GeoVEs as tools to communicate in Urban Projects: requirements for functionality and visualisation

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Abstract

Urban planning is a complex decision-making process involving a large number of actors who interact intensively. Such groups often have conflicting expectations and backgrounds. Therefore, consultation and interaction is vital for the success of urban projects. A Geo-Virtual Environment (geoVE) can play an important role as a communication tool in the field of spatial planning, but such tools are still in limited use. We investigate the requirements for visualization in urban planning by analyzing user perceptions of visual materials and their needs for interaction in the different urban phases. The study is completed with the cooperation of several large municipalities in the Netherlands.

1 Introduction

Urban planning is the process of shaping and organizing the real world. Lynch & Hack (1984) define it as follows: 'Urban planning is concerned with assembling and shaping the urban- i.e., local or municipal- environment by deciding about the composition.' Urban design acts as the interface process of design between urban planning and architecture dealing with shape and form of the geographical urban objects and the quality of the created space. Several researchers have studied how 3D visualization can be used in design processes (Camillo 1965, Al-Kodmany 2001, Whyte 2002) through the use of hand-drawn sketches, 3D CAD, GIS and VR. In urban planning, virtual 3D models can be used to visualize a designed area in the context of the existing situation to estimate the impact of planned changes. 3D models in geo-virtual environments (geoVEs) can be used as interaction tools for the designers to communicate new ideas to involved actors and to minimize misunderstanding.

This paper presents our study on the use of geoVEs in the different phases of urban planning. Section 2 presents the taxonomy of visualization materials and functionalities of interest for urban planning. Section 3 presents the case study and discusses the methodology. Section 4 analyses the results and draws logical conclusion on visualization requirements for urban planning. Section 5 compares several geoVEs that might be of interest for municipalities in performing urban tasks. Section 6 summarises the most important findings.

2 Taxonomy of geoVE functionalities & visualization materials for interaction in urban planning

A Geo-Virtual Environment is broadly defined as a spatially referenced digital world that comprises visual (and non-visual) objects in an immersive and interactive 3D scene to represent and mimic reality through dynamic real-time simulation. Zlatanova *et al.* (2007) mention that 3D VR models provide flexibility in interaction and exploration. These models include active and passive interaction functionalities for users.

2.1 Functionalities of geoVE

There have been several attempts to define the functionalities of geoVEs. Heim (1998) defined the so-called I-factors of Immersion, Interactivity and Information Intensity (or Levels of Detail, LoD). MacEachren *et al.* (1999) added the I-factor of Intelligence (of Objects). Wachowicz (2002) and Lammeren & Hogerwerf (2003) tried to extend this classification. Adopting some of these developments, we introduce a classification of geoVEs for urban planning with respect to *construction, capabilities, experience, controlling, interacting, exploring* and *components.*

Construction: This functionality refers to the system architecture of a geoVE and the type of data used to build a 3D scene. The construction of the 3D scene is inseparable from the scale and resolution of the 3D data. These are often defined as Levels of Details (LoD). In urban planning, LoD can also be used to create different 'visual materials' (see Section 2.2). Different types of data can be integrated in a 3D scene through a data-fusion. The data for the 3D scene can be stored in Relational Database Management Systems (RDBMS) or other databases and visualized 'on-the-fly' in the geoVE.

Capabilities: The capability domain consists of functionalities related to the interface of the geoVE; it enables users to interact with the interface, 3D models and attribute information. The foremost capability of the geoVE is representation and rendering capability. Visual representation deals with visual contents like color, texture, shape, rendering and geometry.

The same model can be visualized in various representations, by changing the line types, thicknesses, transparencies, colours and textures of the model. Fig. 1 shows the '*Poptahof* Urban Design' project in different representations keeping the same geometry. There can also be multiple representations where different 3D models (containing different geometries) are used to represent different design solutions on a single site. Fig. 2 illustrates the study of alternative geometry models of *Poptahof* Urban Project, Delft using same representation in geoVE to avoid bias.

Multi-dimensionality refers to the possibility that the objects in a geoVE can be visualized as text, 1D points, 2D images, graphs, maps and 3D models. Muti-layering enables various layers to be added. The capabilities of simulations trigger change in the 3D-scene by pre-defined algorithms. Animations are pre-recorded simulations usually used in presentation.

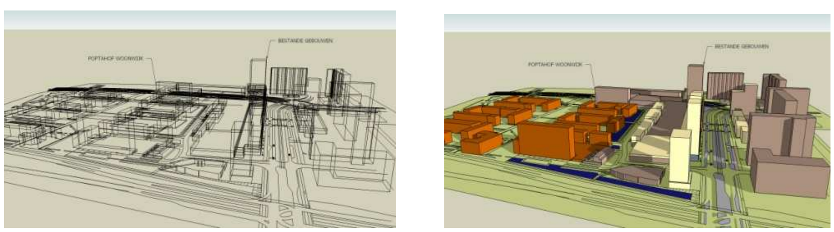

Fig. 1: Different representations of the *Poptahof* Urban Renewal Project from the same data (wire frame, coloured block models).

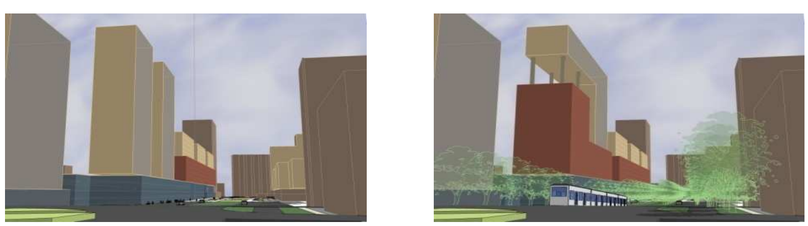

Fig. 2 Alternative design solutions with different geometries using the same rendering representation of the *Poptahof* Urban Renewal Project.

Experiencing: Sneiderman (1998), Craig & Sherman (2003), Lammeren & Hogerwerf (2003), Davis S. B. (1996), and Riedijk *et al.* (2006)

have extensively discussed the experiencing functionalities as the possibilities of a user to interact with a 3D model. We classify experiencing into passive and active. The active form relates to selection, manipulation, elaboration and exploration. The passive form of experiencing is when the user changes position in the scene but does not interact with objects.

Aerial view	Elevated oblique view	Eye level experience
City of Delft	*TU Delft Campus*	*Virtueel Apeldoorn*
Higher than 200m	200m to 2m	1.8m to 1m

Fig. 3: User viewpoint and experiences in an immersive environment.

Immersion in a geoVE is related to user experience and can be described as a ‘psychological state characterized by perceiving and experiencing oneself to be enveloped by, included in, and interacting with an environment’ (Witmer & Singer, 1998). Immersion can be physical and mental. Mental immersion is a state in which the human mind experiences the presence of being in the virtual world. The immersive environment of a geoVE can have three views: aerial, elevated oblique and eye level (Fig. 3). For urban planning, the aerial view gives an overall perception of the urban project, while an elevated oblique view only focuses on exterior forms. The eye level experience reveals architectural and interior details.

Controlling: Controlling functionalities relate to the user’s grasp on the controls of the desktop geoVE. Selection is the primary functionality of controlling. Without the ability to select data, control is not possible. Sherman & Craig (2003), Sneiderman (1998), and Davis S. B. (1996) defined the controlling functionalities of a 3D scene (see Table 1). Fig. 4 shows the instruction on keyboard / mouse control on Cebra’s VirtuoCity (*Virtueel Tilburg*).

Table 1 Controlling functionalities of the 3D scene.

Controlling geoVE	**Control types**	**Selection of**
Control of objects	Keyboard/mouse: select, click, identify.	3D objects
Control of 3D scene	Virtual controls	3D scene
	Direct-user control (in AR)	
	On-display control (menu)	

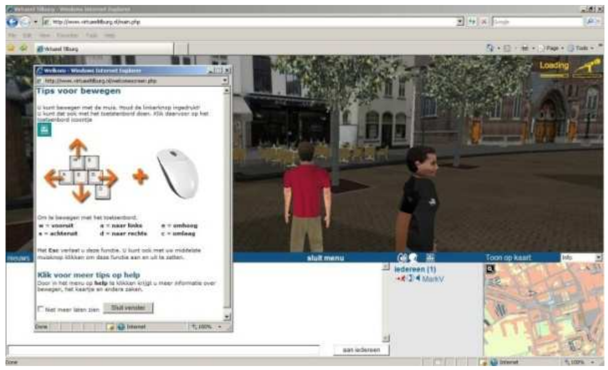

Fig. 4: Keyboard /mouse controls in the multi-user interface VirtuoCity.

Interacting: Heim (1998) defines interactivity as the functionality that describes the user's ability to change the viewpoint. The most important functionality of interactivity is data manipulation. This means that an interactive environment lets the user change the object's physical characteristics (e.g., location, shape, size, colour, attributes).

Wachowicz *et al*. (2002) suggested three extra factors for the domains of geoVEs: Automated Agents, Selection and Augmented Reality. We have reclassified selection in the controlling domain. An avatar is the user's physical projection in the digital world; it gives the choice to represent oneself as one's gender, age, personality, and more to interact with other users.

Dalal & Dent (1993) described five levels of interaction with users: informing, consulting, advising, co-producing and co-deciding. These last two involve collaboration. Consulting the user's email, newsgroups and weblogs are means of consulting, while tele-meeting, video-conferencing and Internet sites are means of advising. Chat-rooms help co-produce decisions and electronic voting on the planning projects lets users co-decide for or against a proposed design. These techniques were omitted from our study, as they imply different forms of communication.

Exploring: In this research, exploration is defined as an interactive method to explore the information behind the visualized 3D data (Kraak, 2002). The functionalities shown in Table 2 can aid exploration.

Table 2 Exploration functionalities for a Virtual environment.

Function	Description
Data Query	Access the spatial database and filter-out

	qualitative/ quantitative information (Fig. 5)
Dynamically linked windows/views	3D objects can be connected to external sources for additional information like web-site, sound, video, text, or images.

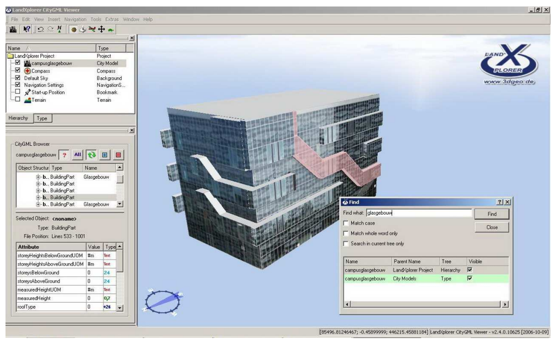

Fig. 5: Exploring a TU Delft building in LandXplorer, CityGML.

Components: The components of the 3D scene are the attributes of the model, like the boundary, background, geometry (simple and complex), lighting and shading, and toolboxes. There can be also analysis components that relate directly to tools such as sun-path and shadow calculation, wind-analysis, noise and air pollution mapping, and cellular automata.

These seven functionality domains listed above are inter-related but give a background for evaluating geoVEs for urban planning (Kibria 2008). Fig. 6 represents the hierarchical relationships. At the top of the hierarchy of the geoVE is the domain of construction of the 3D scene. The construction domain defines the capabilities of the 3D scene. These two domains are not directly related to user interaction. Experiencing is classified as the passive form of interaction that deals with simple visualization. User interaction with the 3D models begins with controlling. The interacting functionalities determine the active form of interaction in the geoVE. Exploration functionalities deal with the information behind the visualized 3D scene. Components are tools that enable these functionality domains.

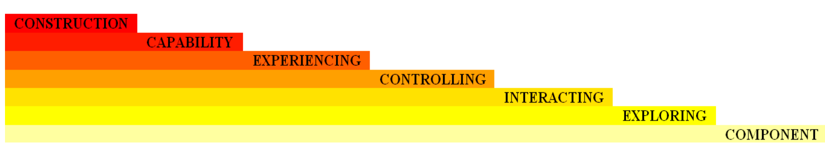

Fig. 6: Hierarchy of functionality domains of a geoVE.

2.2 Visual materials of geoVEs for urban design and planning

GeoVEs for urban planning require adequate definition visual materials to represent urban objects, including 3D models, plans, images, and textual information. A continuous line proceeding from a highly verisimilar to a highly abstract representation provides the *realism axis* as defined by McCloud (1993). The visual representation of reality can be mapped onto this axis falls somewhere between reality and abstraction. On this axis, verisimilar representations show realistic individually identifiable representations through detailed complex models. Indexed representations map the value of any concept according to classes and hierarchies. Iconic representations are naïve forms or representations that emphasize the basic true form of the object. The symbolic representation is the 2D depiction of any concept of the human mind, while finally, textual information provides sensation from the reader's memory on the essence of the object.

Visual materials classified as graphical consist of texts, graphs and images, and model representation can be 2D and 3D (Table 3). The graphical representation of objects, usually multi-resolution model representations (both 2D map and 3D model), has scale and topology.

Table 3 Models and graphical representations.

Type	*Name*	
Graphical representation	Textual information (1D)	
	Images (static, dynamic) and Graphs (2D)	
Model representation	2D models	Plans & Maps (2D)
	3D models	Block models (2.5D) to textured 3D models.

2.2.1 Visual materials: scenic languages CityGML, KML and X3D

Internet, together with the influence of the 'game industry,' has changed the realm of visualization through Web3D's 3D modeling language (VRML/X3D). In the past, CAD models were generated on desktop computers, but VRML models came as the solution to online CAD (Batty *et al.*, 2000). Computer Aided Design (CAD) systems (e.g., Autodesk AutoCAD, Microstation of Bentley Systems, 3D Max, SketchUp) have been the media for planners and designers to interact with 2D/3D models for decades. However, they lack semantics and extended visualisation and interaction tools. KML (Keyhole Markup Language) is a relatively new XML data-format that defines the viewing of visual objects on Google's virtual earth terrain through properties like placemarks, paths, raster images, polygons, and attribute information; it describes different LoDs and realism. While they offer a lot in graphics functionalities to create photorealistic models, they are weak in providing means for 3D geo-database object storing and representing semantics.

CityGML is a geographic information model that can be an exchange format for virtual city and regional models for municipalities based on XML (GML for geometry) based markup language. The goal of this data format is to have a rich source structure to store and exchange 3D information.

Fig. 7 shows 3D models in LoD1 to LoD4 in CityGML schema. 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 detailed 3D architectural model containing exterior architectural aspects. LoD4 from the outside looks like LoD3 models but contains a walkable interior space.

LoD 1	LoD 2	LoD 3	LoD 4
Block Model and no roofing	Models with roofing	Detailed textured model with roof	Detail models with interiors

Fig. 7: Levels of Detail (LoD) in 3D models.

Clearly, it is difficult to give a single, complete definition of visual materials for geoVEs. Through extensive study, we have defined six types of visualization materials. The visual materials are first classified as graphical (*text, graphs & images*) and model representations (2D and 3D). The model representation is further sub-divided into symbolic '*2D plan/map*' and different 3D LoD models, such as '*Volumetric block models*' for iconic LoD1, '*Volumetric envelope models*' for indexed LoD2, '*Detailed architectural models*' for indexed-verisimilar LoD3 and finally, '*Detailed models with interior*' for verisimilar LoD4 models.

3 Case study: *Poptahof* in Delft

The urban project of *Poptahof* in the Delft municipality was taken as a case study to investigate the requirements of visualization with respect to the defined taxonomy. This urban project has provided information on the current use of tools to communicate urban projects, which helped in preparing questionnaires offering new geoVE tools.

3.1 Traditional approach

In the traditional method of interaction of planning, architects and planners in the *Poptahof* urban design project used pictures and photographs to encourage discussion. The designers found that if such reference pictures are too detailed, they seem to deter the actual purpose of the visual materials. Actors like future inhabitants inspecting agencies emphasized the characteristics that they recognize from memory, like choice of material and colour instead of relevant issues like volumetric study.

The design professionals mentioned that the external actors have difficulty translating two-dimensional maps and floor plans into three-dimensional images. Thus, they were unable to comprehend the impact of the variation of high- and low-rise structures when design was communicated in the 2D plan. The master plan for *Poptahof* was presented in 2D in a clear layout, but with abstract colours. However, these 2D maps/plans failed to transfer adequate information and were not intelligible to non-design professionals, especially when building forms were emphasized. A combination of 2D and 3D visualization was therefore necessary. 3D visualization improved the perception of the actors, but such visualization was confusing when block models were used in aerial viewpoint. Eye level experience in visualization helped the actors understand the details of the design. The case study revealed that the levels of detail of visual material are understood by actors as having a relationship with the phase/stage of the design project. Actors regularly interpreted visual materials with respect to their background knowledge. The case study of *Poptahof* helped us draw some requirements:

- Visualize information in multiple rendering, resolution, dimensionality.
- Visualize information to maximum number of actors without bias.
- Visualize comparison between present situation and designed situation.

Traditional low-tech tools cannot offer such functionalities; therefore, more high-tech computerized tools like geoVEs are needed to interact with actors.

3.2 3D models and Survey Population

To investigate the requirements for new geoVE tools, we generated a 3D virtual model of the city of Delft; the *Poptahof* urban project was inserted into this model. A 2D digital map and LIDAR height information helped reconstruct the city of Delft with the *Poptahof* urban area. The *Poptahof* CAD models were delivered by the Municipality of Delft and were geo-referenced inside the virtual city model. The models were created with four steps: creating landscape (DTM), creating block model from 2D footprints (LoD1), adapting CAD models (LoD2 and LoD3), and creating interior in CAD (LoD4).

Using geo-processing tools in ArcGIS 9.2 and Safe Software FME, the GIS data were prepared and 3D scenes were created in Flux Studio. AutoCAD and AutoCAD Architecture were used to detail the 3D models and convert geometry to 3D faces. Sketchup was used in some cases to texture surfaces. The data used in the *Poptahof* case study are a LIDAR topographic map (1:1000), a large-scale topographic map (1:1000) and a CAD model of the *Poptahof* urban design (LoD2). Kibria (2008) provides more details on the reconstruction procedure.

This model was tested in various geoVEs. Two survey questionnaires supported the tests applied in a field survey and a workshop.

The survey population for the two survey questionnaires consisted of urban planners, GIS experts, architects and planners working for municipalities and social housing companies, as seen in Table 4.

Table 4 Survey population of the research.

Urban planners from Dutch municipalities	17
GIS experts and 3D modellers	2
Communication officers and planners	5
Design professionals from social housing agencies	6
Total participants	30

4 Analysis

The following sections present the findings from the field survey and the workshop, organised with respect to required functionalities and visual materials. The functionalities are not classified with respect to the urban design phases since we believe that they must be available for all the actors in all the design phase. The approach to visual materials is different. The questionnaires were prepared so as to reflect the role of actor in different urban design phases.

4.1 Required functionalities in urban planning

Table 5 lists the results of the survey on required functionalities for geoVEs. The table is organised according to the taxonomy developed in Section 2.1. The actors have validated the listed requirements, which means that municipalities should address these functionality domains for interaction in the urban planning process when they develop their municipality systems.

Table 5 Requirement functionalities of geoVEs for urban planning.

Domain	*Functionality*
Construction	Information Intensity (LoD) for 3D models
	Datasets should be stored in geo-database
	Data integration: open source solutions encouraged
	Data integration: multiple data format & interface
	Visualization through plug-in or software download
	Toolboxes: Tools for experiencing, controlling, interacting, exploring and analyzing should be present.
Capabilities	Multiple representations in different rendering capabilities
	Multiple representations in different geometry capabilities
	Compare/statistically analyze old and new situations
	Animation and simulation for presentation & analysis
	Multi-dimensionality and multi-viewpoints
Experiencing	Minimal steps for movement and navigation
	Orientation with positioning, tracking and north arrow
	Immersion: mental semi-immersive environment
Controlling	Selection of scene/objects: click, highlight & select
	Desktop VR with user mode: multiple/single
Interacting	Ability to move & delete information
	Ability to modify, edit and change information
	Ability to add, copy and save 2D/3D data
	Ability to stop, hide, and censor information
	Real world information like webcams
	Automated agents (avatars) and intelligent objects
Exploring	Spatial query on geometry, semantics and attributes
	Hyper links and linked objects
	Multiple synchronized windows
Components	Log-in interface
	Measurement tool component for dimensions

	Adding labels & icons to highlight
	Multi-layering by adding GIS data/WMS layers
	X-Ray Vision to reduce occlusion
	Geo-referencing and geo-coding components
	Lighting, camera, viewpoints change, tilt, range etc. Transparency and shading (on/off)
	Screenshots, save image, history keeping
	Automatic focus/tracking, teleportation component
	Basic drawing tool (mark and draw)
	Ability to highlight landmarks, nodes, zones, etc
	Reference points (home button, back and forward)
	Audio sound support, identify with attribute information
	Distance function from highlighted 3D object
	Velocity: fast, medium, slow & acceleration
	Gravity and collision (on/off) and time component
	Vector/ raster data, atmosphere and visibility
	Analysis: sun-path, traffic and urban growth, etc

4.2 Required visual materials for urban planning

Visual materials specified in Section 2.2 were investigated with respect to:
- Visual materials (in LoD) versus human perception of understanding.
- Visual materials (in LoD) versus the urban planning phases

The results are plotted in line graphs. Six visual materials form the x-axis (except for Fig. 8, where the x- axis is formed by perception levels) with three intervals indicating the 'degree of freedom' given to the participants. This enabled the participants to avoid crisp decisions and provided flexibility. The y-axis indicates the added maximum and minimum number of times the participants agreed with a certain decision. The graphs indicate the highest number of participants that agreed ('added agreeability') with the decision.

4.2.1 Relationship between visual materials in geoVEs versus human perception

The line graphs in Fig. 8 indicate there is a clear relationship between human cognition and understanding of design using visual materials in multiple representations, LoD and realism. This illustrates that solely textual and graphical information are inadequate to explain design. If the building is visualized in LoD1 models, the population perceives the design as a draft and fails to differentiate between various objects.

When the building is visualized in LoD2, the viewers focus on local details of the building design and think that the final design may be altered, concentrating on the outer looks like roofing and forms. When the same design is viewed in LoD3, the viewers perceive that the building will be fairly similar to the realized project. Visualizing LoD4 models with interior space implies that viewers perceive the design as final. This proves that human perception is largely enhanced when design is visualized at a higher LoD. From 2D plan/map to 3D LOD3 and LoD4 models, the human ability to perceive design increases. The result finally proves that higher levels of detail and realism in 3D models help viewers recognize and understand the area under observation with less difficulty compared to 2D maps and iconic block models (LoD1).

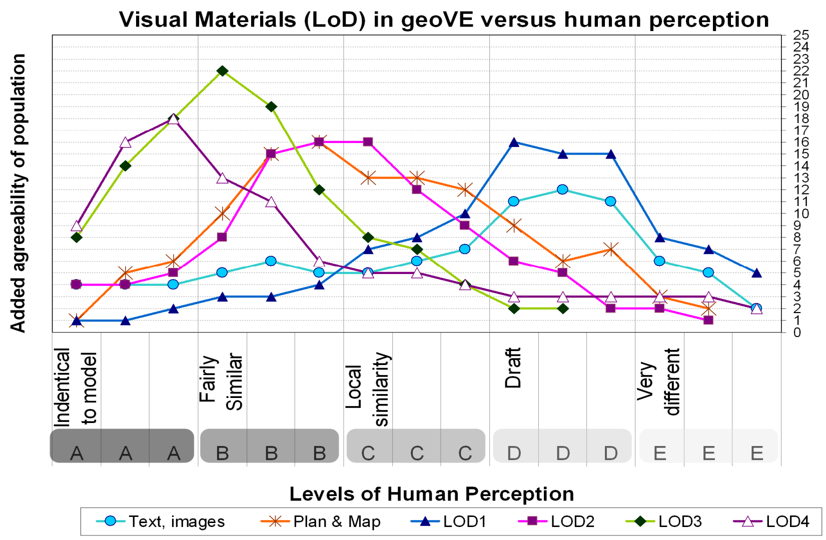

Fig. 8: Visual materials at various LoD and human levels of perception.

By analyzing the line graphs in Fig. 9, it is clear that there is a tendency for block models (LoD1) to confuse people the most, while LoD2 and LoD3 models are most suitable for design comparison. LoD2 and LoD3 models turned out to be navigation and orientation supportive.

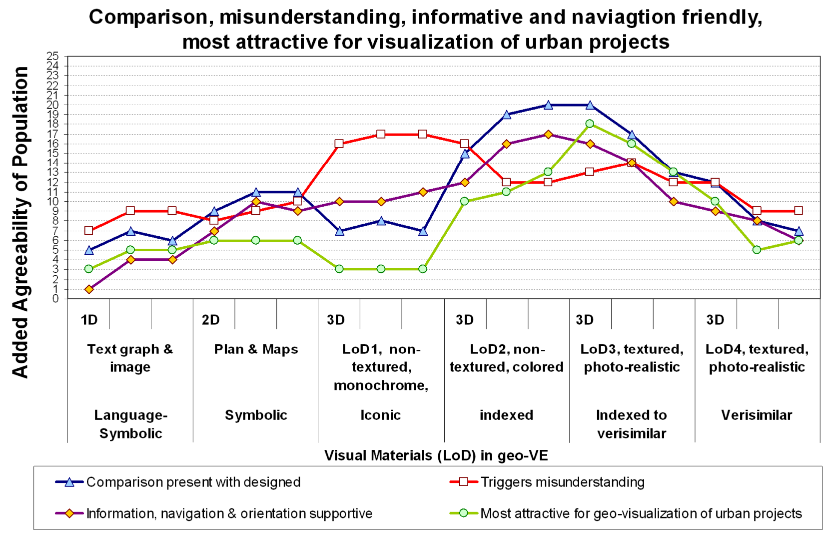

Fig. 9: Visual materials in various LoD and type of interaction in urban planning.

4.2.2 Relationship between visual materials and design phase

We studied the spatial planning phases in the Netherlands; only the major phases are mentioned here. In the field of spatial planning, a *zoning plan* is a juridical binding spatial plan in the Netherlands for permissible land use that covers parts of the municipality that vary from a large city-district to a single building block. It specifies regulations regarding what can be built and the height allowed. The *structure plan* reflects the global expectation and envisioned spatial developments for a municipality or parts of a municipality by defining the phasing of developments. A *master plan* is a large-scale comprehensive plan that provides the development concepts on built form, landscaping, space, urban texture, circulation and solutions to urban services. The *urban design plan* is the detailed worked-out plan from the master plan; it describes what will finally happen in the urban settings with building types, heights, roads, paths, street-furniture, parks, etc. When the urban plan is finalized, the urban planners transfer their goals of the building forms to the architects through the *architectonic quality plan*. The final phase is the *architectural design*, which ends up in creating a detailed building with an interior.

The graphs in Fig. 10 illustrate the relationships of the six major planning phases with visual materials in a geoVE. They indicate that a zoning plan should be visualized mostly as a symbolic 2D map/plan alongside textual and graphical information as attributes. Structure plans should be visualized as symbolic 2D plan/maps. A portion of the survey population argued that iconic 3D LoD1 block models should be used to visualize height restrictions of a zoning plan. The master plan tends to show real inclination to 3D, specifically the use of monochromic iconic block models (LoD1), although symbolic 2D maps/plans are also necessary. Noticeably textured higher LoD models for these three initial phases are undesirable.

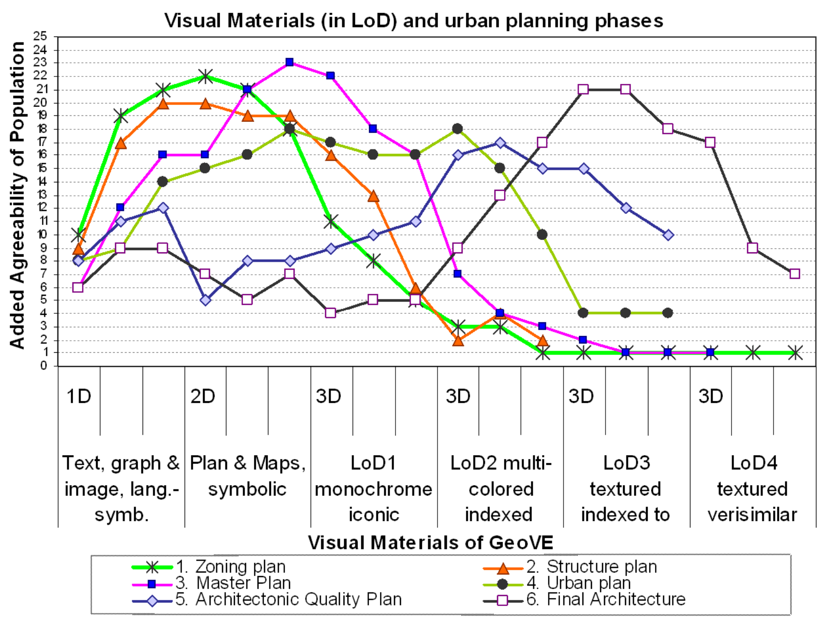

Fig. 10: Visual materials in various LoD and urban planning phases.

Fig. 10 illustrates that in lateral stages like urban plans, architectonic quality plans and final architecture designs, a limited presence of textual, graphical and image representation can be identified. However, from urban plan up to architectural plan phases, the graphs tend to show a gradual decrease in the use of text and images as media for communication and an increase in 3D. The architectonic quality plan shows a primary inclination towards indexed volumetric envelope models (LoD2) and secondarily to LoD1 models. Multi-coloured 3D models in LoD2 should visualize initial architectonic forms like roofing and exterior envelopes. In the architectural design phase, photorealistic, detailed architectural models (LoD3) and verisimilar detailed models with interior space (LoD4) are preferred over visualizing design solutions in a geoVE.

Observing these graphs, it becomes obvious that with gradual progress of spatial (urban) planning, the graphs tend to move from left to right, increasing the importance of 3D. In these initial spatial planning phases, one can identify that there is constant presence of textual, graphical and 2D plans as interaction material. In the final phases, the 3D LoD models with gradual realism dominate as interaction material for visualization.

5 GeoVEs suitable for municipalities for interaction in urban planning

We tested four geoVEs in this research, as seen in Table 6. The first three are based on widely accepted 3D formats like KML, X3D/VRML and CityGML. Cebra's VirtuoCity is chosen due to its growing popularity for designing virtual cities in the Netherlands.

Table 6 Four tested geoVEs of the research.

Geo-VE and data formats		*Open Source*
Google Earth (GE)	KML 2.1	Y
LandXplorer	CityGML	Y
Bitmanagement Internet Explorer plug-in	VRML/X3D	Y
VirtuoCity of Cebra	V3D/Python	N

These four geo-VEs are compared based on their functionality domains. The construction functionalities of the geoVEs largely depend on how the data formats are designed. In the construction domain, LandXplorer viewer's data format CityGML has a clear grammar to model in various LoD attaining thematic and geometric semantics. Google Earth's KML and X3D data formats used in Bit management Internet Explorer (IE) plug-in have a geometric hierarchy but no semantics in thematic attributes. Google Earth, LandXplorer, Bitmanagement IE plug-in and VirtuoCity connect to the Internet and import data. VirtuoCity has a multi-user interface in a three-tier client-server-database architecture, allowing streaming of 3D models in a proprietary client 'engine.' Google Earth (GE) allows streaming in Asynchronous JavaScript and XML (AJAX) for satellite images. The 3D models can be visualized 'on-the-fly' from spatial databases in GE. For LandXplorer, the CityGML-based data has to be first downloaded on a local PC. Bitmanagement IE plug-in can be used to visualize streamed 3D models from spatial databases.

These geoVEs let users passively experience 3D through movement, navigation, and orientation, and are immersive in nature. GE and LandXplorer have advanced navigation, orientation and exploration controls. LandXplorer lets the user click and select data and explore the attributes. While Bitmanagement IE plug-in and VirtuoCity use avatar-based systems, Google Earth and LandXplorer do not. Google Earth and LandXplorer allow spatial queries based on geometry and attributes. Such queries can be built on top of Bitmanagement IE plug-in.

Google Earth's KML and LandXplorer's CityGML and models in VirtuoCity are geo-referenced. The foremost difference between X3D/VRML-based Bitmanagement IE plug-in and VirtuoCity is the way in which these two geoVEs present the 3D scene. VirtuoCity is based on the concepts of social networking in real-time collaboration in an interactive environment similar to Second Life or Active World, where users can communicate with each other. On the other hand, 3D scenes made in X3D/VRML and visualized in Bitmanagement IE plug-in result in 'deadworlds' of 'ghostly solitude'.

Implementing an X3D/VRML-based viewer for the mass public will require municipalities to build their own interactive interfaces, which may be a laborious and expensive task. However, many developments in X3D and multi-user interfaces allowing collaboration are already taking place. Media Machine has made efforts to combine X3D with Simple Wide-area Multi-user Protocol (SWMP)-3D, fulfilling the collaborative aspects by providing interactive multi-user chatting. Blaxxun Tehnologies is also involved in this research field. For urban planning, X3D fulfills the requirement to visualize the urban projects in LoD1 to LoD4. The CityGML-based LandXplorer is a professional data-mining and exploration tool rather than an interactive visualization tool. While using CityGML is positive as 3D models have semantics and can be used in multiple applications, the de-facto LandXplorer viewer falls short of fulfilling the visualization requirement for interaction in urban projects.

GE has two major advantages over the other geoVEs. First, GE is widely popular; due to its popularity, it is supported by many CAD and GIS companies to export various data formats in GE. Second, the free availability of large datasets like satellite images, web services and 3D models in GE is second-to-none. KML is accepted as Open Geospatial Consortium, Inc. (OGC) best-practice specification, which is a positive development. However, GE does not allow collaborative chatting or voting functionality for urban projects. Incorporating instant messaging functionalities in GE could overcome this limitation. The drawback of GE is that it cannot visualize interior and underground objects. For large-scale urban projects, GE is suitable to obtain an overall view of the designed area but fails in elaborating details of architectural design. VirtuoCity contains most of the relevant functionalities, but searching and exploring functionalities are limited. Eye-level experience in VirtuoCity allows the finest detail of architecture to be visualized.

We have examined the geoVEs through a positive approach to open source solutions for the municipalities. In order to use 3D models in cross application domains, semantics cannot be neglected. In a best-case scenario, 3D models should maintain semantics and LoD by following well-defined schemas like CityGML (also an OGC standard) and visualize the design in multiple Internet-based geoVEs. Given the complexity of building a custom-made collaborative multi-user X3D viewer, this makes Bitmanagement IE plug-in a lesser choice. Google Earth is a geographic visualization tool that is not specifically designed for visualizing architectural details and interior. However, due to its mass popularity to reach the maximum number of actors, GE should be used for visualizing exterior 3D models. Finally, VirtuoCity is custom-made for collaborative design process and holds solution for interactive multi-user geoVEs for urban planning in the Netherlands. However, it leads municipalities away from open source solutions. The multi-user interactivity functionalities like avatars, intelligent objects, feedback, and audio support are positive aspects of this geoVE.

6 Concluding remarks

In this paper, we have defined the requirements of visualization materials and the taxonomy of geoVE functionalities for urban planning. The hierarchical functionality domains are relevant for comparing geoVEs. In our case study, we found that the visualization method is important in transferring information on urban renewal and planning. We determined that increases of realism, Levels of Detail (LoD) and dimensionality increase the user perception of understanding the design linearly. This has an effect on the relationship between LoD and the planning phase. As the planning phases progress in time, the dimensionality, realism and LoD in various interaction models in geoVEs should increase. Finally, we conclude that text, images and 2D maps/plans are important in the initial planning phases. When design is at a definitive stage, 3D LoD models should be used in gradual realism.

Interest in 3D models is high. Appropriate solutions must be found to ensure that all users can access the information they need in a particular urban planning phase. The tested geoVEs support only some of the required functions; it is therefore difficult to make recommendations. Some of the municipalities may need to consider in-house developments to enrich the most popular geoVE.

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

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.

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.

Dalal, B. and Dent D. (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.

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

Kibria M. S., (2007), 'Functionalities of GeoVE to visualize urban projects', GIMA MSc. Thesis, conducted at OTB, TU Delft, The Netherlands, accessed at http://www.gdmc.nl/publications/2008/Geo-virtual_environments.pdf and http://www.gdmc.nl/publications/2008/Geo_virtual_environments_annexes.pdf

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), 'GeoVirtual Reality and participatory planning', Virtual Landscape position paper, Alterra, Wageningen University, Centrum voor Geo-Informatie, CGI Report 2003-07 ISSN 1568-1874

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

McCloud, S., (1993), 'Understanding Comics', Kitchen Sink Press, 1993. Mentioned in Dykes, J A.M. MacEachren, and M.-J. Kraak, 2005, Exploring GeoVisualization by, Elsevier, Amsterdam, the Netherlands, February 2005.

Riedijk A., R. J van de Velde, T.C. Hoogerwerf, R.J.A. van Lameren, (2006), 'Virtual Netherlands, GeoVisualization for interactive spatial planning and decision making: From Wow to Impact', Definition study, Vrije Universiteit, Amsterdam.

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.

Wachowicz M., Bulens J., Rip F., Kramer H., van Lammeren R., Ligtenberg A., Wageningen UR Centre for Geo-Information, 5th AGILE Conference on Geographic Information Science, Palma (Balearic Islands, Spain) April 25th-27th 2002

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/