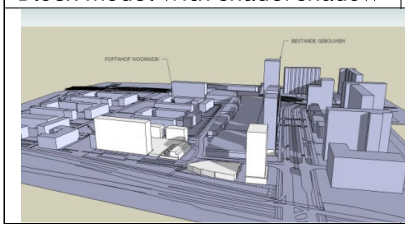
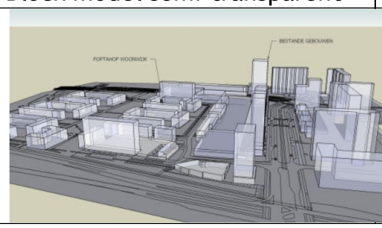
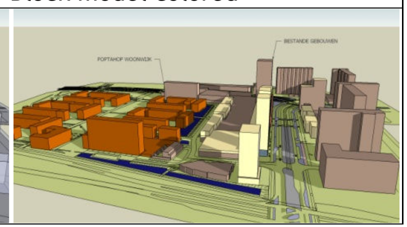
Table5:Representation in generic visualization software

NR.	Type of representation	Description
1	Wireframe mesh models	Only frames of the models are seen. No sides of the 3D objects are visible.
2	Transparent mesh models	Mesh frame of the model is very visible and the polygonal walls of the 3D objects are semi-transparent
3	Hidden-line models	Frame of the object is hidden but the side-walls of the polygons are highlighted
4	Flat models	Frame is visible in lines and polygonal sides visible in opacity.
5	Shaded models	The frame is visible in lines and the polygonal sides visible in various opacity with shade and shadow Shaded models can be flat shading to phong and ray tracing.
6	Textured models	The frame and polygonal sides of the 3D objects are visible and are textured representing the real world

Different representation is possible from the same geometrical model. The same model can be shown in various representations, while changing the line types, thickness, transparency, colors and textures of the model. Figure 9 shows the “*Poptahof Urban Design*” project in different representation keeping the same geometry. There can be also multiple representations where different 3D models (containing different geometry) are used to represent different design solutions on a single site. Figure 10 illustrates the study of alternative geometry models of *Poptahof Urban Project*, Delft using same representation in VE.

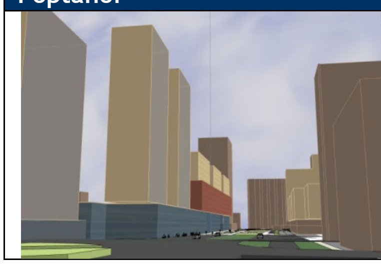
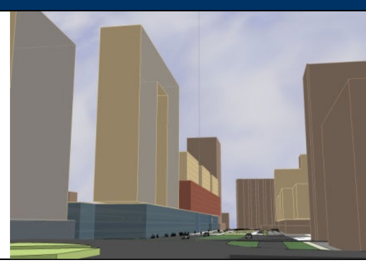
Same geometry model on the same site but the visual representations are different

Figure 9: Different representation of the Poptahof Urban Project from the same data

Wireframe model transparent	Wireframe semi-transparent	Block model opaque
		
Block model with shade/shadow	Block model semi-transparent	Block model colored
		

Different geometry models on the same site but visual representation is same

Figure 10: Alternative design solutions in different geometry same rendering representation of Poptahof


Challenges in multiple representations

There are many challenging aspects in the translation between representations from the same spatial data to visualize different scenarios of the proposed design. For example one can easily get a block model from the textured 3D model but it is not easy to reverse the situation. Managing database integrity, data storage and the process of designing simultaneously is a complex process. An ideal situation will be that designers would be able to design through CAD tools and the information would be automatically updated in the database. The updated information is presented in go-VE through the Internet.

Use of multiple representations in urban projects

In urban planning it is important to visualize the various alternatives of choice in the same site area. If visual materials and data have to be efficiently visualized from a server, there should be a possibility to represent the data in different looks and geometry on the client side. '*Virtueel Tilburg*' is a test case in the Netherlands, where three alternative geometry models representing three design solutions were disseminated from a centralized database from which citizens were able to vote on the preferred design. The way the 3D models are rendered have impact on the human cognition how one perceives information. Having the possibility to move between different representations of the same design lets the user get rid of bias to come to a decision.

Spatial analysis on representation models

Once the virtual city models are made, the can be used in scientific analysis. Despite growing recognition of the importance of multiple representations in planning there is a lack of computational support in the scientific analysis in 3D. At this present moment most of the computational support is concentrated on building a spatial databases. No 3D GIS systems are yet equipped with all the functionalities needed for data capture, data-structuring, data-manipulation, and data-analysis and data presentation in 3D (Zlatanova et al, 2007). But such functions are needed for urban management, like air and noise pollution, 3D cadastre, safety route calculation, network analysis, etc. Functionalities provided by most Internet-based geo-VEs concentrate on visualization and not in GIS analysis. Internet based ArcGIS Explorer is one of the few exceptions that let the user perform spatial analysis in 3D models and import geo-processing toolboxes.

d. Multi-dimensionality

The objects in a geo-VE can be visualized in as text, 1D points, 2D images, graphs, maps and also 3D models and there should be multiple representations possible of the same data. A time component makes the spatial information dynamic in 4D.

e. Simulation and animation capability

Simulations create changes in the 3D-scene by pre-defined algorithms. The algorithms are connected to a certain class of the 3D object and the user gets the function to trigger the simulation. The sequences of events in the simulation can be controlled in time and by locations. Examples, for such simulations in urban issues can be such as urban cellular model, growth models of cities, traffic congestion model, pollution models, etc. Simulation let the users visualize complex spatial analysis and come to decisions. Animations are pre-recorded simulation used in presentation.

f. Feedback capability

Geo-VE can have feedback functionality to understand what the users want or what the impacts the visualization has for the target group. Dalal and Dent (1993) have identified 5 levels of interaction with users for having feedback such as: *inform, consult, advise, co-produce and co-decide*. The last two involves collaboration with the user. To inform people animation and interactive hyper-texts are effective methods for visualization. To consult the users email, bulletin board, newsgroups and weblogs can be used. To advise people tele-meeting, video-conferencing and Internet sites can be used. In terms of collaboration, group discussion in chat-rooms can be effective to co-produce decision and finally to co-decide on an event electronic voting can be used.

4.3 Functionalities regarding controlling

Sherman & Craig (2003) have defined the controlling functionalities of the 3D scene. The controlling functionalities are basically two types as seen in Table 6.

Table6: Controlling functionalities of the 3D scene

Controlling geo-VE	The control types	Selection
Control of objects	Keyboard controls (hardware control)	Selection of 3D objects
Control of 3D scene	Virtual controls	Selection of the 3D scene
	Direct-user control (using AR)	
	On-display control (menu)	

Figure 11: Key board and mouse control in multi user controlling interface

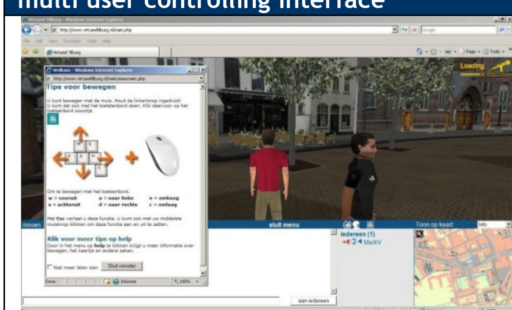
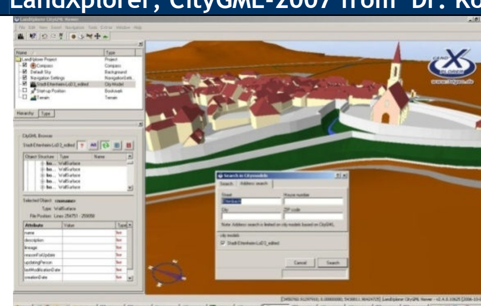


Figure 12: Searching Stadt Ettenheim in LandXplorer, CityGML-2007 from Dr. Kolbe.



The controlling of the 3D scene is directly related to the experiencing modes. Control functionalities for objects in the geo-VE are related to selection functionality. The user can control 2D/3D objects and ask for more information only if it can be selected. The selection types for virtual environments are pointer directed, gaze director, cross-hair directed (mouse), menu select (mouse, keyboard, pointer) and co-ordinate selected (for head mounted display full immersive VE), etc. In Figure 11 shows instruction on keyboard and mouse control on Cebra’s VirtuoCity (Virtueel Tilburg).

4.4 Functionalities regarding exploration

Exploration is the basis of information gathering and analysis. Kraak (2002) has described the functionalities the virtual environments should have to explore data. They comprise of the following as seen in Table 7:

Table7: The exploration functionalities for Virtual environment

Function	Description
Basic Displaying	Users should be able to zoom, pan, transform and rotate the visual objects.
Navigation & Orientation	The user should be able to know the location and what the symbols mean. In 3D scenes, orientation is vital.
Data Query	The user should be able to access the spatial database from which the visual objects are created. Online search (Figure 12) should be possible.
Multi-scale	Data should be harmonized to fit similar scale of representation. LOD and representation methods need to be taken into consideration
Re-expression	The user might need functionalities to change the data behind the representation or view.
Dynamically linked views	Data in the scene should be connected to external sources for additional information like website, sound, video, text, images.
Animation	Animation can show the temporal and non-temporal flow of spatial information. Animation can be also seen as a capability of the VE. It can show results of analysis.

4.5 Functionalities regarding experiencing of geo-VE

Sneiderman (1998), Craig & Sherman (2003), Wachowicz et al (2002), Billinghurst et al (1996), MacEachren et al (1999) have mentioned the experiencing functionalities. The forms of experiencing the digital environment are way-finding, navigation, orientation, and manipulation (e.g. focusing, color map manipulation, moving objects), spatial queries and feedback mechanisms. The passive form of experiencing is when the user only changes position in the scene but does not interact with other objects as seen in Table 8:

Table8:Functionalities for passive experiencing the 3D Scene

Interaction	Description	Domain
Movement	Can be predefined in routes or free movement in the 3D scene. Can be by walking, fly to and crawls in the scene	Passive experience without interaction
Navigation	This is the directed move to an object in the 3D scene which constitutes the free movement	
Orientation	Is the direction in the 3D that indicates "where to move to" functionality	

These three functionalities are regarded as the passive experiencing in the 3D scene without interacting with the objects. Flexibility in changing Field of View (FoV) improves user experiencing of movement, navigation and orientation. Automatic tracking of objects, auto focusing and velocity aid navigation. Selection, explanation, elaboration and manipulation are related to active form of experiencing and controlling.

4.6 Functionalities regarding the I-factors

The "I" element of these four factors corresponds to the fact that they begin with the English letter "I". Heim (1998) has defined the first three of the I-factors such as: *Immersion, Interactivity and Information Intensity* (or Levels of Detail, LoD). MacEachren et al (1999) has added the last factor of the four factors, which is *Intelligence (of Objects).*

4.6.1 Immersion

MacEachren et al (1999) describe immersion as “being in” the virtual environment. It can be defined as a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment” (Witmer and Singer, 1998). Immersion can be of physical immersion and mental immersion. Mental immersion is the state in which the human mind feels the presence of being in the virtual world.

Table9:Mental and physical immersion

Mental Immersion (Thesis issue)	Physical Immersion
Psychological state for any immersive environment	Full body or body parts

Figure 13: Immersion in VE in Ephémère

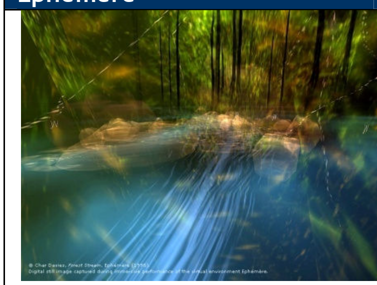


Figure 14: Use of BOOM

Even though it physical immersion is not investigated, it is worth mentioning a few words. Physical immersion can be of full immersion (being in) to semi-immersion (looking at). Head-mounted displays, BOOMs (Binocular Omni Orientation Monitor), and the CAVE are VR-accessories for full immersion. BOOM is a head-mounted viewing box suspended from a two-part rotating arm. The CAVE is different. The user steps into a physical room with digital screens. Multiple people can experience it at the same time with unrestricted movement. But this thesis only deals with mental (partial) immersion on high resolution desktop CRT applications and not full immersive CAVE and BOOM. Osmose and Ephémère are VR projects that deal with human perception being fully immersive in VE (Davies C., 2004) as seen in Figure 13 and Figure 14.

4.6.2 Interactivity

Heim (1998) defines interactivity as the functionality that describes the user’s ability to change the viewpoint. It can be achieved though navigation. Another functionality of interactivity is data manipulation. This means that an interactive environment would let the user change the object’s physical characteristics. Interactivity functionality falls in the interactive use of geo-VE. Table 10 shows the basic forms of interaction. MacEachren et al. (1999) defines interaction as manipulation of the characteristics of the 3D environment and its components (e.g. color of objects, shades, editing, etc).

Table10: Functionalities for interactivity

	Functionality	Description
1	Object entity change in 3D scene	Interaction with object through deleting, adding, copying and pasting.
2	Object position change in 3D scene	Interaction with object by picking up and moving the objects.
3	Object attribute change in 3D scene	Interaction with object by changing color, texture, shade, shape and thematic attributes.
4	Object query in 3D scene	Interaction with objects to derive qualitative and quantitative information about the objects.
5	Object editing in 3D scene	Interaction can be enhanced if the users have the option of editing 2D/3D designs online

Interactivity means enabling a user in a virtual environment to change their viewpoint on the environment and to change relative position to that of other objects (Heim 1998).

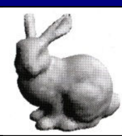
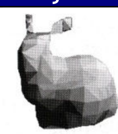
4.6.3 Information Intensity

This I-factor deals with the “Levels of Detail (LoD)” of the object. In urban planning LoD can be a used to show different “visual materials” of the design in different resolution. “LoD” deals with a real level definition of the representation and not only the detail, which an object in the virtual world is seen in a larger zoom. Information intensity if related to how the 3D scene is constructed and falls in the construction domain of the 3D scene. LoD in computer graphics can aid in faster computer performance to handle large scenes and data.

LoD in computer graphics: zoom and scale

According to Bodum & Niels (2005), LoD is needed when the “main objective of the database is to support interactive visualizations, it is necessary to consider that it will not be possible to load the whole database during visualization”. The second reason for having this is to increase faster rendering capacity of computers. Zoom function can be used to represent the 3D objects in different LoD and scale. For increasing proximity to an object should allow a user to see increasing detail or the use of a “zooming to scale beyond those of normal vision to continue to provide additional detail” Wachowicz et al (2002).

Figure 15: Visual impact in which the bunny become gradually finer in higher LOD

Figure					
Triangles	69,451	7,385	1919	462	100
Description	Max resolution & Min Zoom				Minimum resolution & Max Zoom

Source: Stanford Bunny from Exploring Geo-visualization: Dykes, Maceachren & Kraak (2005)

LoD in CityGML and design phases

It is necessary to make a clear difference between the LoD in computer graphics and that of CityGML that is meant for data-exchange, storage and visualization. LoD in this thesis is used in the context of the lateral and not that of Standford bunny in Figure 15. In the CityGML, a city is defined to have buildings, elevation, vegetation, water bodies, street furniture etc. The hierarchy goes on implying that buildings are composed of rooms, interior doors, stairs, and furniture, etc in various LoD. Chapter 5 discusses elaborately CityGML and the various LoDs (four for building class). The LoD functionality in the context of urban planning is not only a distance function but also a function to represent an urban design in a certain phase (in time). There is little research done in the domain of multi-resolution representation of the different phases of the urban design phases and this is investigated in this thesis.

4.6.4 Intelligence of Objects

This fourth and final I-factor added by MacEachren et al (1999) defines how objects in the virtual environment have a certain behavior, which can be classified as intelligence. He argued that there is evidence that the realism in virtual environment is enhanced if the objects in the virtual world have some kind of behavior corresponding to the behavior of the object of the real world. Intelligent objects in the geo-VE can guide the users to understand and interpret the design solutions better. Intelligent objects can also be in the form of avatars or humanoid objects, moving automobiles, prompt-opening doors, instruments that can be used by the user to perform certain human activities, etc.

4.7 Functionalities regarding use and interaction

Wachowicz et al (2002) have divided the four I-factors of Heim (1998) and MacEachren (1999) according to their use and construction and added three extra factors as Agents, Selection and Augmented Reality.

“Agents (Avatars)” falls in the domain of “use” and “construction” of virtual 3D scenes. The “use” is meant in the domain of active interaction. Avatars are models to represent the user in the geo-VE.

It allows the user to interact with other users in a chat, instant messaging (IM), and multiplayer gaming session as seen in Figure 16 & Figure 17.

Figure 16: Active World: Multi-user Avatars

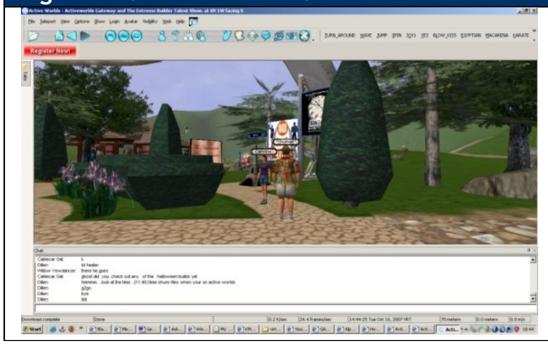
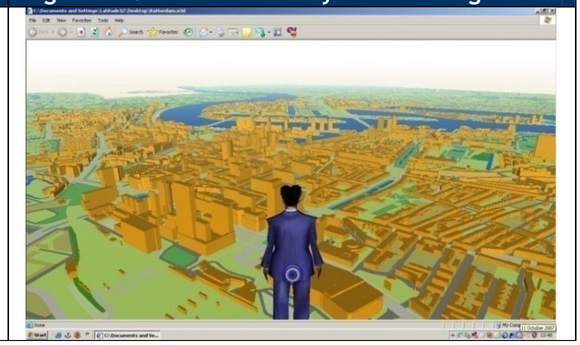


Figure 17: Rotterdam City in Bitmanagement



Wachowicz et al (2002) argue that selection is the ability for the users to dynamically select the spatial data, objects, simulation models, and scale in order to construct a VR environment. Augmented Reality (AR) falls in domain of the "use" of virtual environments. A virtual reality replaces the real world, but in AR supplements the real world with extra additional information. AR systems are not widely used in such systems, as they require specific hardware and dedicated software (Zlatanova et al 2007) and therefore not investigated in this thesis.

4.8 Functionalities of interactive geo-VE, Sneiderman, 2003

Sneiderman (2003) has defined three functionalities that are needed to make a VE better than reality. The VR should make the user aware of the whole 3D scenes through effective overview of the whole picture. The number of tasks to accomplish an activity must be minimized. They should have interactive prompt, which means that there should be feedback from and to the system.

Functionalities relating to VE usability

Sneiderman (2003) and Craig & Sherman, (2003) mention that some breakthrough functionality can change the usability of the VE interface dramatically. Davis S. B. (1996) also mentions some of these interaction functionalities in the realm of VRML. It has been noticed many of these functionalities are implemented in Google Earth, MSN VE 3D and '*Virtueel Tilburg*' as seen Table 11.

	Table11: The basic guidelines of VE interface design
The VE should	use shadows, occlusion, colors, perspective but with care.
	minimize the number of navigational steps for users to do a task.
	keep textual information easily readable (good contrast with background)
	avoid unnecessary visual clutters
	simplify user & object movements (facilitate docking, predictable paths, rotation)
	provide multiple coordinated view (plan view with 3D model synchronously)
	have teleportation functionality for rapid movements in the 3D scene
	have X-ray vision to help the user to see beyond the solid objects
	provide functionality of history keeping (undoing, replaying, editing etc)
	provide rich interaction with objects (save, copy, send, share)
	have multi-user entry to the interface facilitating collaboration.
	have explanation functionality through text (popup, floating, screen tips)
	offer functionality to the user select for detailed information of objects in demand
	offer functionality tools like mark, draw and measure
	allow dynamic queries for searching an filtering
	allow semantic zooming and movements
	show landmarks in cities at distance and have human activities to represent reality
	use icons to represent concepts that are memorable for the user
	offer animation and simulation facilities
	have apparent intelligent object to aid tasks

4.9 Defining the functionality domains of geo-VE

The functionalities appropriate for geo-visualization in virtual environments for urban design and planning has to take into account the functionalities mentioned in this chapter. The added value of this thesis is to perform taxonomy on geo-VE functionalities for interaction. Putting all these theories in a matrix presents the following non-hierarchal chart in Table 12.

Table12: The functionality theories of geo-Virtual Environments

Capabilities & Construction	Experiencing	Controlling	Use	Exploration	Components
	Passive/Active Experiencing	In terms of Selection	In terms of Interaction	In terms of searching	In terms of functions
Con: Modelling, data acquisition, formats, etc.	Movements	Control modes	Interactivity	Display tools	These are the components and the toolboxes that are part of the VR software leading to specific functionalities to interact with the 3D scene.
Object preparation	Navigation	Selection of Scenes	Intelligence of Objects	Navigation	
Con: Data-Fusion & Integration	Orientation	Selection of 3D objects		Orientation	
Con: Information Intensity (LoD)	Selection	Data extent	Agents (Avatars)		
Con: Control, Experience, Interactivity, Exploration tools	Explanation	VE Accessories		Hyper links & Linked windows	
Cap: Interfacing	Elaboration		AR		
Cap: Representation	Manipulation			Re-expression	
Cap: Simulation & animation	Immersion			Query	
Cap: Feedback				Scale	
Cap: Multi-dimensionality					

ELICITATION: VISUAL MATERIALS
CHAPTER 5

5 The visual materials of geo-VE for urban design and planning

This is the second chapter of the elicitation phase of the requirement engineering process. It identifies how visual materials are represented in virtual environments from different theoretical and application perspectives. The visual materials that make up 3D scenes are described from wide range parameters including dimensionality, realism and LoD. The different theories and application to categorize visual artifacts are discussed with the relevance of visualizing urban information in the geo-VE.

5.1 Visual representation: different theories and practices

5.1.1 Visual materials: realism, abstraction and generalization

Images must be lively, active, striking, charged with emotional affects so that they may pass through the door of the storehouse of memory.
Giordano Bruno (1591)
Mentioned in **Yates 1966**

An important factor of how the geo-VE is experienced is related to how one chooses to map thought, data, images and representation in the digital environment. If human beings can relate to a visual material to that of urban objects, a mnemonic image is created in the human brain. Realistic appearance of 3D models in geo-VE stirs the human imagination towards this aspect. Sherman & Craig (2003) described that in the computer environment, "representation is the choice of what to render." Representation comprises how human beings through their cognitive knowledge understand the visual representation in the VE. Ervin (1992) has defined and categorized the graphical visual representations based on their attributes as follows:

"Diagrams are abstract and schematic and are used to explore structural relationships between parts. Maps involve scaled representations using a consistent system of reference (e.g. coordinate systems) and allow inferences about dimensional and spatial relationships. Graphs are concerned with representation of statistical and quantitative data. Pictures are primarily concerned with impression, expression and realism."

Some interesting facts come out from Ervin's definition of visual materials. He argues that diagrams and graphs can represent accuracy. Graphs, maps have quantitative quality. Maps and images can represent an abstraction of the real world. On the other hand, images can also represent extremely detailed realism. Even though images can be the abstraction of the 3D world, images are not themselves 3D objects and they are static. He did not mention the 3D digital models explicitly.

The computational advances in designing virtual environments have challenged this categorization through 3D digital representation. Pietsch (2000) has argued that with the advances of computing power visualization and representation in terms of 'validity and content' must be reviewed. According to her, in a complex process as design (also urban planning and design) the factors related to accuracy, abstraction and realism might vary in importance (according to the various design phases). If the spatial world needs to be visualized in geo-VE, the appropriate level of abstraction and generalization should be used. Singh (1999) argues that 3D scenes, video montages, 2D maps, plans and sketches are nothing but multiple views of the same abstraction of the real world object. The level of abstraction represents the level of information, detail and grain available in the visual information. A visual object in higher level of generalization only represents the key (important) information.

5.1.2 **Visual materials: virtuality, diegesis & imageability**

All really inhabited space bears the essence of the notion of home.
Bachelard 1958

Not all VE systems appear realistic and some of them are designed specifically to deviate from realism for specific cases. Test shows (Pape, 1998, Figure 18) that an interactive but anti-realistic VEs engaging the users in various levels of interaction through visualization, 3D sound, etc are very effective in transferring information. Therefore, the assumption that realistic geo-VE can improve user interaction can be proven wrong. Felix (1995) cited that being bodily immersed inside or outside in the VR has no real influence to increase understanding. Physical immersion and photorealistic 3D scene are not the reasons why a VR becomes interactive, but how the user can interact at ease (*notion of home*) in the virtual space. The researcher tested two geo-VE for usability and interaction. Virtual Ljubljana (See Website, Figure 19) is an example of beautifully modeled realistic virtual city model but unsuccessful ghostly environment lacking interactivity. On the other hand *'Virtueel Tilburg'* has high level of interactivity attracting user attention through intelligent object, virtuality, interactive information, feedback, etc. So if a virtual space lacks the quality of interaction with the surroundings, the usability of the geo-VE decreases considerably.

Figure 18: Interactive anti-realistic CAVE

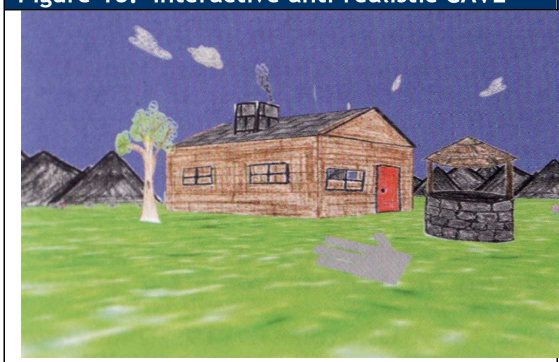
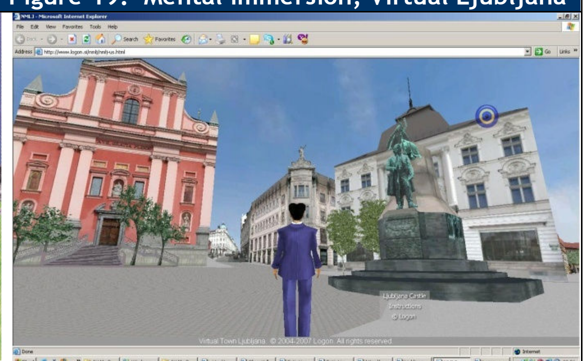


Figure 19: Mental immersion, Virtual Ljubljana



'Virtuality' is based on the idea of "direct manipulation" of Sneiderman (1998) and aims to produce forms of human computer interaction, which give the users the feeling that they are engaging with the data rather than the tools to manipulate data (Davis, S. B., 1996). Virtual world that closely resemble the real world are called *"mimetic"*. On the other hand, *"diegesis"* is the implied consistency (which can be translated as semantics of space in geography) within a particular world. These three topics need attention in visual representation of objects in geo-VE.

To describe the representation and detailing of urban areas, Lynch (1960)'s "The image of the City" provides the framework to study cognitive maps, urban forms and the spatial relationships of urban areas. Lynch identified the concept of *imageability* of the city (also mentioned in Al- **Kodmany**, 2001), which points out the physical elements (paths, nodes, edges, landmarks and districts) that enhance the structure and identity of the city and aid navigation and interaction.

5.1.3 Visual materials: the realism axis

A continuous line proceeding from highly verisimilar to highly abstract representation is called the realism axis. Any visual representation can be mapped into this representation that fall somewhere in this axis between reality and abstraction. McCloud (1993) defines that the degree to which display is realistic or abstract is a continuum. A representation of pine forest in the reality axis is seen in the Figure 20 and human face in Figure 21.

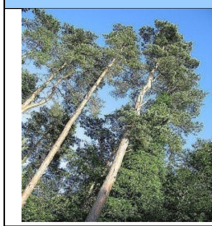
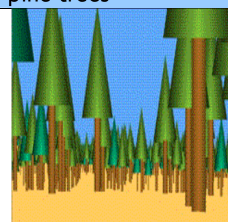
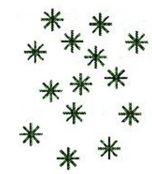
Verisimilar

In this axis the verisimilar representations show the very realistic representation of a pine tree in the virtual world. If 3D modeler designs a tree as an individually identifiable photorealistic tree, one would end up in creating a very highly detailed and highly complex model, which in this case is the verisimilar representation.

Indexed

Indexed representations map values from some phenomenon onto a new form that can be easily understood (Sherman & Craig, 2003). This can explained through the representation of a tree. From background knowledge the modeler knows that the pine tree consists of various types of genus, each of the genus of pine trees has different stems, leaves, patterns of growth, height, color, placement of branches, etc. This makes a logical semantic classification of trees possible by indexing them and their parts. This is defined as the indexed representation. The concept of CityGML modeling for classified building objects is based on indexing.

Figure 20: Visual representation in realism axis adapted from Dykes, MacEacheren & Kraak (2005)

Verisimilar	Indexed	Iconic	Symbolic	Language
Photorealistic pine trees	Classified & Mapped pine tree with semantics of parts	Volumetric Shaded represents generic pine trees	Flat 2D maps/ 2D images pine symbols	Textual
				Pine Forest (English), Pinaceae (Latin), Pijnboombos(Nederlands) Pinede (Francais) Tannenbaum (Deutch)
Physical reality	↔			Abstract

Iconic

Iconic representation is a naïve form or representation. For example a mountain can be represented with a prism, a pine tree can be represented through a cone and a cylinder, etc. Through the iconic representation the human cognition ability can make a discrimination between a pine tree and a mountain. But one would not be able to make a difference between different pine trees through iconic representation. In urban geography, iconic representation can be 2D maps, DTM/DEM or 3D block models.

Figure 21: Representation of a human face in the Virtual Environment on the Internet

Verisimilar	Indexed			Iconic	Symbolic	Language
Face of Miss Lara Craft	Class of males according to nationality (Cebra, VirtuoCity in Netherlands)			Generic Human Face	Concept of face (Yahoo Face)	Textual information in Dutch & English
	 Dutch	 Bulgarian	 Indian			GEZICHT, FACE
Received Information	↔					Perceived Information

Symbolic

The symbolic representation is the first 2D depiction of any concept of the human mind. If one is interested in symbolic representation then one does not care about the finest detail of the model. A cartographic representation (Bodum, 2005) or plan view of the 3D model is sufficient to represent a tree, building or road in the symbolic representation. Geographic maps are made of symbols.

Language

The final version of visual representation of any object is the use of text. Using the word "Pine Tree" brings sensation from the reader's memory of the kind of tree it means, its approximate height, color, geographical location of growth.

5.1.4 Visual materials: graphical to model representation, 1D to 3D

Graphical representation consists of texts, graphs and images. Textual information is used to describe the attributes of the visual object. One can argue here that the graphical & relational representation of objects usually does not have scale (texts, pictures, graphs, images, etc) and multi-resolution model representations (both 2D map and 3D model) have scale and topology. The classification can be seen in Table 13.

Table13: Models and Graphical representation

Type	Name
Graphic representation	Textual information (1D)
	Images (static, dynamic and panoramic) and Graphs (2D)

	Type	Name
Model representation	2D models	Plans & Maps (2D)
	3D models	Volumetric Models (2.5D) to highly detailed 3D models with textures.

According to the definition as described by Morgan and Morrison (1999) models are "instruments that enable designers to explore the world, to predict it and to plan it, prior to acting in the world in any irrevocable way". Models play an autonomous role in science and design and they are not theories neither full reality. Models try to represent or manipulate the real world. Batty et al (2007) in his scientific paper "Modeling Cities" classified city models into the material and digital categories.

The term model representation in the thesis is used in the context of digital geometrical models (both 2D and 3D) making up the dynamic 3D scene of geo-VE. Models can be subdivided into 2D and 2.5D and 3D models. The modes for modeling and representation for urban design can be seen in Table 14. In the computer world, 3D visual data tends to be built on 3D geometries such as polygon meshes, 3D lines and 3D points. 3D geometry includes constructive solids and all kinds of parametric representation. The 3D geometry of models can also contain polyhedrons and tetrahedrons. In the domain of data and visualization, 3D models can be determined as plots in the Cartesian coordinate systems having x, y and z values (Kirchenbauer, 2005).

Table14: Types of Models

	2D	3D
Physical Models	Paper 2D maps and plans	Physical models
Digital Models	Digital 2D and 3D models for computational simulation/ analysis	

In most cases of urban design Computer Aided Design (CAD) models are used for design communication and interaction. CAD systems (like Autodesk AutoCAD, Microstation of Bentley Systems, 3D Max, SketchUp, ArchiCAD, etc) have been the mediums for planners and designers to interact through 2D/3D models. But these traditional CAD models are through remote computers and not visualized through the Internet and lacks interaction capabilities. The Industrial Foundation Class (IFC) is an attempt to standardize and bring semantics in CAD for the building construction industry. Using GIS, 3D models can be created for visualization and analysis.

5.1.5 Visual materials: plan, model and world view

Whyte (2002) indicates that 3D visualization is related to representation in virtual reality. Visual objects representation can be buildings, landscapes, elevation models, 3D, etc. Visual materials can be a plan or a block model. Using textured surfaces a real world representation can be applied. According to Verbree et al (1999) in order to support the visualization process in the virtual world, three visual representations can be defined as seen in Table 15.

Table15: Different dimensionality for visual objects in geo-Virtual environments

	View	Definition	Purpose for user	Dim
1	**Plan View (PV)**	2D maps (dynamic and static) are contour representations	Initial orientation with study area.	**2D**

2	**Model View (MV)**	Non-textured 3D city block models for volumetric analysis.	For professionals to analyze spatial analysis.	**2.5D to 3D**
3	**World View (WV)**	Photorealistic textured 3D models give impression of reality	For presentation as communication medium.	**3D**

The 3D scene is enhanced on the method how the viewer visualizes the data. Danahy J. (1998) in the Centre for Landscape Research (CLR), Toronto identified the viewpoints that are needed for 3D visualization as seen in Table 16.

Table16: User viewpoint and experiencing

View	Aerial camera view	Elevated oblique camera view	Eye level experience
Definition	Provides strategic overviews, Berlin, (Dr. Kolbe)	Allows spatial arrangement, TU Delft Campus	Personal sensation human experience Virtueel Apeldoorn
Height	Higher than 200m	200m to 2m	1.8m to 1m
			

5.1.6 Visual materials: scenic languages CityGML, KML and X3D

Due to technological push from the Internet it is necessary to look into representation according to state of the art Internet and scene based languages like X3D/VRML, KML and CityGML to visualize urban information. The LoD of CityGML is emphasized in to define visual materials in this thesis.

VRML/X3D and KML

Internet with the influence of the "game industry" has changed the realm of visualization and how objects of the real world are viewed in virtual environments. Web3D's 3D modeling language (VRML/X3D) make visualization of building models in XML based open source data format. In the past CAD models has been generated on remote computers, but VRML models came as the solution to online CAD (Batty et al, 2000 A). While such languages offer a lot in graphics functionalities to create photorealistic models, they are weak in providing means for 3D geo-database objects and represent object semantics. The reason behind is that they are not designed to represent relationships of objects they represent.

KML/KMZ is a XML data-format that defines the viewing of visual objects on Google's virtual earth terrain with different kinds of properties like placemarks, paths, raster images, polygons, attribute and metadata, etc. The KML specification describes how placemarks, image-overlay, screen-overlay, path and polygons are combined on the Google Earth virtual interface in different LOD and realism. In practice models in KML or VRML/X3D can be also used in these five different LOD steps. KML defines the level of detail function through the "Region" attribute. It can place geographic objects on the terrain using 'Ground Overlay' attribute. However KML cannot define the interior of buildings that can be visualized on the GE terrain. Even through KML 2.1 can define the geometry of a 3D model it cannot explicitly define textures to polygonal surfaces. It uses the COLLADA (COLLAborative Design Activity) specifications to import 3D textured models inside the GE terrain (COLLADA, 2007, See Website). It uses the .dae (digital asset exchange) XML based format. COLLADA is originally made by SONY for the Playstation Environment and can be read in 3D Max and Maya.

To define visual materials on the Internet, such modelling languages must be taken into consideration. Like most virtual city models, these formats provide only graphic or geometric models, neglecting the semantic and topological build-up of the real world. KML or X3D/VRML are very strong in visualization but have serious limitation for spatial relationships and semantics.

CityGML for urban information (Candidate Specification, OGC 07-062, CityGML 2007, Dr. Kolbe)

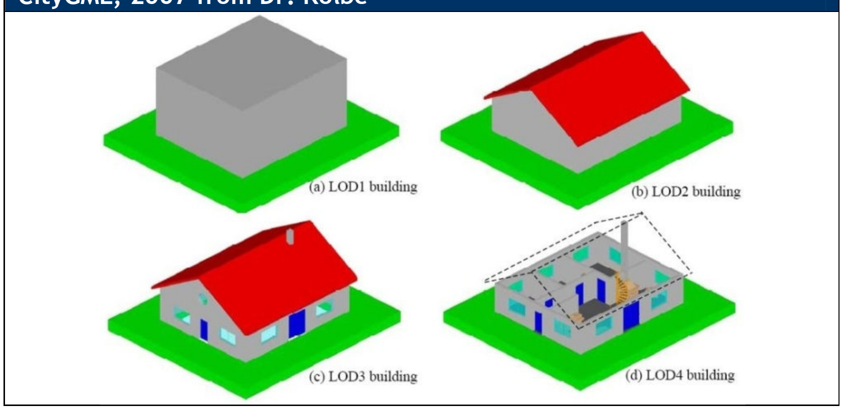
CityGML is a geographic information model and can be an exchange format for virtual city and regional models for the municipalities. It describes objects of the real world in the XML (GML3 for geometry) language. The goal of this data format to have a rich source structure for visualization process, not intended to be used by 3D formats like X3D, VRML or KML. The simplest method of portraying CityGML to other formats is to perform a 1:1 conversion of geometry and appearance. XSLT conversion engines can be used in this regard.

CityGML contains a geometric and a thematic schema. The geometric schema in CityGML contains the geometrical properties and describes how the urban objects are constructed using geometries like points, polygons, curve, multi-points, multi-polygons, multi-curve, surface, solids etc. CityGML does not have topology at this moment. The thematic model of CityGML can describe thematic real world scenarios and fields like earth terrain, the city buildings, greenery of cities, exterior city objects, rivers and water bodies, etc (Annex 3 Section A). Through external reference 3D models like X3D/VRML or KML/COLLADA can be imported into CityGML as seen in Annex 3. Spatial objects of equal shape can be used repeatedly in the city model like trees, cars, people, animals, etc as prototype objects. The concept that a building does not float above or sink in the terrain is met with the "*TerrainIntersectionCurve (TIC)*".

Representation of a Building in CityGML

For visualizing buildings and their attributes like surface, walls, openings, doors, installation etc, CityGML is of profound interest. This can be done through the building class of CityGML (Annex 3 Section A, B, C). The representation of buildings has major importance and therefore the building class in CityGML is extensively investigated. Figure 22 and Figure 23 shows the different types of CityGML models in LoD1 to LoD4.

Figure 22: LoD & increase in geometrical/semantical complexity, CityGML, 2007 from Dr. Kolbe



LoD 1 model

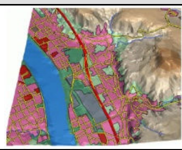
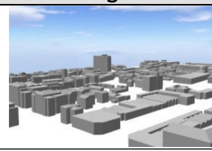
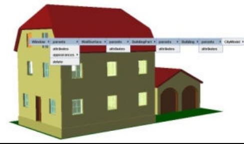
In the case of LoD1 model, a building model consists of geometric representation of the building volume. They are also named as block models. Such models are useful to conduct spatial analysis.

LoD2 model

In LoD2 (also in LoD3, LoD4) model, the exterior surface of the building can be defined by two nested classes for surface boundary and installation for buildings (Annex 3, Section B to E). The boundary surface is the part of the building's exterior shell (also the interior shell in case of LoD4 models) with a special function like outer wall, roof, ground plate and closure surface, etc. The LoD2 model can have building installations, which is used for building elements like chimneys, dormers & outer stairs, etc.

LoD3 model

LoD3 contains doors and windows as objects. It contains an abstract class ("*Openings*") that defines the doors and windows. Thus the doors and windows in LoD3 are defined as individual entities. The boundary surface of the LoD3 model is topologically correct, without holes and discrepancies in the openings caused by windows and doors. Basically there is not much difference between the LoD2 and LoD3 building models except for the accuracy. LoD3 models can have textured surfaces.

Figure 23: LoD models in CityGML, 2007 from Dr. Kolbe				
LoD 0	LoD 1	LoD 2	LoD 3	LoD 4
DTM	Block Model and no roofing	Models with roof	Detail model with roof textures	Detail models with interiors
				

LoD4 model

LoD4 has the highest level of detail for buildings in CityGML and it contains interior rooms of the building. One to several rooms can compose the interior (defined in the "*Room*" class). The room can be classified according to functions like commercial room, living room, kitchen, etc. The room is geometrically closed. The room can have surfaces like floor, ceiling, and interior walls. It can have installations like lamps, radiators that are permanently connected to the room and also moveable furniture like chairs, tables, etc. It can have textures on wall surfaces. Table 17 shows that a certain LoD model contains certain theme.

	Table17: Geometric & Semantic themes of a building	LoD1	LoD2	LoD3	LoD4
1	Volumetric Part of building shell (outer surface/volume calc.)	X	X	X	X
2	Surface Part of building shell (used for straight buildings)	X	X	X	X
3	Terrain Intersection Curve, TIC	X	X	X	X
4	Curve Part of building shell (used for curved buildings)		X	X	X
5	Boundary Surfaces (like outer wall, roof, ground plate)		X	X	X
6	Building Installations (like balcony chimney, stairs, dormers)		X	X	X
7	Openings (like doors & windows)			X	X
8	Rooms & furniture (Interior installation and Room Furniture)				X

Therefore in visualization terms, the LoD1 model is the volumetric representation of the building. The LoD2 represents buildings in volume with coarse details. In terms of design, LoD3 can be seen as a very detailed 3D architectural model containing the doors and windows and all other architectonic aspects from the exterior. LoD4 from the outside looks like LoD3 models but it contains a walk-able interior space. Such models can be used for not only visualization but also in disaster management to calculate escape routes.

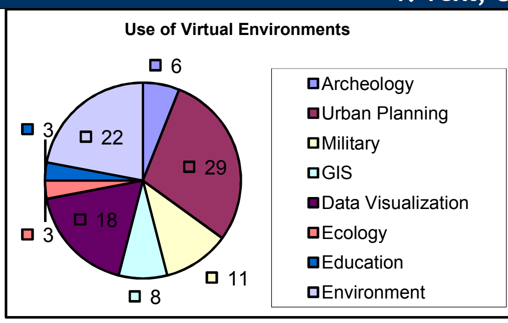
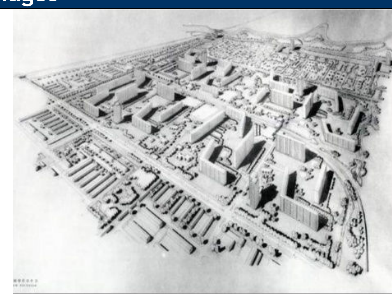
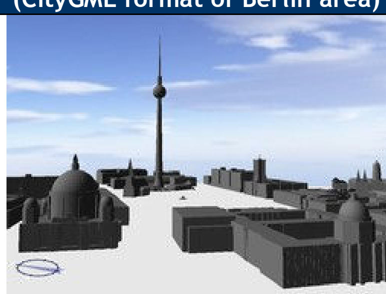
5.2 Defining the visual materials of geo-VE

There has been a broad discussion on the various theories and methods to define the visual materials that make up the 3D scene of virtual environment. It is obvious that it is quite difficult to define all the different approaches in one single definition. The visual materials are initially defined as graphical (*text, graphs & images*) and model representation (2D and 3D). The model representation is further sub-divided into different 3D models according to the CityGML LoD schema like "*Volumetric block models*" for LoD1, "*Volumetric envelope models*" for LoD2, "*Detailed architectural models*" from LoD3 and finally "*Detailed models with interior*" from the LoD4. In Chapter 6 these visual materials are further classified according to the parameters discussed in this chapter. In Table 18 the *Visual Materials (VM)* are defined as follows:

Table18:	The Visual Materials (VM) of geo-VE
VM1	Text, graphs and images
VM2	Plan and map
VM3	Volumetric block model (no detail)
VM4	Volumetric envelope model (few detail)
VM5	Detailed architectural model
VM6	Detailed architectural model with interior

Figure 24: The Visual Materials of geo-VE

The following figures are the various forms of visual materials as defined that build up the 3D scene of the geo-VE. The first two images are text and graphs and a sketchy image. The plan and map shows TU Delft campus in 2D zoning plan. The following consists of block model of the TU Delft campus followed by volumetric model with detail of the city of Berlin in CityGML LoD2. The next image shows the Aerospace Engineering faculty of TU Delft in Detailed architectural model and followed by detailed interior of a room.

1. Text, Graphs & Images	
	
2. Plan and Map, (Top10vector, TU Delft area)	**3. Volumetric block model (no detail) (3D of Top10vector, KML format, TU Delft Area)**
	
4. Volumetric envelope model (with detail) (CityGML format of Berlin area)	**5. Detailed architectural model (textured, KML format TU Delft Area)**
	
6. Detailed architectural model with interior (textured, X3D format, navigable model)	
	

6 Conceptual domain and analysis

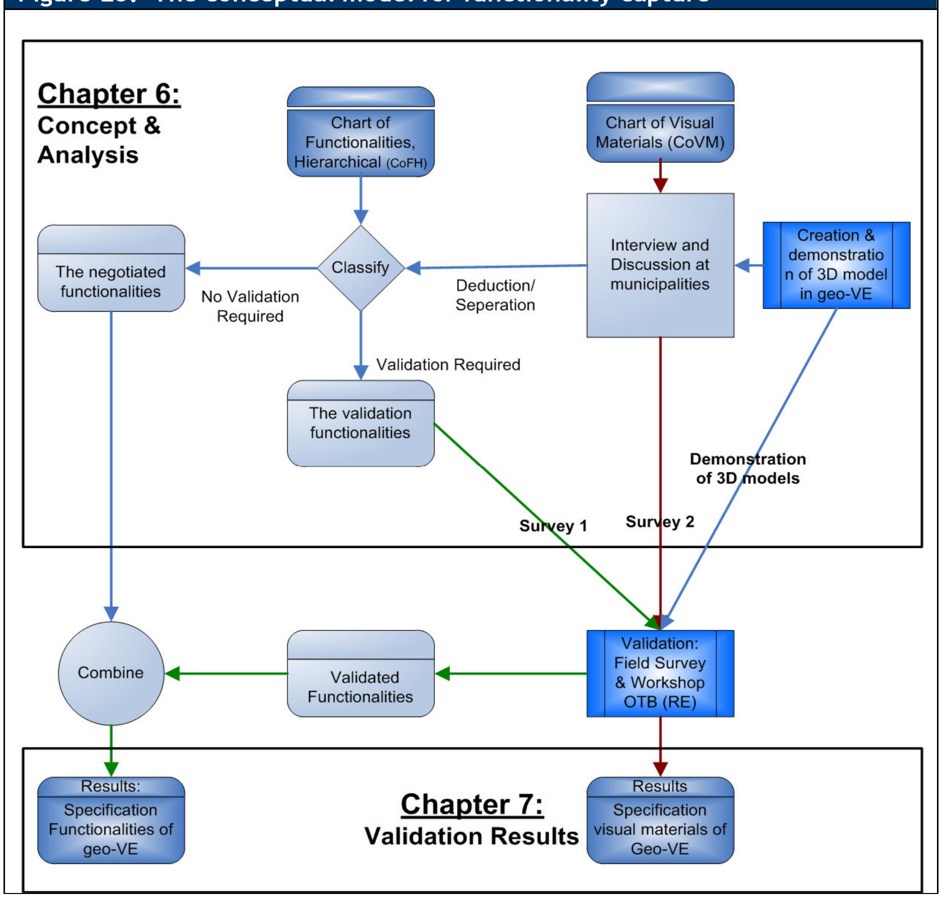
6.1 Analysis of functionalities and visual materials of geo-VE

The previous two chapters have defined the functionality domains for geo-VE and the theories behind representing visual materials in the virtual world from a wide spectrum of ideas. These two chapters make up the input of the elicitation phase of the requirement capture process where information is gathered. The hypothesis or conceptual part of this thesis contains a two-folded question as seen below in Table 19. The Figure 25 illustrates how the functionality capture process is conducted.

Table19: Core research question related to functionalities and visual materials

Questions	Leading to Taxonomy	Leading to Questionnaire	Validation Method
What functionalities of geo-virtual environments are required to visualize urban projects?	Chart of Functionalities	Survey 1	Field Survey & Workshop
How can visual materials of geo-virtual environments be used in urban planning phases?	Chart of Visual Materials	Survey 2	Field Survey & Workshop

Figure 25: The conceptual model for functionality capture



The thesis follows a software requirement engineering process. It looks at the functionalities of the VR system based on tasks that they perform for interaction to visualize urban projects. The elicitation phase is related to gathering information on requirements from the stakeholders. In user centered software design, when the users are not aware of requirements they come from existing systems. In the case where there these systems do not provide the functionalities to perform a task, an extensive analysis is a way forward. To describe requirement acquisition process in software engineering, Ian Crew (2007) in 'User centered design for IT Services' mentioned that gathering a group of expert users together to discuss their requirements from the software can generate a lot of feedback in a short time.

In requirement engineering, the elicitation phase consists of gathering information from the end user. But in this thesis this has been not possible as the end users did not have any background knowledge on geo-VE. Therefore, in the elicitation phase the functionalities and the visual materials are identified in Chapter 4 and 5. The urban planning phases and the actors have been identified in Chapter 3. This forms the ethnographical study of the elicitation phase. The functionalities and the visual materials are observed, analyzed and documented in this chapter leading to the creation of two charts as follows:

- Chart of Functionalities (Hierarchical)
- Chart of Visual Materials

It is necessary to validate the hypothesis. The second part of this thesis is to create appropriate validation questionnaires for the users to check if the information gathered in the elicitation phase is relevant. The two charts are discussed during interviews at the municipalities and with mutual understanding these functionalities are structured in two parts. They are those that need validation and those that are negotiated and accepted. The functionalities that negotiated reflects that these are functionalities that generic geo-VE should have and not directly related to tasks of visual interaction in the process of urban planning. The validation functionalities on the other hand, need to be proven that they are required. From each of the functionalities that require validation statements are formulated. Similar questions are also formulated for the visual materials. The visual materials are discussed with the municipalities and they are accepted to be appropriate to represent 2D/3D models in geo-VE. The whole process has lead to the creation of two validation questionnaires (survey 1 and survey 2) based on the two charts.

The third part of the requirement engineering process is conducting validation by the end users with the help of these questionnaires. The validation is conducted in two phases: firstly, by conducting field surveys and secondly through a workshop. The field survey was smaller in scale and provided a trend but no statistical results. Therefore, a workshop was held at OTB, TU Delft with a larger number of participants leading to statistical results. During the interviews, field survey and workshop 3D virtual models are used. Therefore it is necessary to emphasize on the general modelling techniques used in this chapter. An extensive modelling technique based on polygons and height information using ArcGIS has been discussed in this chapter. The 3D models created through this process are demonstrated during survey 1 and survey 2.

6.1.1 Conceptual overview of 'Chart of Functionalities'

There has been a broad discussion based on a wide variety of theories on the construction, capabilities, control, experiencing, use and components of geo-virtual environments. The functionalities for geo-VE are discussed in theory, lead to the formation of the 'Chart of Functionalities (Hierarchical)' as seen in Table 20. This table focuses on the entire functionality domains for interactive visualization in virtual environments.

The chart shows the functions that are interrelated in same colors. There is also a hierarchal approach from top to bottom and left to right. Not all of the functionalities are relevant for visualization of urban projects through geo-VE and a therefore a conceptual understanding of the functionalities needed for visualization of urban planning is needed.

The functionalities listed in the chart have a hierarchy in the interaction activities. When there is duplication of functionalities in different domain, the submissive domain is seen is light grey. Thus when functionality is shown in light grey, the similar functionality in the other domain is highlighted. The reason behind this is not to select duplicate functionalities for validation.

The table identifies the relationships of the domains of the functionalities. If one observes carefully, one can see that the active forms of experiencing (manipulation, explanation and elaboration) are closely related to controlling and use (interactivity) and exploration domain of the 3D scene. The active form of experiencing are listed in light grey and these functionalities fall in domain of controlling, use (interactivity) and exploration. This thesis has classified experienced as a passive activity that happens through moving and navigating but not interacting. It happens without direct interaction with the 3D scene. The experiencing here is seen as a passive activity of movement, navigation and orientation.

Wachowicz (2002) has already listed Information Intensity (I-factor) belonging to construction of the 3D scene. Information intensity or LoD is related to how the system. This includes other issues like spatial database solutions, data preparation, data formats and integration etc. The construction functionality in this thesis is based on the LoD as defined by CityGML. The construction of the VE must contain the experiencing, controlling, interaction, exploration toolboxes in order for the system to be useable for the users. The capabilities of the 3D scene are subclass of the construction domain. These are the basic capabilities of the geo-VE like repressing the data in multiple dimensions, interfacing and interaction capability, feedback, simulation and animation, etc.

The active interaction or controlling is based on the selection of scene and data. Without click and select of data and scene, controlling is not possible. Controlling is based on controlling modes that can be single user or multi-user modes. The use domain is based on user interaction. In this thesis the controlling is based on direct control of the user through VR accessories. Controlling is related to the control modes (keyboard, mouse, touch screen, virtual controls, VR accessories, etc) and selection of the data. Controlling is a form of active experiencing. This thesis classifies controlling as direct user control of selection of 2D/3D objects and also the 3D scene.

Manipulation or interactivity (I-factor) is the basis of the use functionalities. The interactive functionalities are functionalities that let the users change object appearance, delete objects, save objects in the 3D scene. Intelligent objects, AR and avatars are to that of interactivity of use (interaction) domain. The use domain of geo-VE is seen as interactive activity.

The exploration is seen in this thesis is searching the data and the information in the attribute and hyper-linking. Immersion (both physical and mental) is classified as an experience. As studies proved that full immersion does not increase the ability of human cognition, only desktop mental immersion is the type of VR that is relevant. The components are the basic functions and tools that form the 3D scene of geo-VE. These are the toolboxes geo-VE.

The researcher observed the relationships between the functionality domains and in the chart the functionalities are listed in a matrix of hierarchy and apparent relationship. The chart is a milestone for this thesis to list the various functionality domains in a single taxonomic hierarchy table. The table can be used to classify various geo-VE software.

Table20: The Chart of Functionalities (Hierarchical)

Construction& Capabilities	Experiencing		Controlling		Use (Interaction)		Exploration	Components
Control Tools	Experiencing							
Experience tools			Controlling					
Interaction tool					Use (Interaction)			
Exploration tools							Exploration	
Components related tools								Components
Capability: Interfacing: Interaction			User mode	Single / Multi	Automated (Avatars)	Agents		Multi-user interface (login)
A. Interaction in the 3D Scene	Mode	Active / Passive					Basic display tool	Viewing, control, interaction, experience, exploration toolboxes.
	Movement *Degree of Freedom (DoF)*						Navigation	Navigating & movement tools
								Fly to, Crawl to, teleporting, Zooming, Panning, Transform and rotate
								Highlight Landmarks, nodes
	Navigation							*Way finding tools, bread crumbs, arrows*
								Velocity and acceleration, Way finding + Travel, teleportation
	Orientation						Orientation	Orientation aid
								North Sign, Location & Coordinate display
	Selection (ACTIVE & related to Controlling)		Selection of Scenes/objects					Switch, Click Mouse, Keyboard, Laser pointers to click and select objects and scenes
			Pointer directed					
			Gaze directed					
			Cross hair directed					
			Menu select					
			Co-ordinate directed					
B. Interaction of the 3D scene (Modes of computer interaction)			Controlling Mode					
	Manipulation (ACTIVE & related to Interactivity)				Interactivity	Entity Change	Re-expression	Editing tool, Dragging & moving toolbox
						Position Change		Drawing toolbox
						Add Object		Measurement toolbox
						Attribute Change		Attribute changing toolbox
						Query	Query functionality	Spatial query toolbox

Construction & Capabilities		Experiencing	Controlling	Use (Interaction)	Exploration	Components	
		Explanation			Hyperlinks, Coordinated linked Windows, Linked objects, Hyperlinks	Hyper-linking, interactive exploration. Home page, back, forward.	
		Elaboration		Augmented Reality		Gloves, Touch screen tables, Webcam	
Capability: Immersion		Immersion				Atmosphere, Data extent, Background, horizon, Multi-Layering, View points	
		Mental (Presence)					
		Physical (Semi, Full)					
				Intelligence of Object behavior		Moving objects, prompt on user demand	
Capability: Representation	TxtGraph&Img				Representation	Rendering/Resolution mode	
	Map & Plan					Light/Camera mode	
	Block Model					Shading/Visibility mode	
	Envelope Model					Visual Properties	
	Photo-real Model					Colors/transparency mode	
	Photo-real Interior					Representation mode	
Construction: Information Intensity	LOD0				Multi-scale	Distance functionality, Scale & Zoom	
	LOD1						
	LOD2						
	LOD3						
	LOD4						
Capability: Simulation and animation					Animation	Algorithms, Time Component, Animated movies, GIS Analysis	
Cap: Multi-dimensionality						Multiple D in multi-windows and viewpoints	
Capability: Feedback	Chat, Online Conference					Java Applet Chats, MSN, Skype, Webcam, etc	
	Email/Voting					Internet & interactive website connection	
	Gespreksavond					Electronic Conference	
	Telephone, Weblog					Internet telephony	
Construction: Object Preparation	CAD/GIS tools		Control of Scene Control of Object			Data type	Geometry
	Geo-referencing						Vector/Raster
	Modelling tools						1D/2D/3D/4D
Cons: Data fusion and Integration			Geo-data extent			Software components, data geo-referencing	
			VE Accessories: CAVE, BOOM, Fishtank, etc			Hardware components (beyond research)	

6.1.2 The validation of functionalities (deduced from Table 20)

The interviews the four municipalities act as the initial requirement structuring process for geo-VE functionalities. During the interviews the 'Chart of Functionalities (Hierarchal)' is restructured to define the validation functionalities in Table 21. Discussion on the project *Virtueel Stadmodel Rotterdam* has important input for this phase. In general term cost issue is related to the amount of functionalities that the geo-VE can provide. But some geo-VEs provide various functionalities for free. Cost of implementation increases if functionalities related to analysis are incorporated in the system. In any case the geo-VE should be free of cost for the general public. It must be a democratic and universal interface where various user groups come together for discussion and exchanging ideas on urban and spatial planning projects.

The functionalities are restructured through interviews at the '*Gemeentenwerken (GW)*' and '*Dienst stedenbouw en Volkshuisvesting* (dS+V)' and '*Ruimtelijke Ordening (RO)'* departments at the municipality of Rotterdam. The urban planning departments of Den Haag, Delft, Oldebroek participated in this process. The interview also revealed what kinds of spatial data are relevant, which data standards have preference, etc. The officials at '*Gemeentewerken*' are interested in the technical possibilities of implementing OGC and wide accepted standards like (CityGML, KML, X3D) for 3D spatial information storage in spatial database. From such a database the idea is to disseminate information in various formats for visualization in various geo-VE. The same models can be also used in spatial analysis.

During the interviews it became evident that the virtual environment should be easily reachable via the Internet for actors (like citizens) and therefore CAVE, BOOM, touch screen and discussion tables are not applicable. These kinds of geo-VE require expensive software and hardware unaffordable for most people. The system should be a desktop fish-tank VR and work on a semi-immersive environment. Semi-immersive VR can provide very high level of mental immersion if designed intuitively. The system should have control, manipulating, navigating, experiencing, exploring and display like all generic VR systems. The availability of these toolboxes does not need validation as all VR has them. The system should be able to visualize visual materials like texts, raster images and vector 2D/3D models in multiple dimensionalities. These visual materials should be represented in multiple LoDs. The system should probably be built on a multi-user interface. These functionalities of the geo-VE need to be validated.

The system should have multiple interfaces from the same data source stored in a spatial database. In the future, Oracle Spatial 11g[4] supports GIS for city planning, city modeling and adopting features to support CityGML guidelines and virtual reality solutions. The 2D/3D data should probably be geo-referenced but this statement needs to be validated. In the first phase of the VR system may or may not have external links to real-time data like RSS feeds, web cam connections, etc. The statement needs to be validated. The geo-VE accessories include monitor as a display unit and can be controlled through keyboard, mouse, laser pointers and joystick if necessary. The thesis deals with desktop Internet based VR operating on small screens. In such a case the 3D scene is visualized several centimeters before the eyes. The fact that the screen is situated at a short focal distance from the human eye makes it necessary that the visual materials have precision, high resolution (raster), fair interlacing, appropriate use of texture and most importantly appropriate detail or LoD.

The system should be based on client-server architecture. But the design of the type architecture is for the municipalities to decide themselves. The statement that the system should be built on open source solutions cannot be decided and need validation. Navigation and way finding is vital for the success of the system. Navigating should include, fly to crawl to, panning, zooming, rotate and

---

4 Oracle 11g has 3D data types. The supported types includes points, lines, polygons and solids, multi-points, multi-lines and multi-surfaces. It will follow Geography Markup Language (GML) 3.1.1 and ISO19107 specifications. As it will follow GML 3.1.1 it will be able to upload CityGML schema. The support for simple solids is closed surfaces such as a cube or pyramid. It will support large, high density and volume of 3D city models. Additional new data types supported by Oracle 11g are the massive volumes of point data, such as point cloud and triangulated irregular networks (TIN). Oracle 11g will associate a coordinate system with 3D data. The coordinate systems for 3D data are based on EPSG specifications. But it does not yet support parametric representation of cubes and pyramids.

transform. In navigation, the problems of tight space and Degrees of Freedom (DoF) are issues that the system should address. The system should have some reference point like 'Home Button' or 'First Viewpoint'. Auto tracking for navigation can help the users to find ways in VE. These are general features for all VR systems.

It is necessary to explain design projects with textual and oral information. This functionality does not need any validation. The 3D scene of the geo-VE should be expandable. Even though the boundaries of all 3D scenes are limited, it should be possible to add newly designed models of built areas and detailed landmark models. But this functionality needs validation. The thesis does not explore the hardware components needed for the geo-VE to operate.

The system should have basic online 3D editing tools for areas where a new design project is taking place for the inter-exchange of ideas. The spatial plans and models are restricted to ownership rights and therefore, the possibility that these models and plans can be downloaded to the local computers. But such functionalities are left to individual data providers. These functionalities are vital for the geo-VE and require validation.

There are general regulations on the type of objects the users can interact to and the tasks or functions these objects can perform in literature. The VE should be such that it leads the user to performing each task as an individual goal, like arrows and icons to help in navigation, way finding and exploring intuitively, intelligent objects must guide the user to do tasks, etc. The necessity of the use of humanoid objects or avatar is not certain and must be validated. The system may or may not have intelligent objects and this statement needs validation. In the case of using avatars, the user must enter a building, through a door and not through the wall.

The system should follow the generic regulations of visual properties, lighting, transparency, rendering, viewpoints etc to visualize information. The system probably should have a login interface but this needs validation. The system should probably visualize information in vector 2D/3D models and raster panoramic photographs. To explore the geo-VE, a combination of virtuality, mimicity and usability of dynamic possibilities like teleport functions, online search, shuffling of the objects, highlighted nodes and landmarks, on demand transparency, X-ray vision to reduce occlusion, etc should be present. Exploration is based on database query. This can be like searching a street, building, a business entity, etc. Such search should be also possible to give answers like population information, housing prices, neighborhood living quality, etc.

The functionalities related to usability needs special care when the system is built or chosen. The users should be able to find a relationship between the real world experiences and recognize the same experience through their presence in geo-VE. It should able the users achieve exploration goals and interact efficiently and respond with sound feedback when errors occur. The geo-VE should have rich interaction like pick up things, click & select, open doors, access rooms, change worlds, change transparency, change colors of objects, etc. The system should probably let the user change the size and perspective views of the 3D scene. This statement needs validation.

The use of CityGML LoD to describe 3D urban data, representation, selection, direct manipulation, interactivity (like hide, delete, add, position, attribute, properties change), hyper-links, exploration, elaboration, interactivity, automated agents, feedback capability, electronic conferencing, coordinated multiple-linked windows visualizing different dimensional information, animation & simulation capability, measurement tools, X-ray vision and transparency tools, spatial query, labeling, multi-layering, etc that form the core of the functionality chart are directly related to interaction in urban projects. The functionalities that are directly related to visual interaction are used in the validation process. All VR systems have some general components and it is necessary to mention them. These functionalities are listed as negotiated functionalities in Table 21. The functionalities related spatial analysis needs to be mentioned as they can be incorporated in future updates. Spatial analysis tools can include basis GIS tools for network analysis, visibility, urban growth, volume, sun-path, shadow analysis, etc. In this thesis these functionalities are mentioned as the analysis functionalities. The bottom line is that once, the models for the geo-VE are created, these functionalities can be gradually incorporated into the system.

Table21: The validation functionalities[5] through Requirement Engineering Process Model

Domain	Functionality	Validation	Negotiation	Y	N
Construction	Information Intensity (LoD)	V 1			
	Data fusion& integration: Dataset and database at local municipality	V 2			
	Data fusion& integration: Open Source solutions	V 3			
	Data integration: Different Data types & Interface (CityGML, X3D/VRML, KML and VirtuoCity)	V 4			
	Plug-in or Software download	V 5			
	Toolboxes: Control, Experiencing, Navigating & Movement tool		N 1		
Capabilities	Representation: Multiple Representation in different rendering	V 6			
	Representation: Multiple representation in different geometry	V 7			
	Representation: Comparison of old and new situation	V 8			
	Animation and Simulation capabilities	V 9			
	Feedback: Interactive chat (online *gespreksavond)*	V 10			
	Feedback: Leave a message, email	V 11			
	Multi-Dimensionality/Viewpoints	V 12			
Experiencing	Movement and navigation aid	V 13			
	Orientation aid	V 14			
	Manipulation, exploration and elaboration		N 2		
	Immersion: mental semi-immersive environnent		N 3		
Controlling	Selection of Scene/Objects: Click & Select	V 15			
	VR Accessories: Fisk tank VR / User mode: Multiple & Single	V 16			
Use (Interaction)	Interactivity: move & delete	V 17			
	Interactivity: modify and change 2D/3D information	V 18			
	Interactivity: copy & save	V 19			
	Interactivity: add 2D/3D data	V 20			
	Interactivity: stop, hide, sensor information	V 21			
	Primitive AR like webcams	V 22			
	Automated Agents (Avatars)	V 23			
	Intelligent objects		N 4		
Exploration	Spatial Query functionality	V 24			
	Hyper links, linked windows	V 25			
	Re-expression functionalities (3D Editing)		N 5		
Components	Log-in interface	V 26			
	Time component	V 27			
	Measurement tool component	V 28			
	Teleportation component	V 29			
	Labeling & icons	V 30			
	Multiple layering	V 31			
	X-Ray Vision	V 32			
	Geo-referencing	V 33			
General components	The general features of all interactive 3D scenes like lighting, camera, viewpoints, transparency and shading, atmosphere and visibility, making screenshots and save image, automatic focus and tracking toolboxes, basic marking toolbox, highlighted icons for landmarks, nodes, adding functionality for floating street names, building names, reference points, spatial analysis tools, etc		N 6- N 24		

[5] In the specification chart extra column is added for prioritization in MoSCoW method.

6.1.3 Conceptual overview of 'Chart of Visual Materials'

Visual materials can be represented through different representation parameters like, reality axis, Information Intensity (CityGML LoD), dimensionality, graphical & model classification, etc to represent the different urban objects in the 3D scene of geo-VE. Hoogerwerf et al (2006) (mentioned in Riedijk en al, 2006) cited that the manner in which the 'Levels of Detail' for different planning phases can be applied is important and a subject for research. Which LoD and representation for visual material is suitable for which phase of the design process has been addressed in this thesis.

All the parameters of Chapter 5 are plot together to form the 'Chart of Visual Materials' as seen in Table 22. Text, graphs and image are visual materials that are not models. The 2D models are sub divided into 2D plans and maps. There is no acceptable difference between the two in terms of representation except that plans are used to explain building plans and maps constitute to larger geographical entity. But usually the plans reflect building and the interior relationships. Maps are mostly about the building exterior footprints. The thesis emphasizes on the use of 3D in geo-VE and therefore, the 3D models are extensively defined into four more categories based on LoD.

While plotting all the parameters of the visual materials, it becomes clear that these parameters overlap. For example, decision had to be taken for the reality axis for the visual materials. As the description of the higher-level class 'building' in CityGML (LoD1-LoD4) is classified, they fall in the indexed category and on the other hand LoD1 can be defined as iconic. The LoD2 and LoD3 both can be defined as iconic, but LoD2 building is also indexed, while LoD3 building can be verisimilar when textures are used.

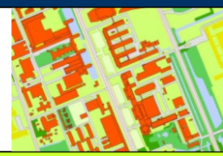
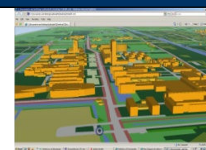
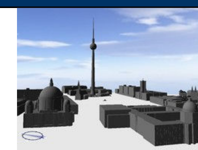
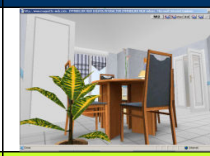
Similar categorization problem exists when defining visual materials within abstraction and realism parameter. While texts & images are used to depict the urban objects in an abstract representation, one can argue that computer 3D modelling is nothing but textual and numerical values to describe the real world in high detail. It is also hard to categorize, plan & map in the precision parameter as they can be of low and high precision depending on resolution. Plan and map can be abstract to highly realistic (geo-referenced satellite images). The different resolution and LoD for 2D plan and map has not been considered in this thesis.

The CityGML LoD1 and LoD2 buildings can contain textures, but when the municipalities are interviewed, it became clear that they are reluctant to use textured photorealism in block models (LoD1) or volumetric envelopes (LoD2). The chart is designed in such a manner that '*Volumetric block models*' and '*Volumetric envelope models*' are both considered without textured surfaces.. The 'Chart of Visual Materials' as seen in Table 22 is a compromise state to describe urban objects in virtual environments through various perspectives and overlapping parameters. This chart was too complicated to be used in the survey and some of the parameters had to be omitted. The parameters that are vital for this thesis are:

- The dimensionality,
- The reality axis
- Level of Detail (LoD) (including photo-textures)

These three parameters are shown in the results and listed in the specification documents. The rest of the parameters are mentioned here for the taxonomy of visual materials but not used for results. The same colors indicate in Table 22 the similar attribute of the visual materials.

Table22: The Chart of Visual Materials

Visual Materials / Parameters	Text, graphs & images			Plan & Map			Volumetric block models (no detail)		Volumetric envelope model (some detail)	Detailed architectural model	Detailed model with interior
	VM1			VM2			VM3		VM4	VM5	VM6
Figures	HOUSE										
Graphical & Model	Graphical			Model			Model		Model	Model	Model
Scalability	Not scalable			Scalable			Scalable		Scalable	Scalable	Scalable
	Text	Graphs	Images	Plan	Maps	DTM					
Dimensionality	1D	2D	2D	2D	2D	2.5D	2.5D	3D	3D	3D	3D
Precision	Low			Low to high			Low		Medium	High	Very High
Visual regime				PV			MV		MV	WV	WV
Abstraction & Realism	Abstract to realistic			Abstract to Realistic			Abstract		Semi-Abstract	Realistic	Highly realistic
	Text	Graphs	Images	Plan	Maps	DTM	(Indexed into 4 LoD)				
Reality Axis	Language	Symbolic	Symbolic	Symbolic			Iconic		Iconic to Indexed	Indexed to Verisimilar	Verisimilar
Photorealism							Non textured*		Non textured*	Textured	Textured
CityGML Level of Detail							LoD1		LoD2	LoD3	LoD4

- *During the interview at the Municipality, it came became clear that the urban designers and planners are reluctant to use textures on side of building for block models and envelope models. In these models that transparency, colors and line depth are more important. LoD1 and LoD2 used here are non-textured.*

Survey 1 questionnaire for Functionalities of geo-VE

The functionalities for validation, the functionalities are negotiated are listed in Table 21, from which validation statements are formulated for Survey 1 (Annex 4, Questions A). To generate a survey questionnaire, the interviews at the municipalities are used as input. The survey population is given a choice of agreeability index to indicate the necessity of the functionality. The questionnaire is pre-tested with some target users to ensure that information gathered is relevant.

Survey 2 questionnaire for Visual materials of geo-VE

The second part of the questionnaire or Survey 2 is based on Table 22. It contains answers to the relationship between human perceptions of understanding design and the type of visual materials used in the geo-VE. The relationship how a certain urban planning phase can be represented in the geo-VE through a certain visual material is investigated. In other words, if the zoning plans or master plans, etc are best suitable to be represented in 2D maps or in 3D models (LoD1-LoD4) are investigated in Survey 2. A sample questionnaire can be seen in Annex 4, Questions B.

Survey Population

The survey population for these two survey questionnaires is urban planners, GIS experts, data modelers working at urban planning departments, architects and planners working for social housing companies as seen in Table 23.

Table23: Population subjects for the thesis	
Urban planners from different Dutch municipalities	17
GIS experts and 3D modelers from *Gemeente Werken* (GW)/TNO	2
Communication officers from the dS+V and planners from RO	5
Design professionals from Social housing agencies	6
Total participants	**30**

6.2 3D virtual models used during interviews and validation

6.2.1 Purpose for 3D models in the thesis

Prototype models are used during the survey to visualize the materials in various representations and LoD. They are used to demonstrate the functionalities of various geo-VE. In urban planning it is necessary to visualize a designed area in the context of the existing city. This helps to understand spatial relationships between the newly designed areas in context of urban scale and conduct analysis. For this purpose, the researcher has generated polygonal based virtual city models using the ArcGIS environment and geo-data that are widely used at the Dutch municipalities. This process is reproducible and can be used by the municipalities to create their own 3D virtual city models. The goal of modelling in this thesis is not to create high precision models, but to demonstrate to the municipalities the process of polygon based 3D modelling. There are two aspects that can be identified for 3D models such as:

- ***Virtual city model of existing situation:*** The 3D model of the existing city can be generated using GIS. It can be used for surveying the existing situation as input for the professionals working in the construction industry. These models are ideal for the visualization of spatial analysis like sun-path, wind-resistance, pollution simulation, etc. In urban planning they are used to study urban textures, forms, volumetric analysis, etc. To generate such models from geo-data, GIS expertise is necessary.

- ***Virtual models of proposed design***: The input of such models is mostly from CAD. The newer versions of CAD let the architects and urban planners draw 3D models with geographical referencing. In GIS, such models can be used to aid navigation (through landmarks) or building interiors for calculating escape routes, 3D analysis, etc. Data-fusion allows various geo-data and 3D models to be combined together and be integrated in the geo-VE.

6.2.2 Common techniques used in 3D model creation

There are various methods to generate 3D model. The two aspects related to 3D models of existing situation and proposed design can be created using the following methods:

Virtual city model of existing situation

Semi-automatically generated polygon models

3D models of the urban area can be generated semi-automatically using 2D vector footprints and relevant attribute height information through GIS tools. In such models the DTM or 2D plan makes the background of the model. Building footprints can be extruded using the attribute of building height. The building sides can be textured by draping or mapping photographs of buildings. One of the basic methods that can be used in this kind of modelling is a vector overlay of footprint of buildings with LIDAR (*Light Detection And Ranging*) height information of point clouds. With the help of GIS, one can calculate the median height of the height-points that fall inside a certain polygon. An extrusion model can be made using this median height. Using CAD software, these LoD1 models can be transformed into higher LoD models adding roof and building parts through manual editing in 3D. This process is extensively elaborated in this thesis.

Automatically generated polygon models

Through photogrammetric images it is possible to create 3D models of cities. 3D models can be generated using building footprints and geo-referenced panoramic photographs with known distance of multiple points in the photographs from an input reference point. The 3D model can be automatically generated using the concept of perspective. Roofing and textures of building sides can be added through CAD software in such models. Some of the models used of the TU Delft campus are made using this technique (see Figure 8).

Point cloud based 3D models

The existing situation of a city model can be created using dense point clouds using pulse laser device for LIDAR (*Light Detection And Ranging*). The test data (*Deltawerken, Zeeland*) of AHN 2 contains high density point clouds and can be visualized in realistic rendering (Website AHN). Using such data, 3D polygons can be created by identifying the outer points of edges. After combining all the points that form the edges of the polygons, a 3D model can be generated. However, this process is not investigated in the thesis.

Interpolation based 3D models

The point cloud information can be used to create interpolation models. The fineness of such models depends on the input data and can be used to visualize the urban landscape. Triangular Irregular Network (TIN) models can be generated from point clouds to represent surfaces. Textures can be draped on the surfaces. Besides, 3D models can be made using complex geometry like polyhedrons, tetrahedrons, etc but they are not investigated in the thesis.

Virtual models of proposed design

Designed polygon models

CAD software (like SketchUp, Microstation CAD, AutoCAD, 3D Max, etc) helps the designers to make high quality representations of urban objects in various LoD. CAD software can make parametric 3D models. Once the models are created visual realism of these models can be achieved by texturing the building surfaces. CAD files (dgn, dwg, dxf, etc) allow multiple layering that can be used for thematic semantics of the model parts. CAD models that follow IFC standards can be converted to LoD 4 models. The *Poptahof* urban design is created using this technique. The researcher worked on the *Poptahof* model to add prototype objects and modify surface properties of the models.

6.2.3 Software and data for polygon virtual models

This thesis deals only with polygon based modelling using building footprints and LIDAR height information. It also used designed CAD models used by urban designers at Dutch municipalities. 3D models of the city of Delft have been semi-automatically generated. The generated 3D model is then combined with designed urban plans of *Poptahof* in order to get a whole volumetric vision of Delft.

Data-format of 3D models and geo-VE

The tested data-formats and the geo-VE that are used are seen in Table 24. (The reason behind the choice of these four geo-VE is explained in the results Section 7.3.2).

Table24:	Data formats and geo-VE used in the thesis		
	Data format	Used for	Geo-VE
1	KML 2.1	Created by researcher	Google Earth
2	X3D/VRML	Created by researcher	Bitmanagement plug-in for Internet Explorer
3	CityGML	Downloaded and Demonstrated	LandXplorer viewer
4	V3D	Demonstrated	VirtuoCity (*Virtueel Tilburg*)

Software used for model generation

Geo-processing software

Using ESRI ArcGIS 9.2 software and other freeware open source extension tools it is possible to make 3D (polygon with height) models. The following software is used:

	Geo-processing tools
1	ArcMap 9.2
2	ArcScene 9.2
3	ArcCatalog 9.2
4	ET Geo Wizards

Editors and Converters

Google KML 2.1 supports full 3D boundary representation. Editor tools like SketchUp or 3D Max can add textures on the side of the buildings of this generated 3D city model. SketchUp can export CAD models to KML. Open source software like Flux Studio can convert CAD models to VRML, X3D and KML. Safesoftware FME can be used to convert KML data to GML. At this moment, there is no commercially available software to convert CAD or GIS models to CityGML format. Therefore, CityGML models that are used for visualization during survey are downloaded from the CityGML website (CityGML, 2007 see Website). The following converters and editors are used in this thesis:

	Editors and converters
1	SketchUp 6/ AutoCAD 2007/ MicroStation-CAD
2	Flux Studio 2
3	ArcGIS to SketchUp converter tool
4	Arc2Earth Converter tool
5	FME data interoperability tool

Geo-Data used for model generation

The choice of data by Rotterdam municipality for creating the 3D virtual city model can be seen in Annex 5. In this thesis, the following geographic data are used as input for creating the virtual city models:

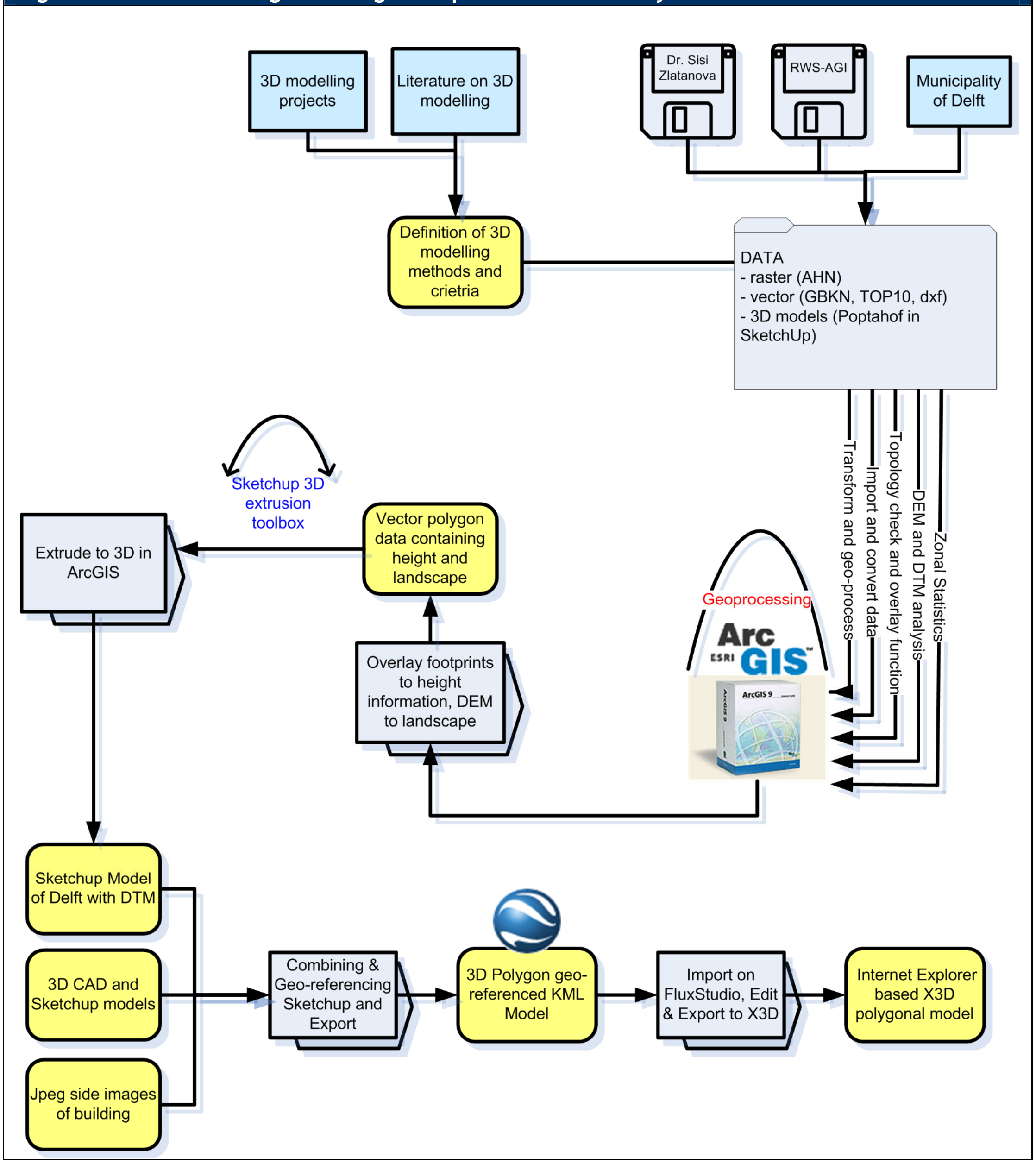
- Vector polyline shape geometry GBKN (*Grootschalige Basis Kaart Nederland*) for the existing buildings of Delft.
- Vector polygon shape geometry TOP 10 data (Topographical Map of the Netherlands, Scale 1:10,000) for landscape.
- LIDAR high density height information in unfiltered 5x5 grid in XYZ format for height of buildings.
- CAD model of *Poptahof* urban design to visualize the proposed situation.

Modelling steps

Using geo-processing tools in ArcGIS 9.2, the GIS data is prepared and 3D scenes are made as seen in Figure 26. The input data are converted to scenic models using specific converters. Three types of models are applied and visualized:

- Visualization of polygon based 2.5D models (footprint + height) in KML
- Visualization of polygon based 3D models (polygon surfaces) in KML
- Visualization of polygon based 3D models (polygon surfaces) in X3D/VRML

Figure 26: Process for generating an implicit 3D virtual city model in ArcGIS



6.3 Creation of virtual city model in LoD1

6.3.1 Processing of the height information

In the Netherlands, most municipalities acquire commercially available height information data. Height data/information is gathered usually using Airborne Laser Altimetry. The resulted data of this new technique of laser altimetry has various and diverse applications specifically for checking the safety related to flooding and dykes. A popular version of height information data is the AHN (*Actueel Hoogte Nederland*). In addition to the filtered elevation points file, with X, Y and Z co-ordinates of the RD (national triangulation of national grid) and NAP (Amsterdam Ordnance Datum), there are three grid formats in which is the AHN data is available (5x5, 25x25 and 100x100 meters). The dataset is delivered in different formats.

In order to conduct vector overlay analysis the data have to be processed and converted to vector point shape geometry from the unfiltered XYZ data format. The XYZ format is nothing but the X and Y co-ordinates of points and Z value containing the height information. ArcGIS 9.2 can convert this format to Multipoint or Point data using the 'Conversion' toolbox using the 'From File' option. The XYZ is converted to Multipoint.

The XYZ format tends to use local coordinate systems (centered around 0,0,0). The output shapes geometry is geo-referenced in RD (*Rijksdriehoekstelsel*). The 'Multipoint' shape data needed to be converted to 'Point' shape geometry. The free version of 'ET Geo Wizards' open source geo-processing available at http://www.ian-ko.com/ is used for this purpose. The tool converts the multipoint data into individual points shape file containing height information as seen in Figure 27. ArcGIS extension used didn't allow direct conversion of XYZ data to point.

Figure 27: Geo Wizards Multipoint to Point

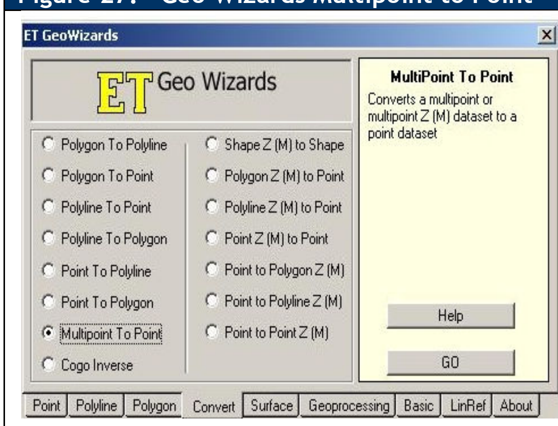
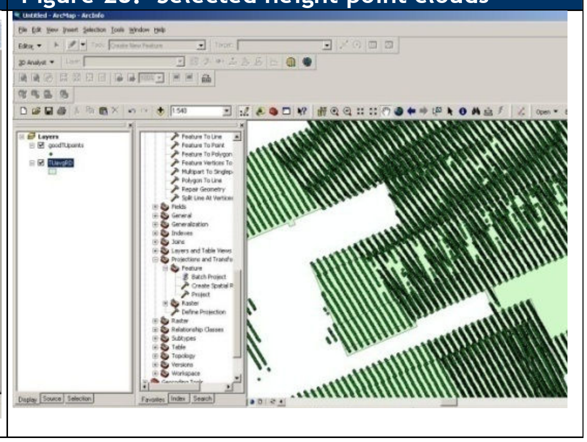


Figure 28: Selected height point clouds



A selection by attribute is then done in this file where all points less than 2 meters are omitted. It is presumed that the buildings are equal or higher than 2 meters. Using the building footprints the points that fall inside the buildings polygons are selected using 'select by location'. Using the 'Copy Features' in the Data Management toolbox a new shape with point geometry is made only from the selected layers as seen in Figure 28. A separate file with point shape geometry is created for all that points that are less than 2 meters.

6.3.2 Processing of the building footprint for 3D models: GBKN data

Creating the building footprints: GBKN data manipulation

The GBKN footprint are supplied in polylines and needed to be converted into polygons. The input GBKN data is delivered as dxf file. The dxf file contains the names of the different layers. From the dxf file the building footprints are selected and a new dxf file is created with MicroStation CAD. This file contained only the footprints of all the different kind of buildings of the city of Delft and omitted the other objects.

Using Software FME, the dxf file is converted to shape geometry. Such exports can be also done in ArcCatalog 9.2. Using FME is a better choice in such conversions as the actions of the software can be traced back if an error occurs. The ET Geo Wizards free ArcGIS extension was used to remove all polylines that were not connected using the 'Clean Dangling Nodes'. Some problems are noted as important building were also removed as they did not have closed polylines. Therefore an alternative method needed to be sorted out.

By validating the topology of the datasets the researcher is able to find out the dangles. But this can be only done in a geodatabase and not in polyline shape geometry. Therefore a file geodatabase is created that contained a feature dataset using ArcCatalog (Figure 29). The footprints of buildings are then exported from shape file to the geodatabase feature class. This was done using the 'Feature class to Geodatabase (Multiple)' tool in the Conversion toolbox as seen in Figure 30.

A topological analysis is done (Data Management Tool> Topology> Add Rule to Topology>) on the feature class in the geodatabase. These include the following rules on the polylines in the feature class (Figure 31):

- Must not have dangles (Identifies which parts of the building footprints are not closed)
- Must not intersect (Lines of same layer should not intersect or overlap)
- Endpoint must be covered by (Each of the lines must close to another layer)

The topology file in the geodatabase is then validated in ArcCatalog and lots of topology problems were noticed. The feature class is then edited in ArcMap using the editor toolbox to fix these topology problems. This proved to be a laborious task. When these problems are fixed the feature class in the feature dataset in the geodatabase is re-converted to polyline shape geometry (Conversion Tool> Shapefile> Featureclass to Shapefile). This process led to topologically correct polyline shape geometry of building footprints for input. It took repaired and closed all lines.

Figure 29: Creating file geo-database and feature datasets

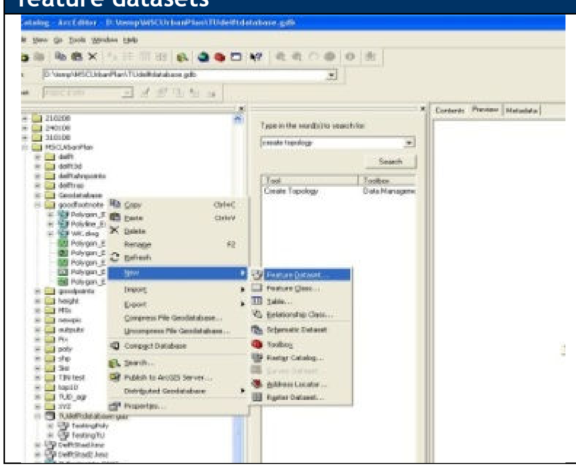
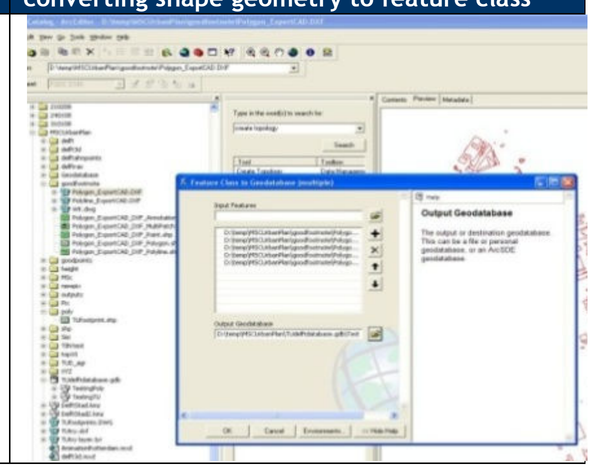


Figure 30: Feature Class to Geodatabase converting shape geometry to feature class



But the shape is in polyline and needs to be transformed into polygon. These polylines of the built areas could not be transformed to polygon using ArcGIS 9.2 as it needed specific ArcInfo license. Therefore open source tools are sought out to find a solution. The polylines are converted into polygons using the ET Geo Wizards toolbox.

The polygon shape geometry is then visually checked in ArcMap and lots of very small closed surfaces are noticed that cannot be considered as buildings. The 'Calculate Areas' toolbox (Spatial Statistics> Utilities>Calculate Area) is used to find the areas of the toolboxes. The areas that are smaller than 0.4 are selected and they are removed (using Select By Attribute as seen in Figure 32). They are taken off and a new feature of polygon shape geometry is made. They are the finalized input (the building footprint) for creating the 3D buildings of the virtual city model.

Figure 31: Add topology rule

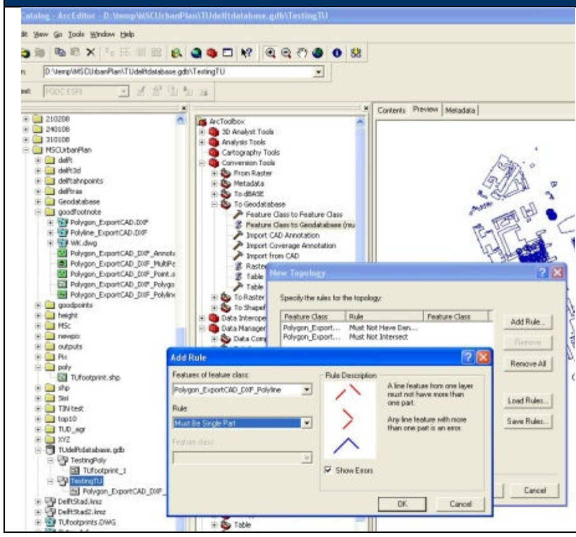
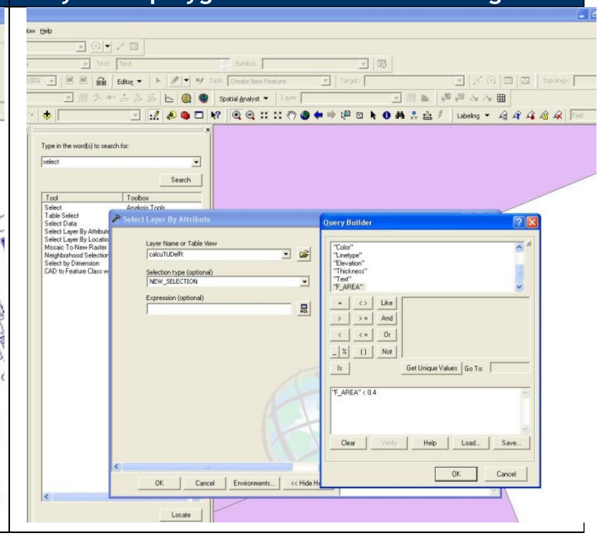


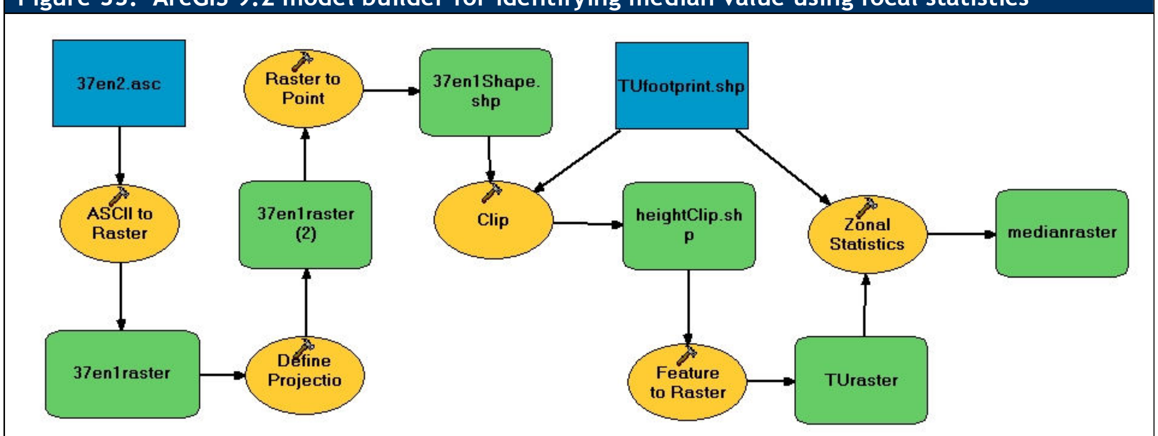
Figure 32: Selection by attribute to remove very small polygons that are not buildings



Overlay analysis and focal statistics for building footprints

Firstly the vector shape point data is clipped from the building polygon footnotes only to the get the relevant points that fall inside a certain polygon. This was done with the 'Analysis toolbox> Extract> Clip' tool. The basic concept of the modelling is to acquire the median values of heights of each of the building footprint polygons. In order to do this the clipped point shape data was converted into raster and the Zonal Statistics tool has been used. This is done using the individual polygons of the footprints as the zones in which all rasters should have the same value. The 'Median' value is selected for calculating the zonal statistics. It resulted in a raster file that contains median values of heights from each of the polygons that contain them. In other words, all the raster grids or points that fall inside a certain polygon entity received the same median height value as seen in Figure 33.

Figure 33: ArcGIS 9.2 model builder for identifying median value using focal statistics



This raster file containing the median value is then converted to point shape geometry using the 'Conversion toolbox> From Raster> Raster to Point' tool. A spatial join is conducted with the polygon footprints of the buildings to the median vector shape height data. This attaches the height information as an attribute to the footprint polygon. The function used is 'Join data from another layer based on spatial location'. This results in polygon shape files containing the height information attached as an attribute field. The polygon shape file needs to be extruded based on this height to generate the 3D model. Using the 3D Analyst the 'Conversion> Feature to 3D' tool can be used to convert the 2D polygon shape geometry into 3D polygon shapeZM. This results in a 3D shape from the building footprints using the height information attribute. The footprints are opened in ArcScene and real 3D polygons are noticed.

6.3.3 Processing of ground surface of the 3D model: Top 10 data

Top 10 data is used for creating the background surface of the virtual city model. The data contains polygon shape geometry. The data needed to be processed before it could be used. The data is firstly checked for topological correctness. Using ArcCatalog the polygon shape geometry is converted into a feature class inside a feature dataset of file geodatabase. The polygon feature dataset were checked for the following 'Topology' rules:

- Must not overlap (Area of one layer must not overlap the area of another layer)
- Must not have gaps (There should be no gaps between two polygons)
- Area boundary must be covered by boundary (It means that boundary area of the feature of one layer must be covered by the boundary area feature of another layer)

The input data of Top 10 was of high quality and no topological errors has been found. The feature class is reconverted into shape file. This polygon shape geometry is made of 2D data. But the geographic earth surface is not flat. 3D shape is made from Top 10 using the height information point shape geometry. Multiple shape-files are made from the Top 10 data to separate water bodies from the rest of the landscapes. In an ideal situation from each of the layers in Top 10 data a separate shape file should be made. The thesis only removed the footpaths, bicycle paths, road and water bodies to create separate polygon shape geometry. It is assumed that each of these layers are relatively smooth and contain few height variation and a constant height value can be taken. On the other hand the landscape contains higher height variation. In the case when there are no drastic changes in landscape, Spline is an appropriate method for interpolation to create a digital elevation model (DEM). The XYZ information is used to create the 3D surface of Delft. A file containing point shape geometry made from the XYZ file they is interpolated using Spline with break-lines to create the DEM (3D Analyst Tool> Rater Interpolation > Spline with Barriers) as seen in Figure 34. The building footprints are used as break-lines. The reason behind using them is that the points falling inside the polygons are not used in calculation of the interpolation process. The interpolation returns no value inside building footprints. Trees and shadows of building are not removed and in an ideal situation, it should be considered. In order to remove offshoots an extensive analysis on the point shape height data is necessary.

Figure 34: Creating DEM with Spline / Barriers

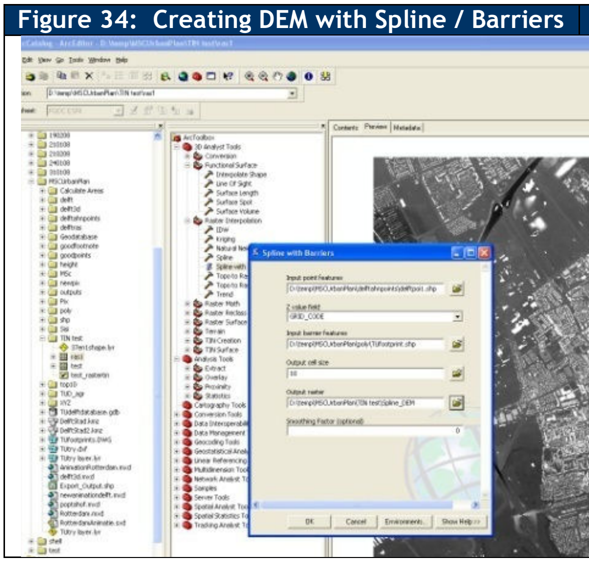
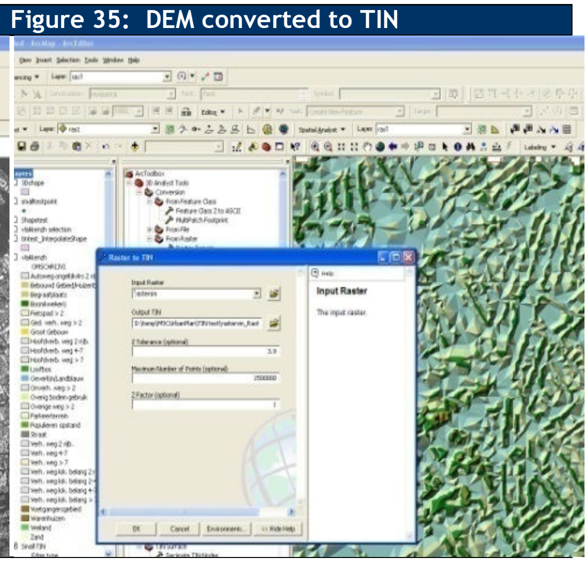


Figure 35: DEM converted to TIN



First method to create 3D ground surface

The Spline DEM raster can be used to incorporate height information to the 2D Top 10 data. The 3D Analysts extension in ArcGIS 9.2 must be turned on. The ArcView tool, 'Conversion> Feature to 3D' is used for this conversion (Figure 36). Using ArcObjects in Python scripting this tool can be called to do the same task. Using python decreases the time needed for such tasks. This process transforms the landscape 2D polygon shape of the Top 10 data into 3D polygon shape geometry. The result is firstly visualized in ArcScene. When the attribute of the data is explored, it was noticed that the geometry of the data changed from polygon shape* to polygon shapeZM. Even though the surface made through this method is not very smooth, this is a process to convert 2D polygonal shape to 3D polygonal shape to visualize landscapes.

Second method to create 3D ground surface

The method can be applied to convert 2D Top 10 data to 3D shape. The DEM raster made using Spline is converted to TIN (3D Analyst Tool> Conversion > From Raster > Raster to TIN) and the TIN (Figure 35) can be used to convert the Top 10 input data to 3D polygon shape geometry. This can be done by using 'functional surface' functionality (3D Analyst Tool> Functional Surface> Interpolate Shape). The results of these methods are visualized in ArcScene as seen in Figure 37. In both cases a lot of processing is needed to create a proper background for the 3D scene. The goal of this thesis is not to compare the different processes as creating such models, as these models are just used as input during the survey, workshop and interview. Offshoots in the DEM has to be identified and taken out to get a smooth 3D surfaces.

Figure 36: Creating 3D shape using 3D analyst

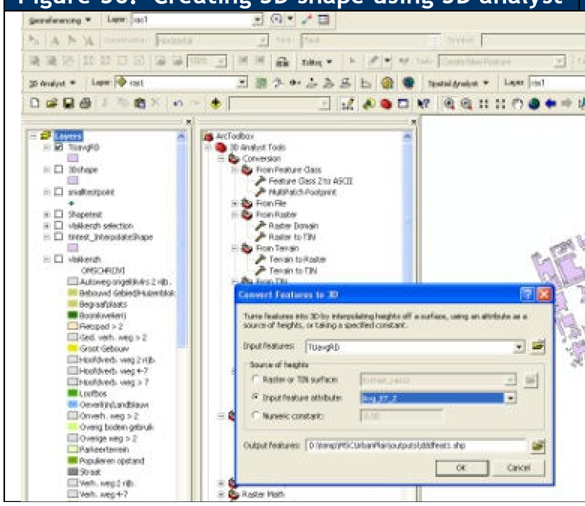
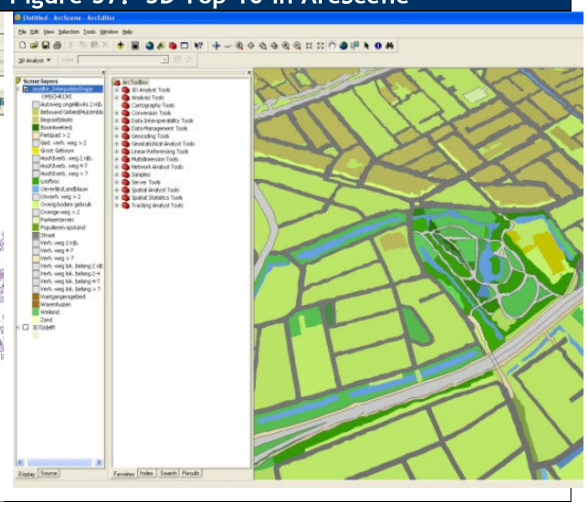


Figure 37: 3D Top 10 in ArcScene



For the layers containing the water bodies, roads, footpaths, bicycle paths etc are made into 3D using the method used for the building footprints. Therefore, there is no height variation inside the single polygon of these layers.

6.3.4 Visualization of virtual city model in geo-VE

The last section of the modelling process is to convert the geo-data and designed CAD models to scene based languages like KML, VRML, X3D, etc. The following methods are applied to create the models:

Method 1: Visualizing 2.5D extrusion model using Arc2Earth in KML

Arc2Earth is an ArcGIS extension that can export any shape geometry to vector KML 2.1 format. Attribute information and also meta-data can be exported to the extrusion model. The free version of the software was used to make an extrusion model from the polygons containing the height information. The software has a function to export to KML in 3D and the median height information was selected. But as the coordinate system of the data was in *Rijksdriehoekstelsel* RD and Google uses WGS84, the extruded 3D model had a considerable deviation of about 100 meters from the GE satellite photographs. In order to overcome this the source data was first converted from RD to WGS84 using the 'Project and Transformation toolbox> Feature> Project' tool. Arc2Earth toolbox (Figure 38) can also export shapeZM geometry. Figure 39 shows the TU Delft campus in GE.

Figure 38: Arc2Earth KML export extension

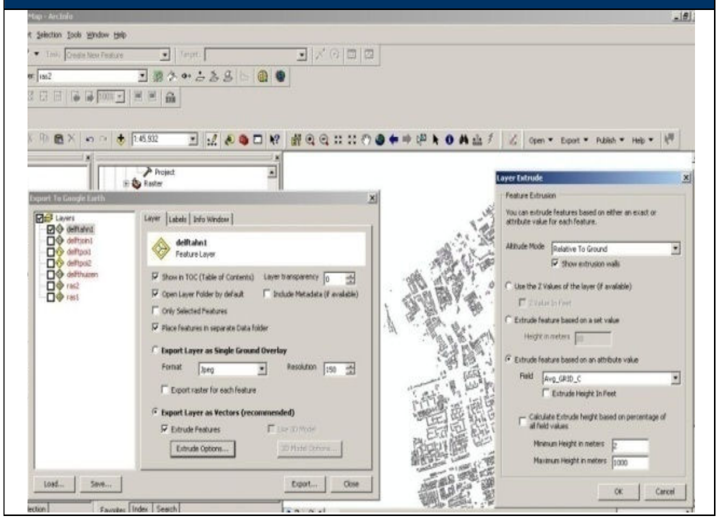
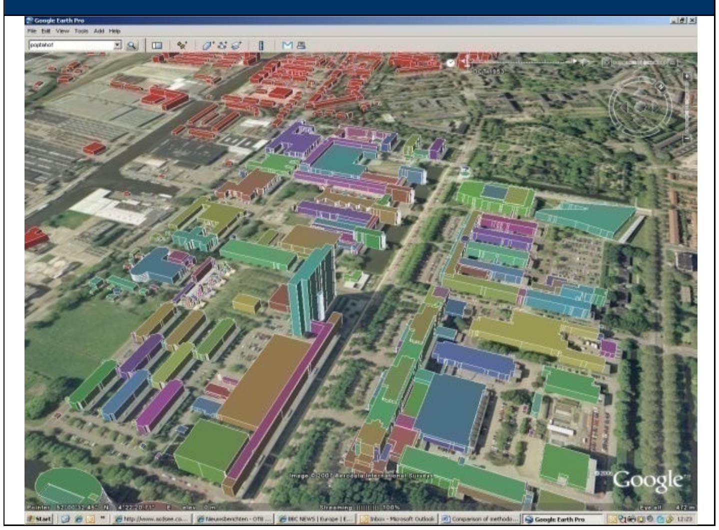


Figure 39: 2.5D model TU Delft Campus in GE



Method 2: Visualizing 3D model using ArcGIS2Sketchup in KML

@LastSoftware has created a free plug-in that allows SketchUp to capture data from ArcGIS (e.g. a building footprint) and open it in SketchUp. Once in SketchUp, the rest of the building can be created and the results saved back to an ESRI 3D data format (multipatch). What makes this plug-in for SketchUp special is that this is the only CAD software package that creates multipatch features back-and-forth from a GIS environment. This toolbox available on the Internet for free at http://www.sketchup.com/?sid=37#arcgis. The toolbox can be added in ArcGIS environment as seen in Figure 40. The 3D Analyst Extension needs to be turned on for the tool to function.

Firstly the shape geometry data is exported from ArcMap to SketchUp *.skp format using this tool. When the data is opened in SketchUp (Figure 41) geo-referenced full 3D polygon based geometry model is observed. The advantage of polygon surfaces is that they can be used for editing to create higher LoD from the base models. Using SketchUp, 3D Max or Maya it is possible to add side images to these models, re-import them in SketchUp and convert them to KML. The data contains the geo-referencing of the original data in ArcGIS and all the layers in ArcGIS are separate in SketchUp. The data needs to be converted to WGS in ArcGIS before exporting it to SketchUp. SketchUp can be used to add textures to polygons and geo-reference 3D models using known points as seen in Figure 42. The *Poptahof* urban design model is then imported inside the SketchUp model and geo-referenced to the right placement using reference points and lines. The whole model is then exported to KML format and visualized in Google Earth. The *Poptahof* urban design is imported in SketchUp and geo-referenced and the combined model is exported to GE as seen in Figure 43.

Figure 40: ArcGIS2Sketchup tool exports to SketchUp

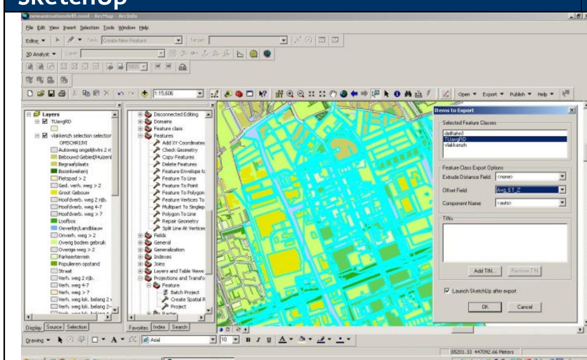


Figure 41: Geo-referenced 3D geometry model in SketchUp

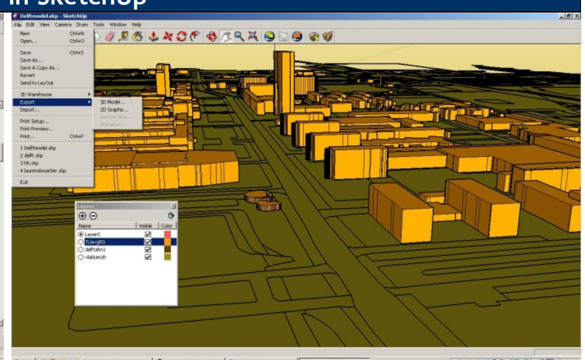


Figure 42: Geo-referenced OTB building with side images made in SketchUp

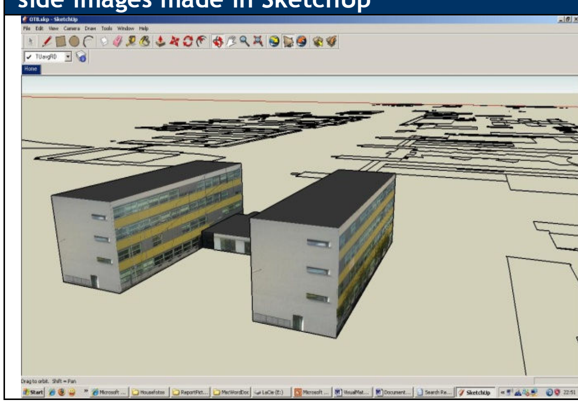
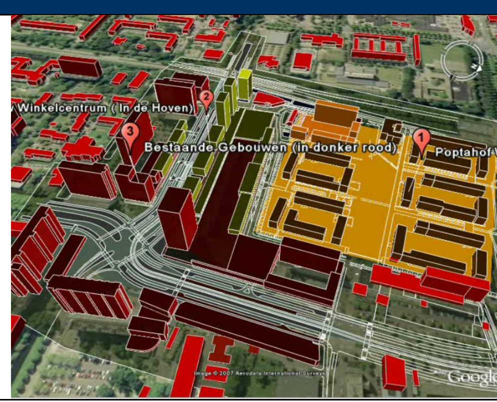


Figure 43: Poptahof urban project in Delft



Method 3: 3D model visualizing in ArcScene and export to VRML

Using ArcScene 9.2 it is possible to visualize the footprint data in 2.5D by extruding the height and adding the z-value from the data as seen in Figure 44. The models and ground surfaces can be exported as a VRML file (*.wrl extension) from ArcScene environment. This results in a full 3D model of the city of Delft and can be visualized in the Bitmanagement plug-in for Internet explorer. Compression of the VRML file is poor and performance to open the model in the Internet Explorer takes high computer power. The VRML model can be seen in Figure 45.

Figure 44: TU Delft Campus extrusion model in ArcScene 9.X

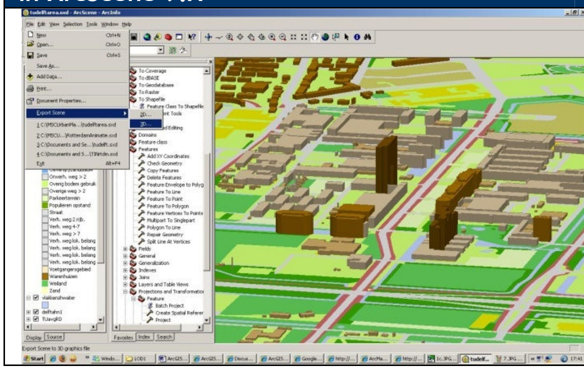
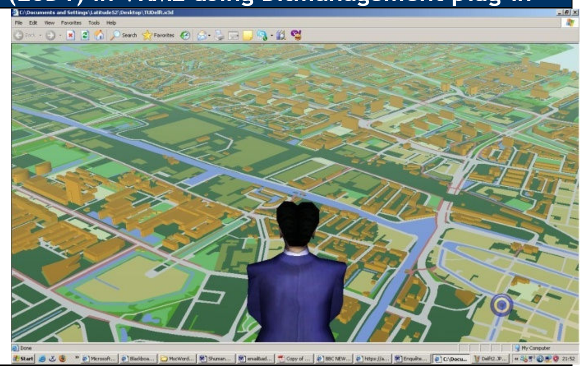


Figure 45: Base model of the city of Delft (LoD1) in VRML using Bitmanagement plug-in



Method 3: 3D model visualizing using Flux Studio in X3D format

Flux Studio 2 (Figure 46) is a data fusion software that can import 3D models of various data format. It can open the VRML file and export it as X3D file, which can be visualized in Internet Explorer using Bitmanagement plug-in (Figure 47). Flux Studio can import also KML files and export them to x3D/VRML/dxf/dwg/3DS etc formats. New avatars can be created and exported with the model. The software allows fog, lighting, shading, click-able hyperlinks, viewpoints and nesting of layers.

Figure 46: Flux Studio 2 imports KML/VRML & exports to X3D

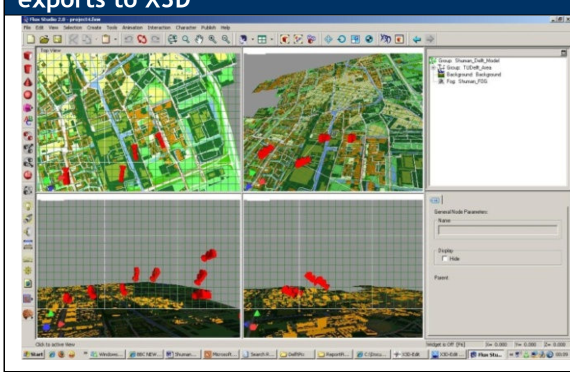


Figure 47: Base model of the city of Delft (LoD1) in X3D using Bitmanagement plug-in

The virtual city model of Delft is combined with a designed model of *Poptahof* and visualized during interviewing and field survey to explain the functionalities of geo-VE and the use of visual materials in such environments. The model was imported in SketchUp and converted to KML 2.1. The KML file wan imported in Flux studio and referenced in the correct place in the Delft virtual model and exported to X3D. There are two more geo-VE that are tested and demonstrated during the interviews, field survey and workshop. They are the LandXplorer CityGML viewer and VirtuoCity. CityGML models are not created for this thesis as there is no commercially available toolbox to create them. Cebra's VirtuoCity uses a proprietary format (V3D) and cannot be imported. These two geo-VE and the models are used only for demonstration and not for data fusion, conversion and modelling.

RESULTS AND DOCUMENTATION
CHAPTER 7

7 Results of validation survey

This chapter discusses the results of the validation questionnaires leading to two kinds of results. The first part constitutes to the validated functionalities of the geo-VE. These are the functionalities that the geo-VE should have for Dutch municipalities to interact with external actors (like citizens and social housing agencies). The second part of this chapter lists the results regarding how visual materials of the geo-VE can be used for different design phases.

7.1 Results on functionalities of geo-VE (Survey 1)

The results of 'Survey 1' are documented here. If a statement is validated by one of the user groups, the system should contain the functionality (even though it is not available for every user group, achieved in the software through different interfaces). But in few cases this rule is not respected and personal choice has been applied. In such cases, it is explained why such a decision is taken. The details of the survey results can be seen in Annex 6. The graphs in Annex 6 indicate percentage on 'agreeability'. A functionality is listed as required if 50% of the population agreed on the statement. The resulting specification document can be used for comparing geo-VEs.

Prioritization through MoSCoW method

The functionalities are listed in the MoSCoW method in the specification document in section 7.2. If the functionality is agreed by 75% of one type of survey population it is considered as 'must have' functionality for the system. It is assumed that 50% to 75% it is should have, 50% is 'could have' and below 50% is 'won't have but want to have in future' functionality. This classification is flexible as interviews also give direct subjective input, which may in times be contradictory to the survey results. In some cases, the survey population has shown bias to free to use geo-VE like Google Earth and the functionalities that come along the software. But this bias is hard to measure in the prioritization method. It is assumed that building or using the geo-VE will not be free of cost. MoSCoW is a management tool to list prioritization in the specification document. This method is used in business and often in software development to get an understanding of the importance on acquiring a functionality of the software. Originated from the DSDM (Dynamic System Development Method), MoSCoW (Coley Consulting, 2007) is a method to show rapid prioritization of requirements of software. This method is very effective in documenting the requirements of the users from software packages indicating which features must and should be delivered to the client. As geo-VEs are software, MoSCoW rule can be applied to list the prioritization of the functionalities that the geo-VE requires for visual interaction. The MoSCoW method is seen in Table 25.

	Table25: MoSCoW method for prioritization
M	Must have functionality (A requirement that is a 'must have' has to be included in software delivery in order for it to be a success. 'Must' is an acronym for ***M**inimum **U**sable **S**ubse**T***.
S	Should have functionality. This is not related to the software success. The 'should have' requirement is nearly as important and should be included for the software.
C	Could have functionality. The 'could have' requirements are less critical and often seen as functions that are 'nice to have'. However the coulds in software delivery can in some cases increase customer satisfaction against little development cost.
W	Won't have functionality at this moment but want to have in the future. The 'won't have' functionalities are the least critical for the software. The 'won't have' functions are often dropped or stated for later developments. Sometimes they are described as 'would like to have' in the future.

The results indicate the survey population through the following abbreviations:

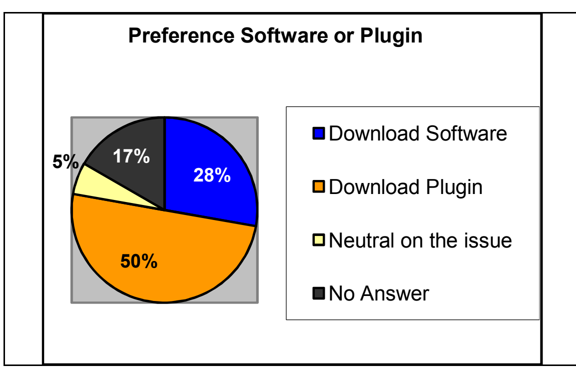
M	Municipality (meaning if the functionality should be available for the user group)
C	Citizens (meaning if the functionality should be provided to citizens by the municipalities)
H.A.	Housing Agencies (meaning if the functionality should be available for the user group)

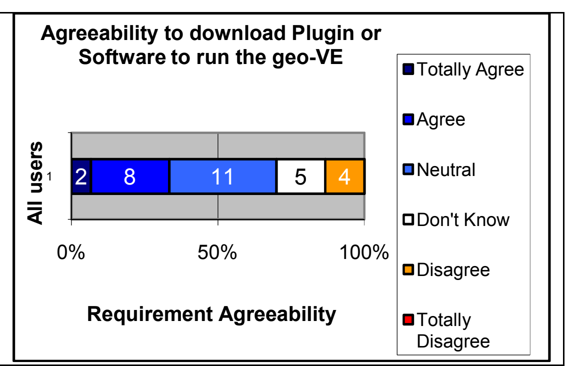
7.1.1 Construction functionalities (Annex 6 for graphs)

The construction functionalities are based on the LoD and the data types, interfaces, plug-in and software issues as seen in Table 26. There is a considerable input from the interviews at this phase, as only a validation cannot provide enough information on the subject.

The municipalities and housing agencies strongly validated that the system can have multiple LoD in relation to multiple design phases ('must have' functionality). The participants failed to agree if the municipalities should administer the data and the central database. Considerable portion of the survey population did not have any answer. But by analyzing the survey data it is found that the GIS experts, 3D modelers, etc agreed with the statement. So even though the statement is not validated, based on expert opinion it can be said that it is a 'could have' issue. A majority of the population agreed that there should be more than one interface ('should have' functionality). There was some reluctance in building the system on open source software and data format. It is a 'could have' issue. Some argued during the interviews that open source VR systems can be prone to hackers and the security is relatively low. The survey population in general agreed that the system will have to download a plug-in or software to run and a plug-in is preferable to downloading software. They are however biased to Google Earth when it comes to downloading VR software (interview input).

Table26:	Constructed related functionalities/attributes					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MosCoW**
Validation 1	Information Intensity LoD	X	X	X	YES	Must
	System should visualize the various design phases (*Master plan, Stedenbouwkundig plan, Beeldkwaliteitsplan, etc*) in various LoD models.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MosCoW**
Validation 2	Integration: Location data/database				NEUTRAL	Could
	System should be situated in central spatial database at municipality & not at external party.					
	Attribute	**M**	**C**	**H.A**	**Validation**	**MosCoW**
Validation 3	Data-integration: Open Source				YES	Could
	System should be built preferably with Open Source Software					
	Attribute	**M**	**C**	**H.A**	**Validation**	**MosCoW**
Validation 4	Integration: data types & interface				YES	Should
	System should have more than one front-end Interface using various data-formats (like KML, X3D, VRML, GML, CityGML (WFS), etc) to decrease software dependency					
	Attribute	**M**	**C**	**H.A**	**Validation**	**MosCoW**
Validation 5	Data-integration: Plug-in & Software				YES	Should
	System may have to download a software or plug-in to run on the Internet.					





The municipalities have shown interest in implementing the CityGML specification (OGC 07-062, Candidate) for 3D data exchange and storage for 3D models for multiple purposes (Annex 5). They want to visualize urban design and architecture for interaction with the citizens in web based geo-virtual environments. But municipalities want to use the 3D models for other purposes like cadastre, disaster management, tourism, facility management, traffic, augmented reality visualization of utility pipes, etc. Implementing CityGML LoD for urban objects can help to use 3D data in various applications in different formats like KML, VRML/X3D, etc. Implementing CityGML LoD will help 3D datasets be exchanged between various municipalities.

7.1.2 Capabilities functionalities (Annex 6 for graphs)

The capabilities of the 3D scene are mostly validated. The functionalities that are validated can be seen in the Table 27.

Table27:	Capability related functionalities					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 6	Representation rendering	X	X	X	YES	Should
	System should allow the visualization of same design solution in various representations and rendering on same virtual site to make a judgment (same geometry different rendering representation on same site).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 7	Representation alternative model	X	X	X	YES	Must
	System should allow the visualization of more than one design solution on same virtual site in order to make a judgment (different geometry models in same rendering representation on same site).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 8	Representation old/new	X	X	X	YES	Must
	System should present comparison between the old situation and the new design of an urban project.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 9	Animation and Simulation	X	X	X	YES	Must
	System should be able to make simulation (time & other parameters) and animation (movies) for presentation.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation10	Feedback: Chat	X	X	NEUTRAL	YES	Should
	System should allow the users to interactively chat with each on urban design issues (Same time different place).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation11	Feedback: Leave message/email	X	X	X	YES	Must
	System should allow the users to leave a leave message, vote or email (feedback) on certain urban issues. (Different time-different place).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 12	Multi-Dimensionality viewpoints	X	X	X	YES	Must
	System should allow the visualization of urban design projects in multiple dimensions (1D, 2D, 2.5D, 3D) in multiple synchronized windows using multiple viewpoints.					

The system should be able to visualize designs in different representation. In the solution to achieve this functionality there should be click buttons on the geo-VE from which a number of design solutions can be visualized. However, the people in the municipalities are divided if they want to share the information of different design phases to the general public. Some urban planners in municipalities in Delft, Den Haag and Rotterdam are opposed to the idea that the general public should be consulted in every phases of design. They are also opposed to multiple rendered representations of buildings in VR systems arguing that it can only make the general public confused. A slight majority of the survey population agreed that the same geometrical model of one design solution should be visualized in various rendering representation ('should have'). Wireframe, flat sketchy, smooth and solid, hidden lines & transparent, monochrome, textured and shaded are different types of representation in most visualization software. Lines can be thickened, lighted, highlighted, hidden, colored, etc.

But the survey population validated that multiple design solutions (in various geometry) should be visualized using same rendering techniques at the end phase of the design project ('must have'). Most of the population agreed that the system should show comparison between existing situation and designed situation ('must have'). Photorealistic verisimilar models can show the difference between the designed situations with the existing one with high efficiency.

The system should be able to animate and simulate a scenario ('must have'). Movies in mpeg, avi etc are the animation formats. Simulation needs an algorithm to perform an animation and present spatial analysis like urban growth models, pollution model, flood model, housing-price rise/decline model, disaster management, etc. It can be used to animate sun-path, shade shadow, wind direction and strength, weather, etc. Many officials at the municipalities (source, interview) and housing agencies do not think that interactive chatting was a must have option for the VR system. But the municipalities validated the functionality ('should have'). Interactive chatting increases collaboration in design interaction, which is the main task of the system. Chats like JAVA applets, integration of MSN or Skype like software in the VE, voice chatting etc are active forms of interaction and increases the interaction of actors in the planning process. Monitoring is needed against cyber-crimes. But almost everyone agreed that the system should have functionalities for email feedback or let the voters vote electronically, etc ('must have').

Almost the whole survey population agreed that the system should have multiple linked windows visualizing co-coordinated views where different data of different dimensionality is viewed ('must have'). If necessary, the user should have the possibility of turn off the coordinated windows and only the 3D scene and/or the 2D map/plan should be visualized.

7.1.3 Experiencing functionalities (Annex 6 for graphs)

Experiencing is based on passive experiencing (Table 28) without interaction with the 3D scene. Navigation, movement and manipulation are the basic functionalities for usability and experiencing the VR. Most people agreed that multiple forms of user-friendly navigation and movement must aid the user in the geo-VE ('must have)'. The forms in navigation can be seen in Table 28. The use should see the location (X, Y, Z) co-ordinates in the VE system and a north-sign compass. They are strongly validated and they are 'must have' issues.

Table28:	Experiencing functionalities					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 13	Navigation and movement aids	YES	YES	YES	YES	Must
	System should have user-friendly navigation (semantic zoom, pan, jump, walk, crawl to, look at, fly, etc) and movement (predictable paths, docking, apply collision) in the 3D environment with the help of automatic focus and tracking.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 14	Orientation Aids	YES	YES	YES	YES	Must
	System should show the user's location on screen (in separate 2D map view) and the 'north sign' for better orientation.					

The immersion type of the VR system is semi-immersive fish tank VR (from validation 16). But such VR is very effective only when mental immersion (presence) is enhanced through appropriate use of visual materials. Mental immersion is vital for the success of the VE system ('must have').

7.1.4 Controlling functionalities (Annex 6 for graphs)

The controlling functionality is based on the direct controlling as seen in Table 29.

Table29:	Controlling functionalities					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 15	Selection of Objects/Scenes	YES	YES	NEU	YES	Must
	System should let the users click & select 2D plans & 3D models in the 3D scene through direct keyboard/mouse control					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 16	Control/Experience: Multi user interface	YES	YES	NEU	YES	Should
	System should be built on multi-user interface (Control) on desktop semi-immersive VR (Experience) (more than one user can use system/mental immersion on Fisk Tank VR)					

The system should allow the users to click and select the 3D models. Direct control through selection is important to control the system. Selection is important for direct user manipulation of the data and the 3D scene. In GE, Bitmanagement X3D plug-in or VirtuoCity one can only click and select the 'pin points' but not the 3D objects. Clicking on 3D object is the basis for elaboration and explanation functionalities. Dynamic interactions like grouping, copying, saving, sending, sharing, etc are only possible only if the user can click and select the data. Even though housing agencies did not extensively validate this, the municipalities validated it with overwhelming majority ('must have'). Availability of this functionality enables the user to click on 3D objects and get attribute information. CityGML viewers like LandXplorer or Aristotle lets the user click and select 3D objects. As the system is at this stage desktop based, the VR accessories are screen, keyboard, pointers and mouse. The user mode for the system is multi-user, validated for the citizens (62.5%) and for housing agencies (50%) ('should have').

7.1.5 Use (interactivity) functionalities (Annex 6 for graphs)

The use of the VE is understood as the interactivity that the system provides. The results from validation are seen in the Table 30.

Table30:	Use (interaction) related functionalities					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 17	Interactivity (Move & Delete)	YES	NO	YES	YES	Should[6*]
	System should let user move and delete 2D plans & 3D models temporarily in the local computer (to see various design options).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 18	Interactivity (Modification, Change)	YES	NO	YES	YES	Should**
	System should let user modify colors, transparency, size and draw 2Dplans/3D models temporarily in the local computer (to see various design options).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 19	Interactivity (Add)	YES		NO	YES	Should
	System should let users add own 3D models on empty-land parcels (for external actors like citizen or real estate agencies through authorization from the Municipality).					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 20	Interactivity (Copy & Save)		NO	NO	NO[7]	Won't***
	System should let users copy and save 2D plans & 3D models (municipality owned) from the system to own local hard disk.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 21	Interactivity (Hide & Sensor)	YES		YES	YES	Must
	System should give the Municipality/Housing agency the possibility to stop/hide/censor sensitive or undecided design projects from viewing.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 22	Augmented Reality				YES	Could
	System should have basic AR like real-time information (traffic, webcam connections, web feeds, other information, etc) for the appropriate users.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 23	Automated Agents (Avatars)	YES		YES	YES	Could
	System should allow the user to enter virtual environment system logging in as Avatar (humanoid object), representing user in real life (name, age, location).					

The municipalities disagreed that the system should allow the citizens to move and delete 2D/3D objects in the geo-VE of existing buildings. Around 80% of the population in the municipalities disagreed with the statement. But this functionality is needed for new design projects where citizens can edit, move and delete 3D objects to express their ideas and communicate with the municipalities. Therefore, this functionality is needed for new building projects, but not applicable for the 3D models of existing buildings. The system does not let the general public modify the

6* VE system should let the citizens move and delete models of new urban projects to express their opinion but should not let them move and delete 3D models of the existing city.
**VE system should let the citizens modify model properties of new projects for interaction but should not let them modify existing 3D models of the city
***VE system shall not let users copy and save spatial data to local hard drives.

models (edit), change attributes like colors, texts etc on existing buildings. At the municipalities 67% of the population said that this functionality should not exist for the citizens and only for internal use. But the system can have such functionalities to modify views, colors and transparency, etc temporarily on local computer of the user. This does not change the original data. This functionality lets the citizens interactively and intuitively design solutions for urban development projects. Therefore this should be present to communicate through alternative design solutions. However, citizens won't have the possibility to update the database.

While the majority of the people in the municipalities are interested in letting housing agencies add 3D models in the system only a minority of the housing agencies and data providers are interested in sharing their 3D data with the municipality. Software like Google Earth, MSN VE 3D, etc lets users add their own data alongside streamed data from WFS/WMS. Considering the popularity of GE, adding data can be seen as 'should have' functionality. In both cases the municipality (67%) and the housing agencies (83%) strongly oppose to let their data to be copied and saved. This is a 'won't have' feature. Both groups demanded strongly that they should have the functionality to hide and censor information in the VE. This is 'must have' issue. Only around half the users agreed that the system should have basic AR like web cams, RSS feeds, traffic information, pipe installation etc. This is only 'could have' functionality. The population was almost equally divided and few didn't have any opinion. A slight majority of people thought that Avatar or humanoid objects should be used to enter the VE interface. The interviews revealed it to be not an absolute necessity. The researcher lists it as a 'could have' functionality.

7.1.6 Exploration functionalities (Annex 6 for graphs)

Table 31 shows the results on the exploring functionalities.

Table31:	**Exploration functionalities**						
	Functionality		**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 24	Query Functionality on spatial objects					YES	Must
	System should allow online search to find a street, area (*wijk*) postcode, etc for the users.						
	Functionality		**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 25	Hyperlinks & linked windows					YES	Must
	System should have hyper linked windows to other websites, datasets, reference pictures, panoramic photos, textual and oral for elaboration of 2D/3d models						

A large number of people agreed that the system should have dynamic spatial query to find street, areas, postcode etc. Through the implementation of CityGML specification spatial query is possible based on building semantics. In KML spatial query is possible on attribute or geometry. Dynamic querying functionalities let the user select by filtering. It lets the user explore data. This is 'must have' functionality. The same is valid for elaboration of 3D models through hyperlinks and linked windows. This is also 'must have' functionality. The linked windows contain websites panoramic pictures, reference images and oral (sound) information, etc. The geo-VE should have multiple synchronized windows showing multiple dimensions of the same objects. Hyperlinks and linked windows facilitate the explanation and elaboration functionalities through the use of explanatory texts (floated pinpoints, popups, screen tips), clickable icons and reference images.

7.1.7 Component aided functionalities: (Annex 6 for graphs)

The components (Table 32) are specific task related functions of the VE system. They are features that enable the system to interact and function. However, none of these functionalities are listed as 'must have' and highest priority is stated as 'should have'. The component includes login interface ('could have') and time component ('should have'). Timer helps the users play simulations back and forth. The population validated (67%) that the system to have measurement tools ('should have'). The same is valid for the teleportation functionality that lets the user navigate from one point to another one on the instance. The population strongly validated the labeling of buildings and landmarks and therefore it is a 'should have' component. Multiple layering for 2D maps and 3D models is 'should have' functionality and one third of the people disagreed. During the interview some had objections to this functionality. Majority (70%) of the population disagreed on the X-ray vision functionality. But this is necessary against occlusion in order to see beyond walls and rooms in 3D. The researcher's personal opinion is that this function is necessary and therefore listed as 'could have' functionality. Most people agreed (80%) that the 2D/3D data in the VE should be spatially referenced ('must have' issue). The general features are listed in the specification document.

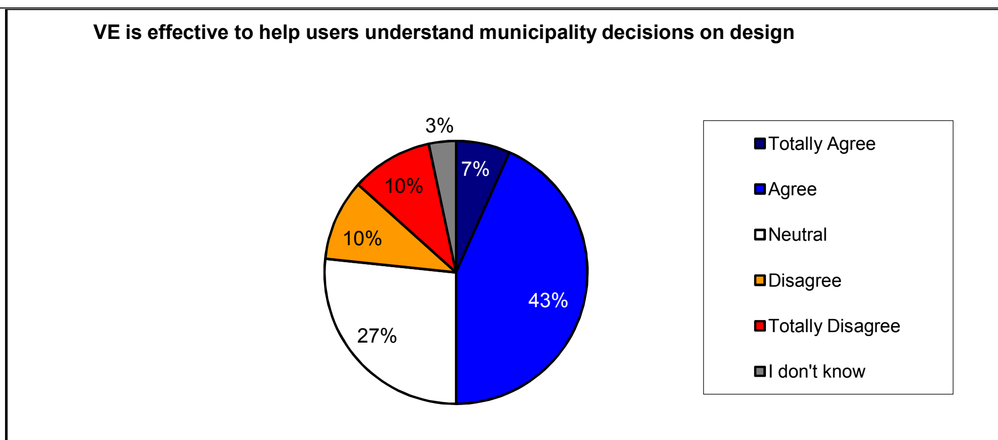
Table32:	Component aided functionalities					
Validation	**Functionality**	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 26	***Log-in***				YES	Could
	System should have an user-log in interface					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 27	***Time component***				YES	Should
	System should have a time component showing the development phases of the urban design project in time.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 28	***Measurement tools***				YES	Should
	User should be able to measure the objects like building height, streets width, etc					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 29	***Teleport tool***				YES	Should
	System should have ***teleport*** function for the user to navigate from one point to another on the instant					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 30	***Labels***				YES	Should
	User should be able to turn on/off labels of building name, street name, etc.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 31	***Multi-layering***				YES	Should
	Users should be able to turn on & off various layers of 2D plans & 3D models.					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 32	***X-Ray Vision and Occlusion***				NO	Could[8]
	System should allow 'X-ray vision' to look inside building's interiors					
	Functionality	**M**	**C**	**H.A**	**Validation**	**MoSCoW**
Validation 33	***Geo-referencing***	YES		YES	YES	Must
	System should contain spatially referenced data with high accuracy					

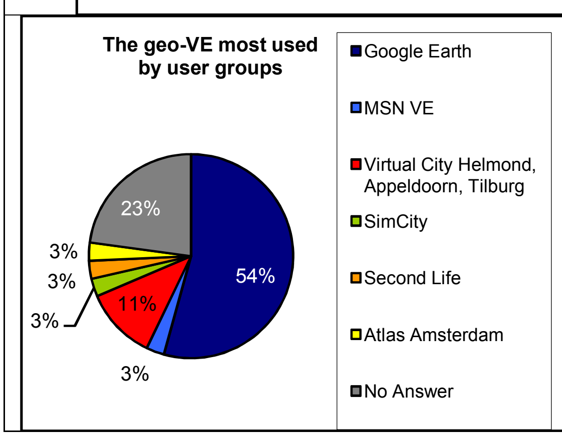
8 The functionality is addressed as 'could have' against the validation as it can help decrease occlusion in finding and exploring objects in geo-VE. The 'could have' functionalities can be seen as neutral.

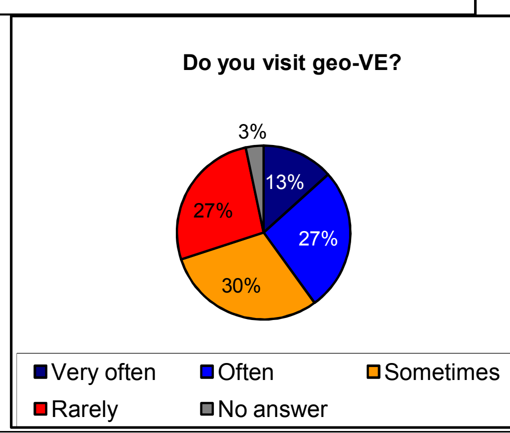
7.1.8 Results on participation and feasibility

Most people agreed (Table 33) that the system will increase public participation and will help as an aid for the external actors to understand the municipalities' decisions better. But during interviewing at Rotterdam municipality, most officials disagreed that the use of collaborative virtual environments will replace existing norm of communication. In the validation phase most of the population agreed that the VE interface can be an aid to the existing methods of communication and can be seen as supplementary and not a replacement. Around 40% of the population said that they use VR systems often or very often. Thus this constitutes to a large group of population already that can be reached through such systems. Google Earth proved to be most popular (54%) viewer. Some of the viewers that the municipalities use like MSN VE 3D are not explicitly discussed in this thesis, but can be found at Kibria & Asperen, 2007.

Table33: Public participation issues	
Validation 34: Issue	**Validated**
Public Participation	YES
Virtual Environment can enhance public participation and inform the public about urban projects.	
Validation 35: Issue	**Validated**
Public Participation	YES
Virtual Environment can help the general public understand the municipality decisions better and help to supplement (and not replace) the existing methods of communication	
Validation 36: Issue	**Validated**
Public Participation	YES
Virtual Environment can act as medium to have live conference with the actors like the general public, architectural firms, '*welstandscommissie*' about urban projects (chat, online virtual-conference or '*virtueel gespreksavond*').	







7.2 Results on visual materials of geo-VE (Survey 2)

The results of the 'Survey 2' (as seen in Annex 7, Question type A, B, C) are plotted in line graphs. Six visual materials form the X-axis (except for Figure 48 where, the X- axis is formed by the level of perception) with 3 intervals that indicate the free choice of the participants have been offered to answer the questions. In urban planning there is no mathematical rule that only a certain type of visual material is best suitable for interaction in a certain planning phase. Therefore, the participants are given more than one choice of visual material to be used in these phases. It helped the participants not to take crisp decisions and provided flexibility.

The y-axis indicates the added maximum and minimum number of times the participants agreed at a certain decision that is taken. These lines illustrate tendencies of expert opinion and should not be seen as a definitive answer. These line graphs indicate the highest number of participants that agreed in a certain decision point but do not show the total number of participants. (See Annex 4 Section B). When a question is abstained, the result is taken as null value. 'Added agreeability' is the total number of times the survey population agreed on a certain decision. The highest added value is taken into consideration for deducting results from each of the line graphs.

7.2.1 Discussion on visual materials in geo-VE versus perception graphs

The relationship between what we see and what we know is never settled.
Berger 1972

The manner how visual information can be visualized in the virtual environment is dealt in this section. How the human cognition perceives 3D models and 2D plans and what kind of knowledge is extracted through human computer interaction (HCI) in the geo-VE is discussed here. Survey 2, Question type A (as seen in Annex 7) is plotted in Figure 48. These graphs indicate the relationship between the certainties of human perception[9] and the increase of detail when design is visualized in geo-VE.

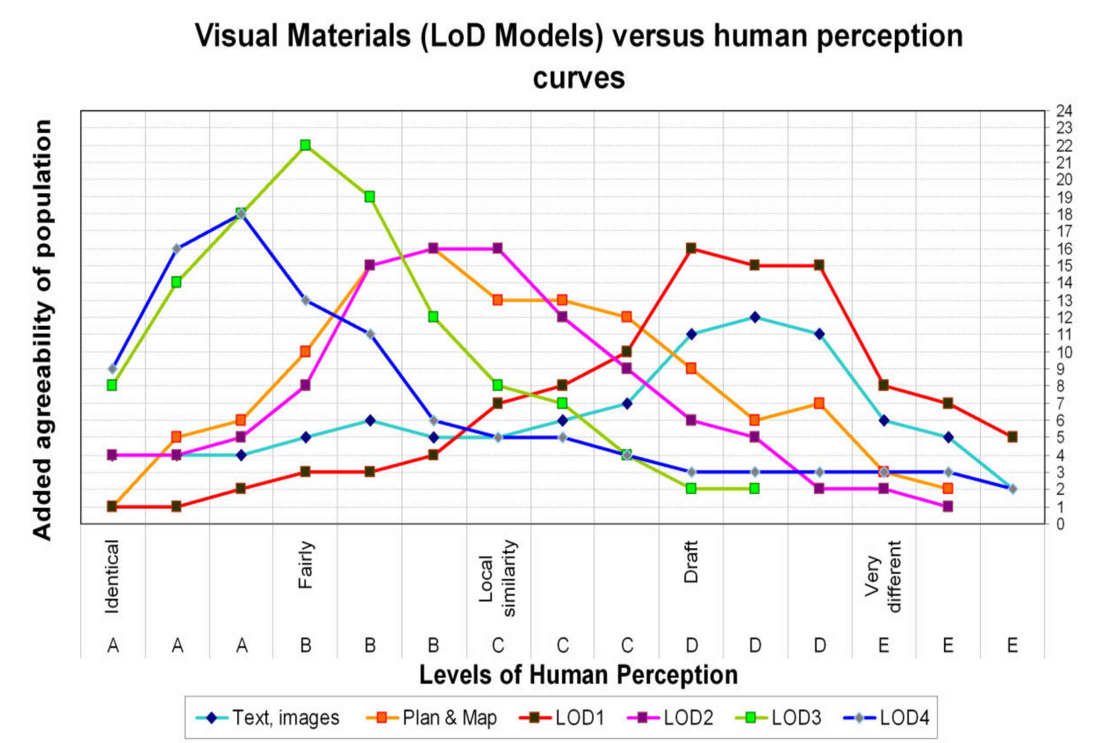
The line graphs as seen in Figure 48 illustrate that only textual and graphical information to explain design in the 3D scene is inadequate. If the building is visualized in LoD1 models, the population perceives the design as a draft. When the building is visualized in LoD2, the viewers emphasize on local details of the building design and not the surroundings. This means the viewer concentrates on the outer looks like roofing, forms etc. When the same design is viewed in LoD3, the viewers perceive that the building is fairly similar up to totally identical to how the building will look like when it is realized. Visualizing LoD4 models with interior space implies that the viewers perceive the design as final.

When the design project is visualized in 2D in the digital environment, the viewer perceives that the end result of the building project is fairly similar to the visual artifact. The 2D plans tends to show local characteristics of the design when a detailed plan of the building is presented. Straight smooth edges of computer rendered 2D maps give the impression to the viewer that the design is almost finalized. To communicate with other actors in design projects in geo-VE, the result of this graph has implications. The graph shows that there is a clear relationship between human cognition and understanding of design through the use of certain visual materials in various representations.

By studying the line graphs, one can conclude that increased of Levels of Detail (LoD) in 3D model in geo-VE, increase the expectation and perception of the viewer. The viewers perceive LoD1 models, texts and reference images as drafts if they are used in the visual interaction process. Thus using such visual material can lead to misunderstanding.

[9] At the Centre for Geo-information at University of Aalborg, Denmark similar study was conducted to plot human perception against geo-visualization, but the two results are not comparable due to the conceptual difference in the survey design. The Danish study considered the PV, MV, WV as visual materials and the uncertainty in the human decision making process through visual perception is not considered.

Figure 48: The visualization versus perception graphs



A	Building and surrounding area will be identical to visual material
B	Building and surrounding area will be fairly similar to visual material
C	Only the building and building parts as seen in visual material will be realized
D	The visual material is a draft and in reality the building can be quite different
E	Reality will be much different than seen in visual material

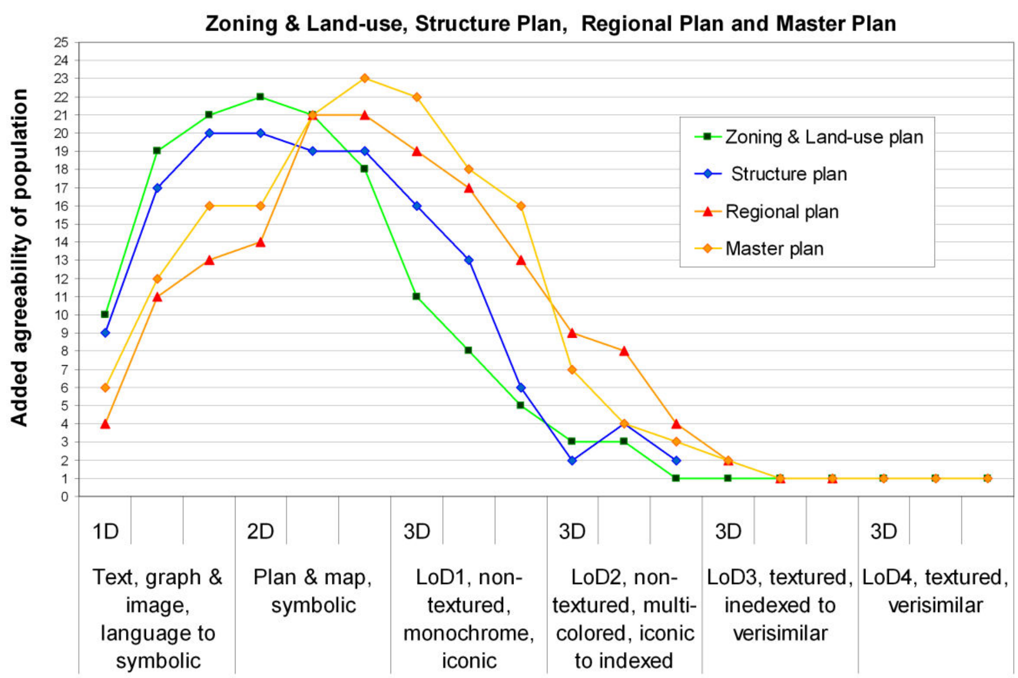
If textured LoD3 or verisimilar LoD4 models are used, the viewers perceive the building project as final. It proves that human perception is largely improved when design is shown in higher LoD. When design is visualized in textured verisimilar LoD4 models then the design is perceived as the end product. One can see that from 2D plan/map to 3D LoD4 models the human ability to perceive design increases dramatically.

For the case of 3D scenes, the viewer is not able to differentiate between buildings if LoD1 models are used. The feeling of spatial reality is simulated when the building projects can be seen (beginning from LoD2 till LoD4). Textures in buildings increase the realism and perception. Therefore, if the design of the urban project is not certain, no textured models should be used for visualization in geo-VE. This will increase user expectation on design issues that may not be implemented. This study proves that representation of planning phase must be carefully selected. On the other hand, the thesis has proven that 3D models help the viewer recognize and understand the area under observation with less difficulty compared to 2D maps and iconic block models.

7.2.2 Discussion on visual material in geo-VE versus design phase graphs

Survey 2, Question type B (as seen in Annex 7) is plotted in Figure 49. In this phase the relationship between an urban planning phase and the use of visual material in various LoD is investigated. Like the previous line graphs, the relationships between the design phase and the use of a visual material has a fuzzy character. It is based on the hypothesis that there is no certainty to decide that a certain spatial planning phase is best visualized with only one kind of visual material. The participants have been given the opportunity to answers with three blocks representing the degree of freedom (See Annex 7). By adding and taking the highest value on the agreed decisions, a tendency can be extracted that reflect expert opinion.

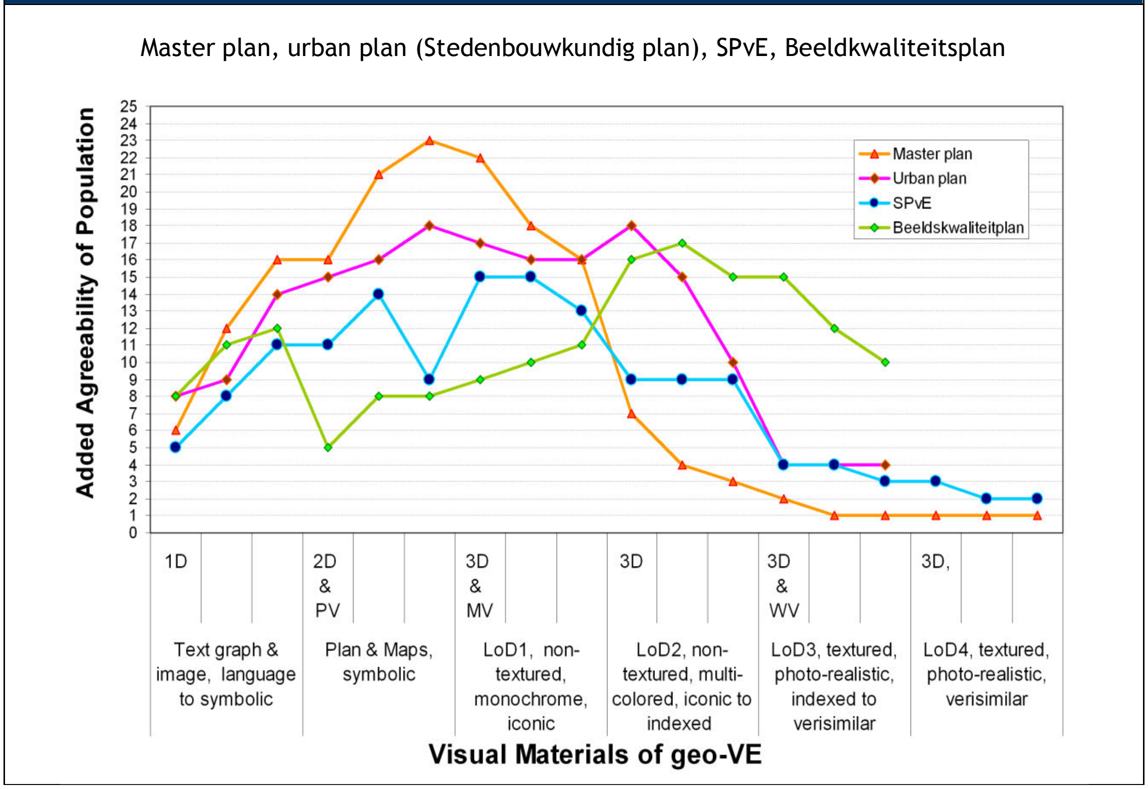
Figure 49: Initial spatial planning phases versus use of visual materials (1)



Results from 'Survey 2' as seen in Annex 7 (Question type B) are plotted

Figure 49 illustrates the relationships of incremental planning phases like zoning (*bestemmingsplan*) & land-use plans, large scale city structure plans, regional plans and master plan with the six defined visual materials. The figure indicates that thematic plans like zoning and land-use plan information can be visualized mostly in as symbolic 2D map/plan alongside of textual and graphical information as attributes. A part of the survey population argued for iconic 3D models for zoning plans (*bestemmingsplan*). As zoning plan in the Netherlands, contain height restriction on the development area, this finding is relevant. According to the DURP project the zoning plans (*bestemmingsplan*) is exchanged and stored in GML format, which can store data in 2D and 3D. The graph indicates that in this phase, representation of spatial information should be through symbolic and language means. Structure plans (*stuctuurplan*) of development projects of large-scale city areas (like *stedelijke visie, gebiedsvisie, bouwplangebieden, inrichtingsplan,* etc) can be visualized in symbolic 2D plan and map. However, a portion of the survey population argued that iconic 3D LoD1 block models should be used. City regional plans can be visualized iconic 3D LoD1 block models. A small portion of the population argued for indexed LoD2 models, but taking to the size of the 'added agreeability' into consideration, the researcher concludes that this is nothing but an offshoot. In the master plan phase, design can be represented in symbolic 2D plans and iconic 3D block models (LoD1). The master plan requires symbolic 2D map/plan for representation. If one observes the line graphs in Figure 49, it become obvious with gradual progress of spatial (urban) planning, the graphs tend to move to the right side increasing the use of 3D. In these initial spatial planning phases one can identify that there is constant presence of textual, graphical and reference images as interaction material in the design process. However, the master plan phase tends to show inclination to 3D, specifically the use of monochromic iconic block models (LoD1). Noticeably, none but few of survey population argued for the use of textured models at these initial planning phases.

Figure 50: Urban planning phases versus visual materials (2)



In the lateral urban design phases (Figure 50, Figure 51 and Figure 52), the survey population was more scattered in their opinion. But through observation of these line graphs, strong opinion can be extracted. From the line graphs of urban plan, SpvE (*stedenbouwkundig programma van eisen*), *beeldkwaliteitsplan*, final architecture design, navigable exterior and interiors limited but constant presence of textual, graphical and image representation can be identified. During the interviews at the municipalities, the designers and planners argued for the importance of explanatory text and reference images. As a result, the necessity of such visual materials in the graphs cannot be seen as an offshoot.

It indicates that if these design phases are visualized in geo-VE, the importance of textual information and reference images for representing building is not negligible. However, from urban plan up to architectural plan phases, the graphs tend to show a gradual decrease in the use of text, graphs and images as a medium for communication and the increase of 3D. There is a gradual tendency to use language to symbolic, symbolic to iconic, iconic to indexed, and finally to verisimilar visual material in these phases (Figure 50 to 52). It proves as the planning phase progresses, the use of 3D against 2D increases. It also indicates that with this progression the use of realism against abstract symbolic representation occur as design of urban projects become certain.

The line graphs shows that urban plans should be visualized in volumetric block models (LoD1) and volumetric envelope models (LoD2). From CityGML specification one can identify that CityGML LoD2 models can represent building forms, roofing, exterior objects etc. During urban design phases, the planners use building envelopes that can indicate building height, functions and different building parts. The iconic 3D models used in this phase are traditionally non non-textured and often non-realistic sketchy representation is preferred.

Figure 51: Urban planning phases versus visual materials (3)

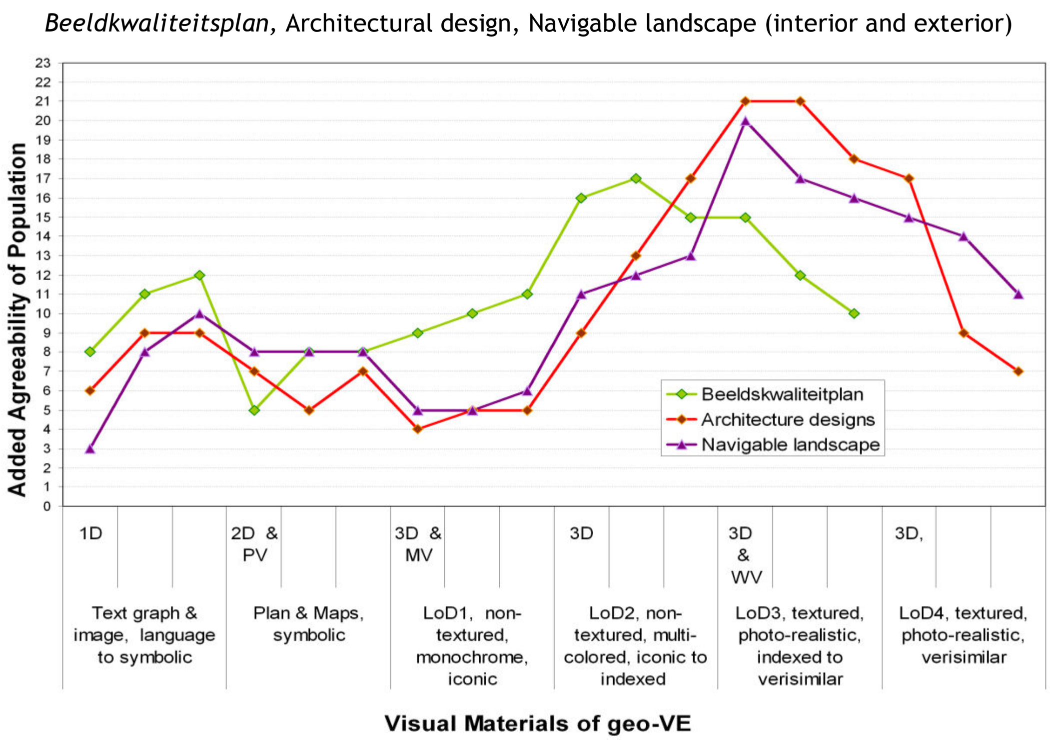
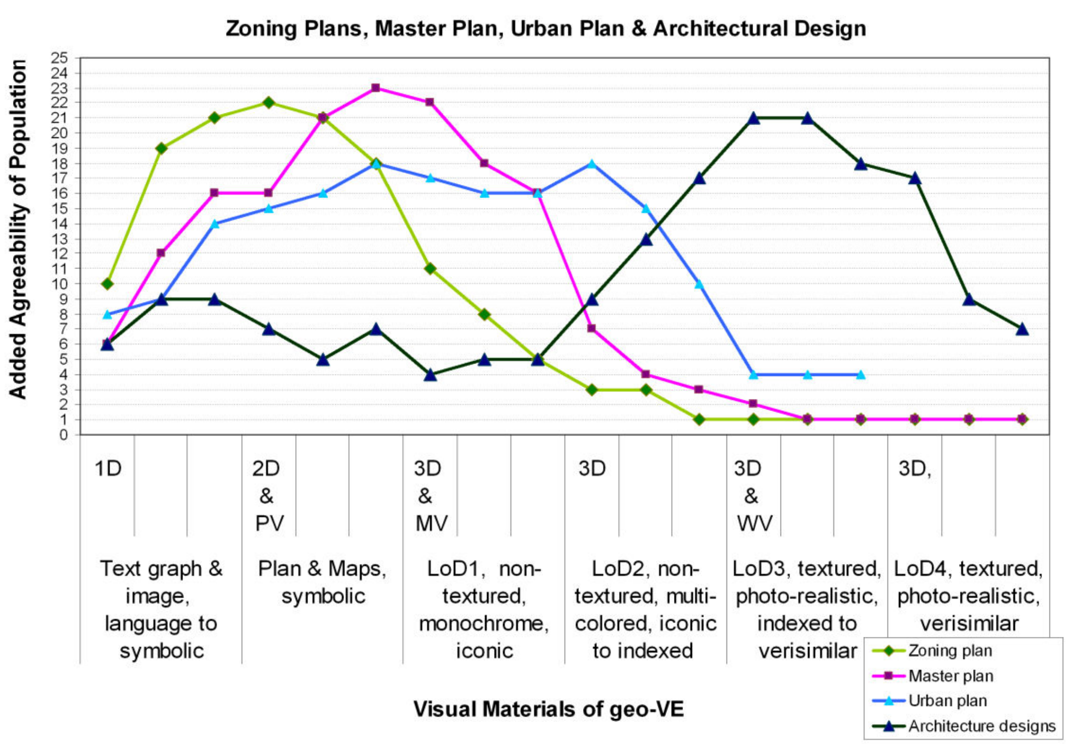


Figure 52: Comparison of use of visual materials of geo-VE for major planning phases



The advantage to use CityGML LoD model is that sketchy and artistic visualization of the digital models is possible. *SpVE (Stedenbouwkundig Programma van Eisen, Urban plan of spatial requirements)* phase shows that 2D maps and volumetric block models (LoD1) are of importance when information is visualized in geo-VE. In both two urban design phases, there is a sharp fall in opinion to use textured verisimilar 3D models (LoD3). During the urban plan phase the building project is still at an uncertain phase and the visual material should use low level of detail.

As mentioned already, *beeldkwaliteitsplan* (architectonic quality plan) is the phase where the urban planners communicate with architects on the architectural aspiration of the building project. For visualizing information in geo-VE, the phase shows inclination towards iconic to indexed volumetric envelope models (LoD2) as seen in Figure 51. The *beeldkwaliteitsplan* line graph shows that multi-colored 3D models in LoD2 should visualize the initial architectonic forms like roofing, chimneys, stairs, exterior envelopes, etc in this phase.

Figure 51 indicates that in the architectural design phase, photorealistic, indexed to verisimilar, detailed architectural model (LoD3) and verisimilar detailed models with interior space (LoD4) have preference to visualize design in geo-VE. The final architectural design line graph shows that there is a sharp fall in the use of iconic block models (LoD1) and iconic-indexed envelope models with details (LoD2) at this phase. The line graph for final architectural design shows a small but significant tendency to visualize the information through explanatory texts and images. To visualize final architectural models in geo-VE, textual and reference images are therefore necessary. A significant portion of the survey population, argued to use verisimilar, textured LoD4 models with interior for explaining finalized architectural design. Such findings can be defended by the fact that architecture is also about the design of interior space. To visualize the navigable exterior and interior space in the 3D scene, the survey participants argued mostly for verisimilar detailed textured architectural models (LoD3) as seen in Figure 51. The graph shows that 2D plans & maps are also necessary for navigating and orienting the 3D space. Figure 52 shows the comparison of the major phases.

7.2.3 Discussion on visual materials in geo-VE & design-task graphs

Survey 2 (Annex 7, Question type C) highlights issues related to the use of visual materials for urban planning task. Figure 53 indicates that for shade shadow analysis the survey population agreed mostly on iconic volumetric block models and iconic-indexed volumetric envelope models (with details). In CityGML schema these two models constitute to LoD1 and LoD2 models. For volumetric analysis in urban design monochromatic block models in LoD1 are best suitable. For visualizing 3D scene, comparison between the designed situations with that of the present situation can be best visualized in volumetric models with detail (LoD2) and verisimilar textured detailed architectural model (LoD3). Verisimilar or indexed textured 3D models (LoD3, LoD4) are easy for people to understand quickly. In case of design comparisons textured verisimilar 3D models are best suitable, as it can visualize building materials.

By analyzing the line graphs in Figure 54, one can see that even though the majority thought that using LoD1 volumetric block models, trigger the most understanding in the communication process of design and planning, the whole survey population was divided in their opinion. The line graph cannot lead to conclusions. But it shows a slight tendency that block models (LoD1) confuses people the most. Many argued for LoD2 and some argued for 2D plans. The survey population thought that LoD2 and LoD3 models were good enough for navigation and orientation friendly in 3D scene. For navigating the 3D space the viewer needs to perceive the whole space, divide and then move or navigate. This is known as way finding.

Through verisimilar textured LoD3 models the viewer's interest can be concentrated on Lynch's imageability (like the landmarks and nodes) leading to the creation of the conceptual view of the whole area on the geo-VE. In VR systems most of the building do not have interior rooms, as it is laborious task to create such models. Only for specific large-scale design projects such for VE (reference to *Virtueel Tilburg* website). Most people found LoD2 and LoD3 models attractive for visualization such virtual environments.

Figure 53: Shade-shadow, volumetric analysis, show difference

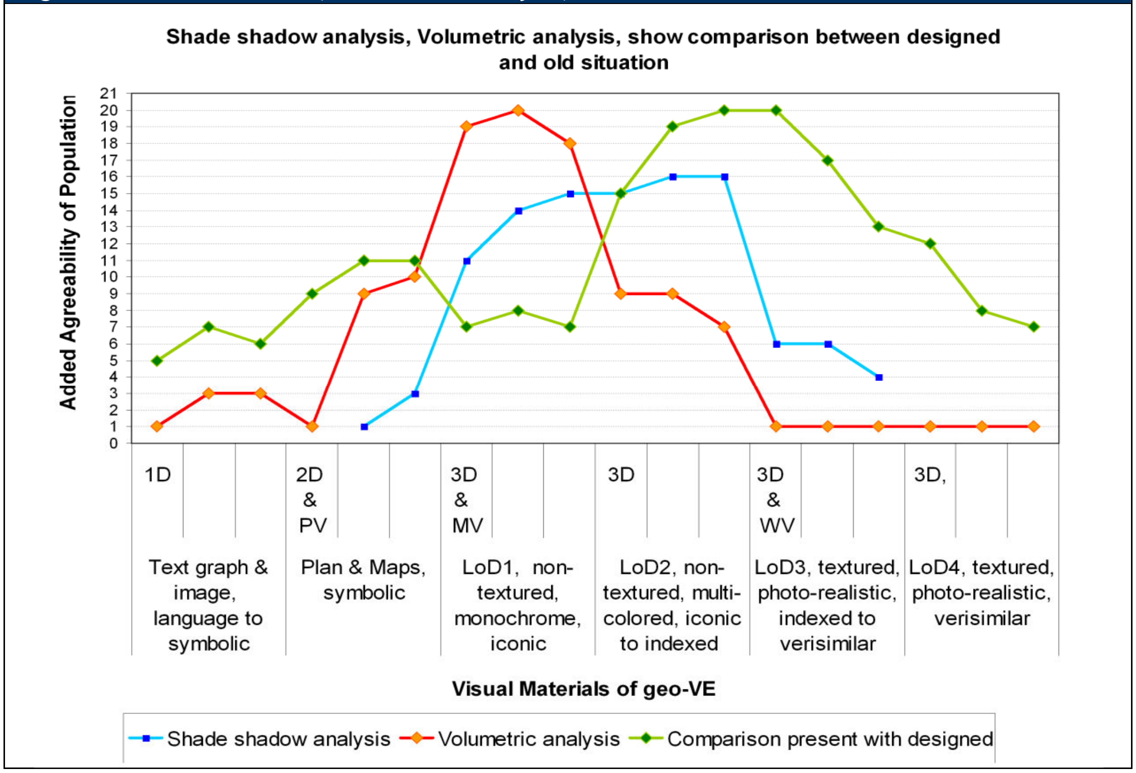
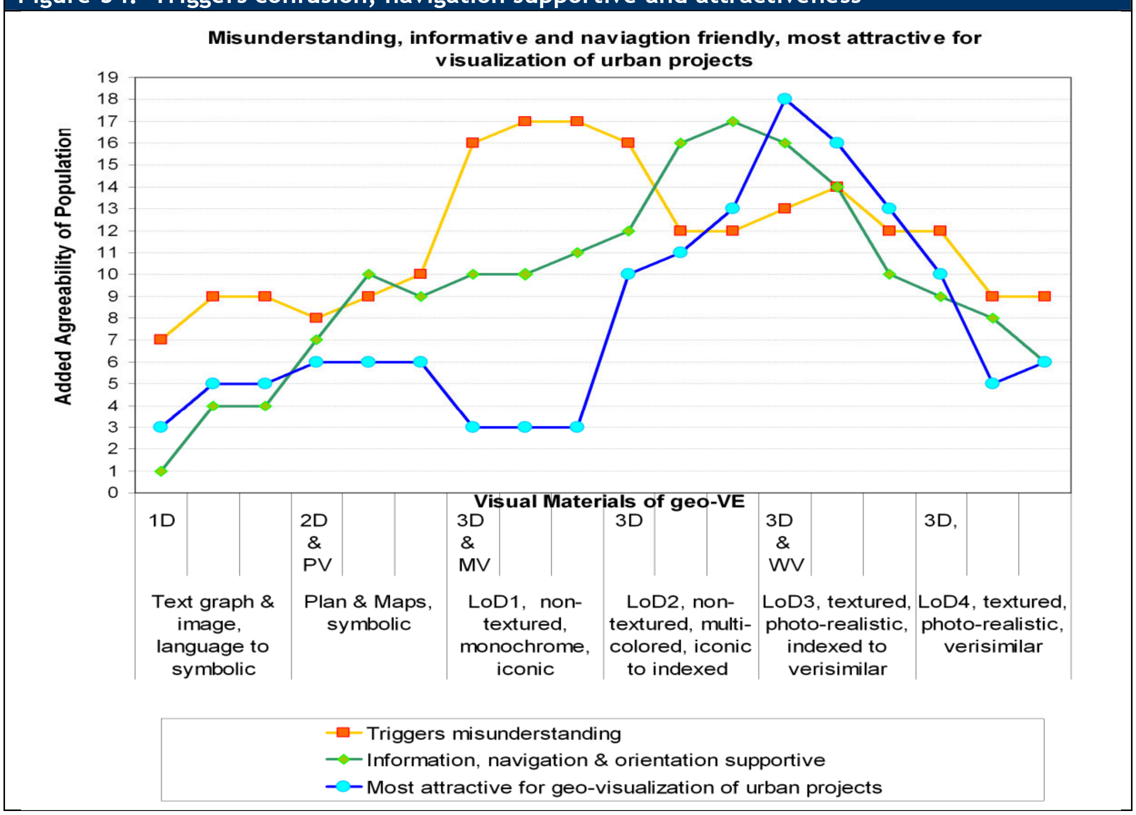


Figure 54: Triggers confusion, navigation supportive and attractiveness



7.3 Specification documents

In the previous two sections the validation results of Survey 1 and Survey 2 have been discussed on the requirement functionalities and visual materials of geo-VE. This has brought the thesis to the last part of the requirement engineering (RE) model. The RE ends with specifying specification documents. Table 34 specifies the functionalities of geo-VE as an end product of the requirement analysis on the basis of Table 21 (Chapter 6). The reference to cost is mentioned in Section 6.1.2.

7.3.1 Specification document for geo-VE functionalities

Table34: Specification document on the functionalities of geo-VE for interaction

Domain	Functionality	Validation	Negotiation	Y	N	MoSCoW
Construction	Information Intensity (LoD)	V1		Y		Must have
	Data fusion& integration: Dataset and database at local municipality	V2		Y		Could have
	Data fusion& integration: Open Source solutions	V3		Y		Could have
	Data integration: Different Data types & Interface (CityGML, X3D/VRML, KML and VirtuoCity)	V4		Y		Should have
	Plug-in or Software download	V5		Y		Should have (Plug-in preferable)
	Toolboxes: Control, Experiencing, Navigating & Movement tool		N1	Y		Must have
Capabilities	Representation: Multiple representation in different rendering	V6		Y		Should have
	Representation: Multiple representation in different geometry	V7		Y		Must have
	Representation: Comparison of old and new situation	V8		Y		Must have
	Animation and Simulation for analysis and presentation	V9		Y		Must have
	Feedback: Interactive chat (online *gespreksavond)*	V10		Y		Should have
	Feedback: Leave a message, email	V11		Y		Must have
	Multi-Dimensionality/Viewpoints	V12		Y		Must have
Experiencing	Movement and navigation aid	V13		Y		Must have
	Orientation aid	V14		Y		Must have
	Manipulation, exploration and élaboration		N2	Y		Should have
	Immersion: mental semi-immersive environnent		N3	Y		Must have
Controlling	Selection of Scene/Objects: Click & Select	V15		Y		Must have
	VR Accessories: desktop fish tank VR / User mode: Multiple/Single	V16		Y		Should have

Domain	Functionality	Validation	Negotiation	Y	N	MoSCoW
Use (Interaction)	Interactivity: move & delete	V17			N	Should have[10]*
	Interactivity: modify, edit and change 2D/3D information	V18			N	Should have**
	Interactivity: add 2D/3D data	V19		Y		Should have
	Interactivity: copy & save	V20			N	Won't have***
	Interactivity: stop, hide, sensor information	V21		Y		Must have
	Primitive AR like webcams	V22		Y		Could have
	Automated Agents (Avatars)	V23		Y		Could have
	Intelligent objects		N4	Y		Could have
Exploration	Spatial Query functionality	V24		Y		Must have
	Hyper links, linked windows	V25		Y		Must have
	Re-expression functionalities		N5	Y		Won't have
Components	Log-in interface	V26		Y		Could have
	Time component	V27		Y		Should have
	Measurement tool component	V28		Y		Should have
	Teleportation component	V29		Y		Should have
	Labeling & icons	V30		Y		Should have
	Multiple layering	V31		Y		Should have
	X-Ray Vision	V32			N	Could have (against the validation)
	Geo-referencing	V33				Must have
The general components	Lighting, angle change (on/off)		N6	Y		Should have
	Camera and viewpoints change, tilt, range etc.		N7	Y		Should have
	Transparency and shading (on/off)		N8	Y		Should have
	Atmosphere and visibility		N9	Y		Should have
	Screenshots and save image		N10	Y		Should have
	Automatic focus and tracking		N11	Y		Should have
	Basic drawing tool (mark and draw)		N12	Y		Should have
	Highlight landmarks and nodes etc		N13	Y		Should have
	Add floating labels		N14	Y		Should have
	Reference points (Home button, back and forward)		N15	Y		Should have
	Audio sound support		N16	Y		Should have
	Distance function from highlighted 3D object, from ground		N17	Y		Should have
	Velocity: fast, medium, slow & Acceleration		N18	Y		Should have
	Gravity and collision (on/off)		N19	Y		Should have
	Vector and raster data support		N20	Y		Should have
	Defined and closed boundaries		N21	Y		Should have
	History keeping		N22	Y		Should have
	Add icons and arrows (to indicate design and 3D objects)		N23	Y		Should have
	Spatial analysis functionalities specially sun-path, network analysis and statistical analysis		N24	Y		Could have

10* Move and delete models of proposed urban design projects but not existing buildings of the city
** Modify models of proposed urban design projects but not existing buildings of the city
***The VE system shall not let users copy and save spatial data to local hard drives.

7.3.2 Comparison of the four geo-VE tested in this thesis (based on the Specification document in 7.3.1)

This thesis took four geo-VEs into consideration as seen in Table 35. Google Earth is selected because it is a geo-VE that is widely popular and has considerable support from many software companies. Many GIS software now allows the coupling of geo-information to GE. This software allows the free visualization of huge amount of geo-datasets (satellite images, WMS, 2D plans, 3D models, RSS feeds, navigation data, etc) for the general public. On the other hand LandXplorer CityGML viewer does not come with any geo-data and everything has to be loaded by the client or from specific service. Using such system, the municipalities have to add all kinds of services for the users. But the viewer is rich in data exploration. Bitmanagement plug-in for Internet Explorer is made by a German company (BSContact GmbH, see Website) and comes with some built-in functionalities for passive experiencing. Many of the functionalities discussed in this thesis can be built within this geo-VE. There is cost related to build extra functionalities on top of Bitmanagement plug-in. But these two are open source solutions. And finally, in the past year *VirtuoCity Tilburg, Apeldoorn and Helmond* have been a topic of discussion in the Netherlands with the introduction of highly interactive virtual cities for planning purposes. They have been rewarded prestigious European eGovernment Awards for collaboration planning practices (Cebra BV, See Website). Unfortunately, the software uses proprietary data format and the implementation of this geo-VE will require investment.

Table35:	Geo-VE interfaces of the thesis	
1	Google Earth	KML 2.1
2	LandXplorer	CityGML
3	Bitmanagement plug-in for Internet Explorer	VRML/X3D
4	VirtuoCity of Cebra	V3D

There is a reason why MSN VE 3D is not included in this thesis. The researcher conducted an extensive research for *Rijkswaterstaat AGI* in 2007 for the use of GE, MSN VE 3D and World Wind and compared the functionalities they provide to disseminate geo-information in 2D and 3D for the general public (Kibria & Asperen, 2007). Including MSN VE 3D would be a repetition of the work conducted in the referred research. The 6th secondary question demands to investigate what kinds of functionalities the existing popular geo-VEs provide. The Table 34 is used to classify the functionalities the four geo-VEs provide to the municipalities. In order to do this comparison, the researcher has gone through each of these geo-VE and the specification documents of data formats (if available). The detailed comparison can be found in Annex 8. The essential findings are stated below:

Based on Streaming

Google Earth, LandXplorer, Bitmanagement (BS Contact) for Internet Explorer and VirtuoCity connect to the Internet and import data. VirtuoCity uses specific format in a client-server architecture in which the data is streamed to the client. This makes a multi-user interface possible to be made. This is a big advantage of the software, which makes it a good candidate for the municipalities. Google Earth allows streaming and comes with huge amount of satellite images and 3D models. For LandXplorer the data has to be firstly downloaded to the local computer. Bitmanagement plug-in (BS Contact) for Internet Explorer visualizing X3D/VRML can be streamed.

Based on Construction

The construction functionalities of these VR viewers are largely dependent on how the data formats are designed. On the construction domain only LandXplorer viewer's data format CityGML has a clear grammar on how to model in various LoD keeping the thematic and geometric semantics. Google Earth's data format KML has geometric semantics but no thematic attributes. The same is valid for Bitmanagement plug-in visualizing the X3D data format.

Based on Capabilities

LandXplorer is weak in the interaction capabilities. VirtuoCity on the other hand is strong these capabilities (letting the user to vote, chat, and leave a message, linked windows, etc). Google Earth lets the user play animation and simulation and has linked windows. These kinds of functionalities can be technically developed with the Bitmanagement plug-in (based on X3D) for Internet Explorer but this will not be cost-effective to build such functionalities.

Based on Experiencing

All the viewers let users to passively experience the 3D through movement, navigation and orientation. GE and LandXplorer have advanced navigation controls. All of the viewers can be controlled through keyboard and mouse. Only CityGML data can be clicked and selected and more information can be asked from the data. For Bitmanagement plug-in (BS Contact) for Internet Explorer, Google Earth and VirtuoCity the user can only select data if there are selectable pinpoints that are pre-defined.

Based on Interactivity (Use)

LandXplorer, Google Earth (with the help of SketchUp) lets the users modify and delete objects. These two viewers let new models be integrated to the VR. VirtuoCity does not allow such functionalities. However, none of these viewers allow the users to interactively draw on the 3D objects except for Google Earth. Bitmanagement plug-in (X3D viewer) for Internet Explorer and VirtuoCity uses avatar-based systems, but Google Earth and LandXplorer are not. Google Earth and LandXplorer allow spatial query based on geometry and attribute. Such query is also possible for Bitmanagement plug-in (BS Contact) for Internet Explorer (X3D or VRML). Unfortunately no spatial query is included in VirtuoCity geo-VE.

Based on Components

Only VirtuoCity contains a login interface. All of the viewers allow the same model be used by multiple users at the same time. VirtuoCity allows teleportation tools to move between landmarks. Google Earth, Bitmanagement plug-in (BS Contact), LandXplorer lets the user add own labels to models. Google Earth lets the users to add multiple layers of information to analyze the situation. Google Earth's KML and LandXplorer's CityGML are geo-referenced. X3D/VRML is not geo-referenced. It is not clear from the information if the models in VirtuoCity are geo-referenced.

In the discussion Chapter 8, an opinion is given on which of these four implementation is the best suitable for the municipalities to aid interaction with actors based on the results discussed above.

7.3.3 Specification documents for the use of visual materials in geo-VE

The specification documents for visual materials lists how visual materials can be used in geo-VE to visualize urban design projects in various dimensionality, realism and LoD. The six visual materials of the thesis are as follows in Table 36.

Table36:	Specification of visual materials
VM1	Text, graph & image
VM2	Plan & map
VM3	Volumetric block model
VM4	Volumetric envelope model (with detail)
VM5	Detailed architectural envelope model
VM6	Detailed architectural model with interior

Annex 7 has three types (A, B, C) of questions as follows:

1. Human perception and visual materials in geo-VE
2. Planning phases and visual materials in geo-VE
3. Planning related tasks and visual materials in geo-VE

A. Human Perception and Visual Materials in geo-VE (in various LoD)

From the results of the Annex 7 question type A, the following answers can be deduced in Table 37.

Table37: Human perception and Visual material						
Visual material			D	Reality Axis	LoD	Perception in design communication
Text, graph & image		VM1	1D 2D	Language Symbolic		Only textual and images of buildings are not enough to explain a building in geo-VE.
Plan & map		VM2	2D	Symbolic		It indicates that design is similar to the end results. Some people get a localized impression of the building when detail plans are used.
Volumetric block model		VM3	2.5 D 3D	Iconic	LoD1	It stirs uncertainty when explaining design human perception. People take such models as drafts when explaining individual buildings.
Volumetric envelope model (with detail)		VM4	3D	Iconic to indexed	LoD2	It stirs the impression of localized and specific characters of the building in the human perception.
Detailed architectural envelope model		VM5	3D	Indexed to verisimilar	LoD3	It stirs the impression that the final constructed building will be pretty much the same up to identical.
Detailed architectural model with interior		VM6	3D	Verisimilar	LoD4	It indicates certainty in design. When such models are used in geo-VE human mind perceives such the design of the building identical to what will be constructed.

B. Planning phases against Visual Materials in geo-VE (in various LoD)

From Annex 7, question type B if one plots the highest values in against the planning phases the results in Table 38. In this case, the highest total value where the most people agreed upon is taken into consideration. These are the points, which have the most strength for deducing an opinion for the use of the visual materials on a certain planning phase. By looking at the results in Annex 8 question type B one can see that the total highest value is around 23 and the least is 1. An index can be made on how the survey population agreed by saying if 20 or more people agreed on the use of a visual material for a certain planning phase one can say that it has the "Strongest Pro Opinion" from the survey group. Total five classes are made as seen below. Each of these classes is given certain color intensity from light orange (meaning that the visual material 'Should not be used') to gradually light shades of blue until black (which mean 'Strongest pro opinion). Only the first three classes are considered.

Strongest Pro Opinion	20-
Strong Pro Opinion	15-19
Pro Opinion	11-14
Neutral to slightly positive	5-10
Should not be used	0-4

By plotting the highest value for each visual material from the line graphs in Chapter 7 (Annex 7) for each urban planning phase the following opinion chart can be generated.

Table38: The planning phases and visual materials of geo-VE

	Text, graph & image	Plan & map	Volumetric block model	Volumetric envelope model (with detail)	Detailed architectural envelope model	Detailed architectural model with interior
Visual Materials	**VM1**	**VM2**	**VM3**	**VM4**	**VM5**	**VM6**
Dimensionality	1D/2D	2D	2.5/3D	3D	3D	3D
Reality Axis	Lan/Sym	Sym	Iconic	Iconic-Index	Index-Verisimilar	Verisimilar
Photorealism					Yes	Yes
Level of Detail			LoD1	LoD2	LoD3	LoD4
Planning phases						
Land use &zoning plan	21	22	11	3	1	1
Structure plan	20	20	16	4		
Master plan	16	23	22	7	2	1
Regional plan	13	21	19	9	2	
Urban plan	14	18	17	18	4	
SpvE	11	14	15	9	4	3
Beeldkwaliteitsplan	12	8	11	17	15	
Architecture designs	9	7	5	17	21	17
Navigable landscape	10	8	6	13	20	15

Table 38 indicates that with the progression of the planning phases the use of visual materials in favor of 3D increases against 2D. It also indicates that there is a linear relationship with Levels of Details of visual materials with the planning phases. As the urban project phase reaches completion, the LoD to represent the visual material becomes more detailed.

C. Urban planning interaction and task against use of Visual Materials in geo-VE (in various LoD)

The method as mentioned in the previous table can be applied for the results in Annex 7 type C questions. The highest values are plotted in Table 39.

Strongest Pro Opinion	20-	By plotting the highest value for each visual material from the line graphs in Chapter 7 (Annex 7) for each urban planning phase the following opinion chart can be generated.
Strong Pro Opinion	15-19	
Pro Opinion	11-14	
Neutral to slightly positive	5-10	
Should not be used	0-4	

Table39: The urban planning interaction tasks and visual materials of geo-VE

	Text, graph & image	Plan & map	Volumetric block model	Volumetric envelope model (with detail)	Detailed architectural envelope model	Detailed architectural model with interior
Visual Materials	**VM1**	**VM2**	**VM3**	**VM4**	**VM5**	**VM6**
Dimensionality	1D/2D	2D	2.5/3D	3D	3D	3D
Reality Axis	Lan/Sym	Sym	Iconic	Iconic-Index	Index-Verisimilar	Verisimilar
Photorealism					Yes	Yes
Level of Detail			LoD1	LoD2	LoD3	LoD4
Planning phases						
Shade shadow analysis		3	15	16	6	
Volumetric analysis	3	10	20	9	1	1
Comparison present/ designed	7	11	8	20	20	12
Trigger misunderstanding	9	10	17	16	14	12
Information, navigation supportive	4	10	11	17	16	9
Most attractive for visualization	5	6	3	13	18	10

From Table 39 certain decisions can be deduced like:

- For shade shadow analysis most people argued for the use of LoD1 and LoD 2 models.
- For volumetric analysis 3D LoD1 block models are the best suitable
- 3D LoD2 Volumetric envelope model with details and photo-textured LoD3 models can show the difference between the present and designed situation
- 3D LoD1 block models triggers the most confusion
- 3D LoD2 Volumetric envelope model with details and photo-textured LoD3 models are information and navigation supportive.
- Photo-textured LoD3 models are the most attractive for visualization.

CONCLUSION
CHAPTER 8

8 Discussion and conclusion

8.1 Discussion on thesis

The thesis is about requirement analysis of geo-VE functionalities and visual materials. It has explored how digital media like geo-virtual environments can be used to support interaction between the actors involved in the urban design processes through interactive functionalities and multiple visual materials. While this has been done, the geo-VE functionalities and visual materials have been classified in taxonomic charts. The discussion will focus on the functionalities of the geo-VE and use the visual materials, the methodology that is applied, the four municipalities, the survey population and the impact on the results, the survey questionnaire design, etc. While doing so the thesis defends what is done, why it is done, which methodology and logical steps are taken, what knowledge is achieved, and what else could have been done in the whole process leading to new research fields.

Related to the 1st research question at least seven actors can be identified for interaction in urban and spatial planning. They are the urban and spatial planners, private design firms, *welstandscommissie*, housing agencies, the municipality, citizens and technical consultants. Regarding to the 2nd research question, the planning phases in the Netherlands constitutes to zoning plans (*bestemmingsplan*), master plan, urban plans, SPvE, architectonic quality plan (*beeldkwaliteitsplan)* and final architectural design.

Regarding the 3rd research question the thesis has defined six visual materials to represent the urban planning phases in geo-VE. On the basis of the 4th research question, the thesis has created fundamental knowledge on eight functionality domains of geo-VE functionalities from various aspects. These functionality domains are required by the municipalities to interact with the actors.

Regarding the 5th research question, how visual materials in various dimensionality, realism and LoD can represent the various planning phases have been identified. These results are listed as specification documents referring the methods to use visual materials for the planning phases. The thesis has proven that by increasing the dimensionality, realism and LoD of visual materials, the human cognition of design increases. It has also proven that in the initial design phases, text, images and 2D map and plans are of importance. When design is in a definitive stage, 3D LoD models can be used with gradual realism. The 6th research question is answered in Section 8.1.3.

A broader definition of visual materials for geo-VE to visualize urban objects and the taxonomy of these visual materials based on a wide variety of parameters, has created knowledge on the use of geo-VE as an interaction tool. The Dutch municipalities can use a specification list of required functionalities for the design and implementation of geo-VE.

8.1.1 Discussion on results: Functionality of geo-VE related

The functionalities of geo-VE in this thesis are sought out from the viewpoints of the Dutch municipalities and social housing agencies. The functionality domains that are identified are the construction, capabilities, experiencing, controlling, use (interactivity), exploring and finally the components. The context of these functionalities has been seen from the task they perform in interaction for urban planning and design. Most of the functionalities listed in the survey questionnaire are validated.

Findings on Construction

Various phases of urban planning should be represented in various LoD models. Using CityGML will allow the implementation of four LoD schemas for 3D models for this purpose. The database and infrastructure should probably be administered by the municipalities for implementing such geo-VE. The survey population accepted to download a software or plug-in. However a plug-in is preferred to downloading software to run the geo-VE. Open source solution is not yet widely accepted by the municipalities.

Findings on Capabilities
Urban development projects should be shown in various representation and different geometry models visualized in geo-VE. The geo-VE should have the capacity to show comparison. Such environments should allow user collaboration. Such collaboration is possible by adding feedback functionalities. The methods of feedback can be chat, leave a message, email, vote, etc. Geo-VE should show animation and simulation of events and for spatial analysis.

Findings on Experiencing
Passive experience lets the user move, navigate and orient in the geo-VE. Orientation is enhanced if landmarks, north-sign, highlighted objects, etc are used. Mental immersion is important factor for the usability of geo-VE.

Findings on Controlling
Desktop VR with keyboard and mouse control is the most feasible for the mass public. The geo-VE should let the user click and select objects and demand more information on the selected objects.

Findings on Use (interactivity)
The geo-VE should not allow existing areas of the city be deleted without permission. However for new design areas it is important the users are able to modify the models, play with blocks, and change colors to express their wishes through the Internet. The geo-VE should allow the users to import their own models temporarily. Such systems can have basic AR like webcam on the construction sites, RSS feed on traffic, weather etc. The user should preferably be using avatars when interacting with 2D/3D objects.

Findings on Exploration
The geo-VE should let the user search properties of objects in the 3D scene. It can be used to query geometry and attribute information. Important landmarks, building projects, etc should have external links and windows for more elaborative information on the projects. Synchronized windows showing global 2D information should be included with detailed 3D models.

Findings on Components
The geo-VE can have a login interface. In order to movement between points, teleportation tool should be present. The important landmarks and new design areas should contain labels that can be turned on/off according to user demand. X-ray vision to look into buildings to minimize occlusion is rejected overwhelmingly by the survey population, but the researcher's personal opinion is this should be present. The 2D/3D data should be geo-referenced and have high quality.

However, there are functionalities that are not included in the thesis. Functionalities that are left unexplored at this stage are different database solutions, AR and VR accessories like CAVE, BOOM, hand-gloves, touch-screen discussion tables etc. The comparison of different modelling techniques has been not a major topic for this thesis. Spatial analysis has not been included in this thesis. The goal of the thesis is to identify the functionalities of geo-VE for interaction with mass public in a large-scale. Taking into consideration the number of computers and Internet connection in the Netherlands, web-based desktop VR can reach out to a wider range of viewers. It is not easily possible through CAVE, BOOM, head-mounted display, large screens, gloves, touch screens, etc. Therefore, such VR accessories are not directly relevant for this thesis. Only the 3D scenes are investigated; the hepatic, aural etc properties are not investigated.

8.1.2 Discussion on results: Visual materials of geo-VE related

This thesis can conclude that there are strong results on the human perception of visual materials in geo-VE. It has found that only textual, graphical and images are not enough to represent building projects. The 2D plan and maps can gives the viewer pretty good image how the design should be. On the contrary, LoD1 models only represent a very draft stage of the design process. The perceiver while viewing LoD1 models has the impression that the project is nothing but a draft. The increase of LoD and photorealism increases the human ability to understand the design. When verisimilar photo-textured LoD 3 models are used the viewer gets the impression that the final result will be similar to that of the visual material.

The findings of the human perception and visual materials have serious implication when interactions are done with visual materials. It means, the initial phase of design if photo-textured LoD3 models are used the viewer will get an impression that the design is already finalized and have high expectations. If in the finalized version of the design LoD iconic block models are used, the viewer will be confused that the design is not complete. The findings suggest that care should be taken to interact through visual materials if knowledge needs to be transferred. It might give a wrong impression to the perceiver if a wrong representation model is used for a certain planning stage.

For the planning phases there have been clear results as well. The thesis can declare that with the progress of the planning phases the importance of 1D against 2D and 2D against 3D decreases. This means that when the in the initial planning phases the design is more likely to be visualized in text and 2D maps and when there is more certainty the necessity of 3D increases. It has also proven that for geo-visualization of large-scale thematic plans like *bestemmingsplan* and land-use plans are symbolic 2D maps, text and reference images are necessary. In the master plan, urban plan and SpvE phase, the use of 3D iconic block models and 2D plan and map are effective manner to visualize information in geo-VE. In the case of *beeldkwaliteitsplan*, the need of 3D LoD2 volumetric envelope models and photo-textured LoD 3 models are of interest to show the various design options. When urban design meets architecture or when the design is implemented the method of representation is verisimilar photo-textured LoD3 and verisimilar LoD4 models

For shade shadow analysis, the 3D iconic LoD1 block models and iconic LoD2 volumetric envelope models with details are the best method for representation. For volumetric analysis the 3D iconic LoD1 block models are the most suitable. The 3D Lod2 and verisimilar photo-textured LoD3 detailed architectural models are the best suitable to visualize the difference between the present situation and the designed situation. For visualization verisimilar photo-textured LoD3 detailed architectural models are the most attractive for visualization. These models are also informative and navigation and orientation supportive.

The 3D model in this thesis is based on the classification of LoD as described in CityGML. There are however, other kinds of representation of modelling. Levels of detail can be also pixel based. It means that the higher LoD models would be created by higher number of pixels (or voxels). But the aspects of pixel representation of 2D map and 3D models are not investigated in this thesis. This thesis has mostly tried to represent the vector models and raster 3D models are omitted.

8.1.3 Discussion on the four geo-VEs used in the thesis

From the discussion it becomes clear that each of the VR viewers have their strength and weaknesses. The biggest weakness of implementing an X3D based Bitmanagement plug-in (BS Contact) viewer for the mass public is that the municipalities have to build their own interfaces. It is technically possible to add functionalities for interaction but they have to be built by the municipalities. This is a laborious and expensive task. The biggest advantage it is open source and lots of support is available for free on the Internet.

LandXplorer is a professional data mining and exploration tool rather than a real visualization tool. But it can dynamically visualize information and disseminate attribute information. In this sense this is a very powerful viewer for real data exploration and scientific visualization. This is probably not the best viewer for dissemination for the mass public.

Google Earth allows a wide range of functionalities that are discussed in this thesis. But it is proprietary software and no alternation can be done to the software. The biggest advantage of Google Earth is its popularity. Most people who have a computer have used the software to look at his/her backyard. Another advantage of Google Earth is the huge amount of geo-referenced satellite images and the Google's 3D warehouse where people can download geo-referenced 3D models. One can add own models, delete, them, see different design solutions and add maps as underlying background to make analysis. But Google Earth doesn't allow collaborative chatting or voting functionality for urban projects. It cannot visualize interior and underground objects.

The strength of Google Earth is that it lets the user to interact in a democratic and freely downloadable viewer with enormous amount of geo-data. This makes Google Earth a very feasible visualization tool for the Dutch municipalities to disseminate 3D models and plans for the general public. This VR can be used to give an overall external view of the designed areas. Google earth can visualize volumetric block models (LoD1), volumetric envelope models with details (LoD2), textured architectural models (LoD3). Therefore most of the design phases discussed in this thesis can be visualized in Google Earth. It is a good choice when the design is visualized in elevated oblique camera view to give an overall view of the designed area.

VirtuoCity are based on GIS footprint data that are combined with AHN height information. The models are worked out in 3D Max to texture them with Cyclomedia images. The end results are realistic and interactive city models. Most of the needed functionalities discussed in this thesis are fulfilled in the Virtuosity software. But however, the researcher would like to point out a few missing features. The search option in VirtuoCity none but exists. VirtuoCity doesn't let the user see the models from an axonometric view or elevated oblique camera view. This view lets the user get an overall picture of the whole area. Only eye-level experience is possible in this software. However the interactivity through chatting, email and the online forum is a very positive approach.

Virtuosity lets the user see in 2D in which part of the city he/she is roaming in 2D plan view. The viewer has intelligent objects to guide the user through newly designed areas. It contains clickable external windows where the design projects are elaborated and explained. The intelligent objects explain design orally. It can visualize also the interior of the new designs. It can visualize LoD1 to LoD4 models from iconic to realistic verisimilar models and therefore can be used for most of the Dutch urban planning phases. This is a definitive good choice for the Dutch municipalities to implement their virtual cities for interaction with the general public. The only disadvantage is that it leads the municipalities away from open source solutions. But the functionalities that the software offers are too complicated and costly to be developed by each of the municipalities individually. Most people from the municipalities and housing agencies said that Google Earth and VirtuoCity are the two VR software they heard of and have used in the past.

Thus for interaction of urban planning phases, the thesis recommends two viewer for the Dutch municipalities and they are Google Earth and Cebra's VirtuoCity. The first one can be used for the overall view of any design and the lateral can be used for collaborative interaction based on human-eye level.

8.1.4 Discussion on methodology applied through Requirement Engineering

The thesis has been conducted using the Requirement Engineering (RE) process. Requirements of software can be extracted using RE. Applying RE allowed the thesis to follow a systematic number of activities in a disciplined process through elicitation, analysis and validation survey questionnaire, validation, documentation and finally making specification documents.

The concept of the RE approach is that 'context of use' or system analysis of the software is highlighted. To achieve this, the researcher firstly has identified why the functionality is needed. The functionality should perform a task or a purpose and this led the researcher to investigate, which tasks are needed in visual interaction in urban planning between actors at the Dutch municipalities. The elicitation phase helped the researcher to successfully extract the functionality and document them. In the analysis part broad discussions were held with the end users at the municipalities. The discussion is called negotiation. The negotiation of the functionalities helped the end user get clear ideas on geo-VE. It has lead to the creation of not-out-of range validation questionnaires. In this process the researcher has observed what is needed from the system by conducting interviews and surveys. This purpose led to the ethnographical study (mentioned as ethnography in RE) to observe the process of urban design and planning in the Netherlands and visual interaction by new digital media. The RE ethnographical study gave the researcher time to understand the users, the planning phases, datasets, software, etc. The modelling technique used in this thesis can be used by the municipalities for creating virtual city models.

One of the biggest failures of software implementation and design is due to the neglect of the elicitation phase. As the end users were not directly aware of the functionalities of geo-VE, the extensive literature study fulfilled this gap. The elicitation phase produced the functionality chart that can be seen one of the milestones of this thesis. Due to time constraints the thesis followed a linear iterative RE model. In this process the activities are clearly separate from each other. Each of the activities is seen as an input for the next activity. Pure iterative RE models are used in projects with longer time-span and where there is over-lapping in activities.

The analysis phase was a success due to the participation of the end users in the classification of the negotiated and validated functionalities. The validation results are also in accordance to the expectation. The specification documents show the summary of the results in a short but clear manner. Looking at the activities and the systematic linear path it followed to achieve results, it can be said that the application of RE in this thesis has been a success. It helped to thesis have structure and well-defined borders in activities. It has successfully list the functionality domain of geo-VE in taxonomic charts. But following the linear iterative RE did not prevent the researcher being flexible and opportunistic. Sporadic simplification and alternation has been successfully applied in the methodology.

Prioritization of the functionalities is necessary when they are identified. The MoSCoW method comes from the Dynamic Systems Development Method (DSDM ®) and is a very successful method for prioritization. Prioritization here in this thesis is necessary as it shows the functionalities that the end users thought that the system must or should have according to importance. It helped to understand which functionalities are more valuable for geo-VE.

The validation questionnaire survey 1 is designed in a way that the each statement begins from the point of view of the VR systems like 'System should have…. '. This was chosen in a compromise state not using strong words like 'System must have…'. The reason for this it that it is assumed the questionnaire should give an idea of freedom for the surveyed population. Such decisions are taken when the statements are designed in accordance with the municipalities. Changing wording on the validation questionnaire probably will change the results of the results in the positive manner. But this bias was taken out. The words 'System should have..' can be seen more neutral and therefore this was preferred.

The 'Survey 1' questionnaire is long for the users to answer. But for such a vast subject of geo-VE functionalities, it was not really possible to make the number of questions fewer. The 'Survey 2' questionnaire could have been better designed by the separation of textual information and graphs/images to form one visual material. But this can be acceptable as text, graphs and images can be considered as the graphical part of the visual materials separated from the models. Multi-resolution maps are not used in the survey 2, which can be an improvement for further study.

8.1.5 Discussion of the Survey population

A total of 30 people took part in this thesis. In terms of requirement engineering process model, this figure can be considered a large number. Therefore, the results that are presented in this thesis can be considered as statistical results. The points where the most people (>15) agreed on a certain decision cannot be seen as random but objective opinion of the survey population.

From raw data however a trend is noticed in relation to the profession. Most of the people who participated in the field survey and workshop are related to design, construction and management of large-scale urban projects. The majority of them were urban planners. The urban planners are most of the time unaware of the trends and discoveries in the GIS and 3D modelling. Many of them did not know about CityGML, VRML, X3D etc. During the workshop a few complained that the subject was too technical for them to understand. This has not been an issue with GIS experts and database managers.

A trend can be noticed on the kinds of functionalities validated by the officials from the municipalities compared to the housing agencies. The housing agencies were more flexible to letting the citizens have interactive use functionalities like deleting and modifying objects. The housing agencies were however reluctant to add their 2D/3D models where the users can download them from an open interface. While the municipalities are interested to let the housing agencies add their spatial information on the geo-VE, the housing agencies overwhelmingly refused share spatial information in an open interface.

There can be some slight differences noticed between the final results of this thesis after the workshop compared to that of the field survey for Survey 1. For the construction functionalities there were more people who answered 'Don't know' for issues like location of datasets, database, types of interfaces and open source solutions. Many people in the workshop had no technical background and they were unable to give appropriate answers on this topic.

In most cases there has not been any drastic difference in results noticed between the field survey and workshop. But the workshop increased the intensity of the results. This means statements that are already validated and rejected are strongly validated or rejected respectively during the workshop. The same can be said for the use of visual materials for Survey 2. In most cases the workshop only increased the intensity of the results what were already achieved in the field survey. When the questionnaires were designed the researcher expected a certain trend of results. The results of both the field survey and workshop did not deviate far from this expectation. The researcher can say that the workshop helped to acquire statistical results compared to a trend that is noticed in the field survey.

The functionalities for geo-VE needed for interaction with citizens are seen in this thesis through the viewpoint of design professionals. It has been a difficult task to make professional actors learn about the functionalities. Due to time constraints real citizens did not participate in this thesis. The researcher expects that the thesis results will change slightly if citizens are included the validation process of Survey 1. The citizens are very demanding in terms of information access and they will not be satisfied that for instance that the authorities can hide and censor information. Citizens would probably want to copy, save and email models, etc. In case of Survey 2, the citizens are not really aware of the different planning phases and it would be quite unrealistic to expect that citizens will be able to answer which kind of visual materials is best suitable to represent urban objects in the geo-VE.

8.1.6 Discussion on the participating municipalities (interview, field-survey)

The municipalities in this thesis are carefully selected. The municipality of Rotterdam comprises to be the second biggest municipality in terms of population (584.356 in 2007). Den Haag is the third biggest municipality of the Netherlands. Delft is midsized municipality. Municipality of Rotterdam has vast experience in geo-data and spatial planning and has been working to create a virtual city model. The other municipalities showed interest for the use of geo-VE as an interaction tool. Rotterdam municipality has provided valuable information and participated actively in most aspects of this thesis. Municipality of Den Haag and Delft were already involved in SUA projects and they had been interviewed in 2006 and 2007 by the SUA-group. They have vital interest to interact. The last study group at the municipality of Oldebroek gave insight on the visual interaction process in small municipalities for the Netherlands. Oldebroek is at the present moment busy with the restructuring the city centre and interaction with the citizens is relevant issue for the municipality.

Geographically, three municipalities are in the province of *Zuid Holland* with densely populated areas where there are lots of large-scale projects and urban renewal taking place. The municipality of Rotterdam is in many cases unorthodox in the search for new media for communicating ideas to actors in urban development projects. The other three municipalities proved to be using more traditional methods like *gespreksavond*, websites, etc. Den Haag has some interactive web maps for new urban areas.

Interviewing the four municipalities identified the actors, the planning phases, the types of data, software etc. The information gathered from large municipalities like Rotterdam and Den Haag are applicable for the whole of the Netherlands. Such information has helped to formulate the validation questionnaires. The identification of actors, planning phases, data sets etc, will not be changed if the survey municipality changed and a new municipality like Maastricht or Helmond is incorporated. The results on the functionalities of geo-VE are dependent if a certain municipality thinks that such mediums are necessary for interaction. There is trend noticed during the interviews at the municipality of Delft that the urban planners are reluctant to consult the design in all the phases. This can lead to take less collaborative approach when geo-VE.

At the workshop municipality of *Amsterdam, Rotterdam, Groningen, Landgraaf,* etc participated and the overall ideas that were discussed that the researcher had were not very different from the initial ideas from the four municipalities (*Rotterdam, Den Haag, Delft and Oldebroek*) of the field survey. The municipality of Tilburg was consulted on the issue of '*Virtueel Tilburg*' and they had very positive remarks on behalf of using geo-VE as an interaction and communication medium. Therefore, the researcher is optimistic that given that the municipalities are open for dialogue with external actors for urban projects, the results of this thesis will not be largely affected by the change of the surveyed municipalities. By taking a random comparison between Delft and Rotterdam based on Survey 1 and Survey 2, the researcher observes that there is no significant difference in the overall results. The choice of a hierarchy of a two large municipalities, one midsized municipality and very small municipality is representative for the state of collaborative planning through geo-VE in the Netherlands.

8.2 Concluding remarks and future approaches

A fool may ask more questions in an hour than a wise man can answer in seven years.
English Proverb

The thesis has come to the end through rational, scientific discussion and findings and it is necessary to list the added value of the research. The thesis has been all about the classification of requirements for geo-VE on the basis of visualization. This has been successfully implemented through the functionality chart. The thesis has contributed in identifying the various functionality domains of geo-VE, applied a hypothesis and proven with Requirement Engineering that these functionalities are needed for visual interaction. It has identified seven actors in the urban and spatial planning process in the Netherlands and listed the requirements to interact with actors for collaborative planning practices. The functionality domains that are used in the taxonomic chart include the construction, capabilities, experiencing, controlling, use (interactivity), exploring and the components of geo-VE. In Table 20, the relationship between these functionalities has been identified.

This thesis has defined six visual materials of geo-VE. In this regards the thesis has proven that the increase of realism, LoD and dimensionality increases the user perception of understanding design. The thesis has listed the types of visual materials that are best suitable for representing urban planning phases. It has been proven that when the planning phases progress in time, the dimensionality, realism and LoD in various interaction models increases incrementally. In the initial planning phases like zoning plans (*bestemmingsplan*), land-use plans, structure plan, etc 2D plan and map are best suitable for visualization. Zoning plans can be also in 3D showing height restrictions. In the master plan and urban plan the importance of 3D increases. Usually LoD1 and LoD2 models are best suitable to visualize such plans alongside 2D map and plan. In the lateral phases like architectonic quality plan (*beeldkwaliteitsplan*) LoD2 and LoD3 can be used. Finalized design is best suitable to be visualized in LoD 3 models. It has proved that LoD1 models create the most confusion when they are used in design communication. LoD3 and LoD4 models the most efficient to show the difference between designed and present situation.

The thesis has identified a process to create base models for the Dutch municipalities using widely used GIS software (ArcGIS) using geo-data. And finally, it has compared the implementation of four geo-VE for the Dutch municipalities and come to conclusion that VirtuoCity and Google Earth are the best suitable for collaboration and interaction in the planning process for the Netherlands. In the future, the importance of MSN VE 3D will probably increase. There are new frontiers that have been opened while conducting this thesis. There are future research topics that can be identified as follows:

Application approach

With the launching of various geo-VE there is a need to investigate if they really effective in increasing interaction. The topic is related to the technical advances in VR and AR for user interaction.

Cognitive approach

Due to time and scope constraints, the multi-resolution 2D map and plan are not investigated. It will be interesting to find out how does user interacts through the visualization of different detailed cognitive 2D maps?

On track approach

Re-applying this GIMA research from the perspective of the general public can be a topic of research. How can geo-VE be used to create knowledge in collaborative spatial planning process?

Evaluative approach

There can be research to measure and evaluate the usability of geo-VE for collaborative planning process. Another approach can be to evaluate geo-VE on Human Computer Interaction (HCI) meaning to test how effective can geo-VE lead human beings to conduct design tasks.

References

Al-Kodmany, K. (2001), "Supporting imageability on the World Wide Web: Lynch's five elements of the city in community planning." Environmental and Planning B: Planning and Design 28, pp 805-832

Bachelard Gaston (1958), "La poetique de L'Espace", translated as "The Poetics of Space" by Orion, 1964, Republished by Beacon Press, Massachusetts 1994

Batty M., Dodge M., Doyle S., Smith A., (1998) "Modelling Virtual Urban Environments", Centre for Advanced Spatial Analysis, University College London, ISSN 1467-1298

Batty M, Dodge M, Jiang B, Smith A, (2000), "New technologies for Urban designers: the VENUE Project", ISSN:1467-1298, CASA, UCL, Last accessed on the 15th of August 2007 at http://www.casa.ucl.ac.uk/venue.pdf.

Batty M. & Smith A., (2002), "Virtuality and Cities: Definitions, Geographies, Designs", published in "Virtual Reality in Geography, edited by Peter Fisher & David Unwin, page 270-293, 2002 Published by Taylor and Francis Inc, New York.

Batty M et al, (2007), "Modeling Cities", Centre for Advanced Spatial Analysis, University College London, Paper 113 - Feb 07 ISSN 1467-1298

Bertin J. (1983), "Semiology of graphics" University of Wisconsin Press, Publication: 1983, ISBN:0299090604

Berger, John, (1972), "Ways of Seeing", BBC/Penguin Books, London

Billinghurst, M., Weghorst S. and Furness T., (1996), "Shared space: an augmented reality interface for computer supported collaborative work". In: Proceedings of collaborative virtual environments '96

Bodum, L., (2005), "Representing Virtual environments in Geovisualization", In Exploring Geovisualization, (Red., MacEachren, A. m.fl.) Elseviers, Amsterdam, In Press

Bodum L. & Niels J, (2005), "Modelling Virtual Envrioments for Geo-visualization: A focus on representation", in "Exploring Geo-visualization", 2005, Elsevier Publishers: Amsterdam, pp 389-400

Bourdakis, V. (1997), 'Virtual Reality: A Communication Tool for Urban Planning' In "CAAD-Towards New Design Conventions" A. Asanowicz and A. Jakimowitz (eds) Technical University of Bialystok, pp.45-59 ISBN 83-86272-63-5.

Camillo S., (1965), "City Planning According to Artistic Principles", Translated from the German by George R. Collins, and Christiane Crasemann Collins. Columbia University Studies in Art, History and Archaeology, no.2, New York: Random House.

CityGML (2007), from Dr. Kolbe Official website from CityGML at http://www.citygml.org/

Coley Consulting (2007) UK based Management Consulting firm at http://www.coleyconsulting.co.uk/

COLLADA, (2007) at http://www.collada.org/mediawiki/index.php/Main_Page

Dalal, B and Dent David (1993), "Sustainable Development Strategies: A Resource Book", Environmental Planning Issues No. 1 Barry Dalal-Clayton 1993, 14pp ISBN 1 84369 205 8, Barry Dalal-Clayton and David Dent 1993, 153pp ISBN 1 84369 203 1

Davis S. B., (1996), The Design of Virtual Environments with particular reference to VRML, Centre for Electronic Arts, Middlesex University.

Danahy, J. (1997), 'A set of Visualization Data Needs in Urban Environmental Planning & Design for Photogrammetric Data', Monte Verita Workshop, Verslag, Basel.75

Davies C., (2004), "Virtual Space, In Space: In Science, Art and Society", François Penz, Gregory Radick and Robert Howell, eds. Cambridge, England: Cambridge University Press (2004) pp. 69-104, illus.

De Vries B., Achten H.H. (1998), "What offers Virtual Reality to the designer", Proceedings of the Int. Conf. on Integrated Design & Process Technology, Berlin, Germany, July 6-9, 1998.

Dykes, J., MacEacheren A. M., and Kraak M. J. (2005), "Exploring Geovisualization". Amsterdam: Elsevier Publishers, 2005

Ervin, S. (1992), "Intra-Medium and Inter-Media Constraints", In G. Schmitt (ed.), CAAD Futures '91, Branuschweig: Vieweg, pp.365-380.

Etien Luc Koua, (2005), "Computational and Visual Support for Exploratory Geovisualization and Knowledge Construction", Phd Thesis, Utrecht University, ISBN 90-6164-229-9 page 65

Felix N. (1995), "Analysis of spatial representation from traditional techniques to computer graphics", PhD Thesis, Strathclyde University, Glasgow, UK.

Fenier, S., MacIntyre, B., Hollerer, T., and Webster, A., (1997), "A touring machine: Prototyping 3D mobile augmented reality systems for exploring urban environment". Proceedings First International Symposium on Wearable Computers, Cambridge, Massachusetts, 74-81.

Ferriès B & Léglise M. (2007), "Frictions Between Heterogeneous Worlds", École Nationale Supérieure d'architecture de Toulouse Published in ACE (Architecture, City and Enviroenment, ACE© Vol.2,Nr 4, June 2007.

Fisher P., and Unwin D. (2002), "Virtual Reality in Geography", edited by Peter Fisher & David Unwin, 2002 Published by Taylor and Francis Inc, New York

Gaborit N.,Howard T., (2004), "A Collaborative Virtual environment for Public Consultation in the Urban Planning Process," tpcg, pp. 104-111, Theory and Practice of Computer Graphics 2004 (TPCG'04).

Goguen J.A., (1996), "Formality and Informality in Requirements Engineering. Proceedings, Fourth International Conference on Requirements Engineering", Los Alamitos, California: IEEE Computer Society Press, 1996.

Haklay E. Mordechay. (2002), "Virtual Reality and GIS: Application, trends and directions.", published in "Virtual Reality in Geography, edited by Peter Fisher & David Unwin , 2002 Published by Taylor and Francis, New York, pp 47-58

Heim, M. (1998), "Virtual Realism". New York, New York: Oxford. pp. 162-167, 171, illus found at http://www.immersence.com

Hix, Deborah and Hartson, H. Rex (1993), "Developing user interfaces: Ensuring Usability Through Product and Process", John Wile & Sons, UK

Hoogerwerf et al., (2006), "Three-Dimensional Geo-visualization for Spatial Planning: Towards a Conceptual Framework", Published by Wagenigen University.

Houdek, F. and Pohl, K. (2000), "Analyzing requirements engineering processes: a case study", Proceedings of the 11th International Workshop on Database and Expert Systems Applications, Greenwich, UK, 6-8 September, pp.983-987.

Kibria M.S. and van Asperen P. (2007), 'Comparing 3D-Earth Viewers, Google Earth, MSN Virtual Earth 3D and NASA's World Wind' . Only the OGC WMS portion is partially published in GIM

International, November, 2007 at http://www.gim-international.com/issues/articles/id1009-Comparing_DEarth_Viewers.html

Kirchenbauer, S. (2005), "Applying True 3D techniques to geo-visualization: an empirical study", in "Exploring Geo-visualization", 2005, Elsevier Publishers, pp 363-388

Kotonya, G. and Sommerville, I. (1998), "Requirements Engineering – Processes and Techniques", John Wiley & Sons, UK.

Kraak, M.-J. (1988), "Computer-assisted Cartographical Three-dimensional Imaging Techniques". Delft, The Netherlands: Delft University Press.

Kraak Menno-Jan, (2002), "Visual exploration of virtual environments" published in "Virtual Reality in Geography, edited by Peter Fisher & David Unwin, 2002 Published by Taylor and Francis Inc, New York

Lammeren R. van, Hoogerwerf T. (2003), "Geo-Virtual Reality and participatory planning", Virtual Landscape position paper, Alterra, Wageningen University, Centrum voor Geo-Informatie, CGI Report 2003-07 ISSN 1568-1874

Loucopoulos, P., and Karakostas, V. (1995), "System Requirements Engineering", McGraw-Hill Book Company Europe.

Lowe, D. and Eklund, J. (2001), "Development Issues in Specification of Web Systems", 6th Australian Workshop on Requirements Engineering, 22-23 November, University of New South Wales, Sydney, Australia.

Lynch, Kevin (1960). The image of the city. 194 p. MIT Press, Cambridge MA.

Lynch, K. and G. Hack (1984), Site Planning, MIT Press, London, UK.

MacEachren, A.M., Edsall, R., Haug, D., Baxter, R., Otto, G., Masters, R., Fuhrman, S., and Qian, L. (1999), "Exploring the potential of virtual environments for geographic visualization" http://www.geovista.psu.edu/publications/aag99vr/fullpaper.htm opened 12/10/07

MacEachren, A. M., and Kraak, M.-J. (2001) Research Challenges in Geovisualization. Cartography and Geographic Information Science 28 (1):3-12.

Macaulay, L. A. (1996), "Requirements Engineering", Springer-Verlag

Martin S., Aurum A., Jeffery R., Paech B., (2002), "Requirements Engineering Process Models in Practice", AWRE'2002, pp 141-153

McCloud, S., (1993), "Understanding Comics", Kitchen Sink Press, 1993.

Morgan & Morrison, M. (1999), 'Models as autonomous agents', in M. S. Morgan and M. Morrison (Editors), Models as Mediators: Perspectives on Natural and Social Sciences, Cambridge, UK, Cambridge University Press, 38-65.

Nielsen Anette, (2004), "User Centred 3D Geo-visualization", Scientific Paper, Center for 3D Geo-information, Alborg University, Denmark. Published in Geoinformatics 2004

Nielsen Jakob (1993), "Usability Engineering", Academic Press, New York (1993)

Pape D, (1998), "Crayoland", SIGGRAPH Video Review, Issue 127/SIGGRAPH,98, Electronics Arts and Animation Catalog CD-ROM, Orlando, Florida.

Pietsch, S. (2000), Computer visualization in the design control of urban environments: a literature review, Environment and Planning, B, v27,pp 521-536

Reeve D. and Petch J. (1999), " GIS Organization and People: A Socio-Technical Approach), Taylor and Francis 1999.

Riedijk A., R. J van de Velde, T.C. Hoogerwerf, R.J.A. van Lameren, et al, (2006), "Virtual Netherlands, Geo-visualization for interactive spatial planning and decision making: From Wow to Impact", Definition study, Vrije Universiteit , Amsterdam.

Rockwell, B. (1997), "From Chat to Civilization: The Evolution of Online Communities", in IMAGINA' 97, Monaco, INA, 1997.

Singh, R.R., (1999), "Sketching the city: a GIS-based approach". Environ. Planning. B: Planning. Design 26, pp. 455–468. View Record in Scopus | Cited By in Scopus

Sherman W. R. & Craig A. B. (2003), "Understanding Virtual Reality: Interface, Application & Design", Morgan Kaufmann Publishers, imprint of Elsevier Science, California, USA, ISBN 1-55860-353-0 pp201-280

Sneiderman, B. (1998), "Designing the User Interface: Strategies for Effective Human-computer Interaction", 3rd Edition, Reading MA., Addison Wesley Longman, Inc.

Tufte E. R. (1997), Visual Explanations: Images and Quantities, Evidence and Narrative.

Van Dorst M., (2005), "Een duurzaam leefbare woonomgeving", Thesis, TUDelft, ISBN 90-597-2075-x, www.eburon.nl

Verbree, E., van Maren, G., Germs, R., Jansen, F. and Kraak, M.-J. (1999), "Interaction in virtual world views – Linking 3D GIS with VR". International Journal of Geographical Information Science, 13, 4, 385-96

Wachowicz, M., et al. (2002), GeoVR construction and use: The seven factors. in 5th AGILE CONFERENCE on Geographic Information Science. 2002. Palma (Mallorca, Spain).

Witmer, B.G. and Singer, M.J. (1998), "Measuring pressure in virtual environments: A presence questionaire. Presence"
7(3): pp 227.

Whyte, J. (2002), Virtual Reality and the Built Environment, Published by Oxford: Architectural Press, ISBN-10: 0750653728, September 24, 2002

Zlatanova S., van Dorst M., Itard L, (2007), "The role of visual information in design tools for urban renewal", ENHR 2007 International Conference 'Sustainable Urban Areas', Rotterdam last opened on 11/10/2007 at http://www.gdmc.nl/publications/2007/

Yates Frances, (1966) "The Art of Memory" published by Routlege & Kegan Paul

Reference books

Virtual reality in geography by Peter Fisher and David Unwin, Published by Taylor & Francis, New York, First edition, November 22, 2001.

Exploring Geo-visualization by J. Dykes, A.M. MacEachren, and M.-J. Kraak, Published by Elsevier Publishers, Amsterdam, The Netherlands, February 2005.

Designing the User Interface: Strategies for Effective Human-computer Interaction by Ben Sneiderman, Published by Addison-Wesley Publishing Company, MA, USA, Third Edition July 15, 1997.

Understanding Virtual Reality: Interface, Application & Design, Published by Morgan Kaufmann Publishers, imprint of Elsevier Science, California, USA, ISBN 1-55860-353-0, 2003.

Websites

	Google Earth
	http://earth.google.com/intl/en/
	Second Life
	http://secondlife.com/
	Virtueel Tilburg
	http://www.virtueeltilburg.nl/
	Virtueel Apeldoorn
	http://www.virtueelapeldoorn.nl/
	Virtueel Helmond
	http://www.virtueelhelmond.nl/
	MSN Virtual Earth
	https://maps.live.com
	Alpha World
	http://www.activeworlds.com/worlds/alphaworld/
	Virtual TUDelft
	http://virtual.tudelft.nl/virtueel.html
	Virtuocity CEBRA BV.
	http://www.cebra.eu/
	Web3D Consortium (X3D specification)
	http://www.web3d.org/x3d/specifications/x3d_specification.html
	Berlin CityGML
	http://www.3d-stadtmodell-berlin.de/online/3d/seite0.jsp
	Osmose and Ephemere Virtual Space
	http://www.immersence.com/index.html
	Online Virtual World “There”
	www.there.com
	Stanford Bunny
	http://www.cc.gatech.edu/~turk/bunny/bunny.html
	KML Specification 2.2
	http://code.google.com/apis/kml/documentation/kml_tags_beta1.html
	CityGML Specification
	http://www.citygml.org/
	Virtual Ljubljana
	http://www.logon.si/nmlj/nmlj-us.html
	Collada Specification
	http://www.collada.org/mediawiki/index.php/Main_Page
	AHN
	http://www.ahn.nl/gebruikersdag/gebruikersdag_2007.php
	Cebra BV
	http://www.cebra.eu/
	SketchUp
	http://www.sketchup.com/
	Bitmanagement plug-in from BSContact
	http://www.bitmanagement.com/