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Affective appraisal of 3D land use visualization

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ABSTRACT

In this paper we discuss the affective appraisal and affective response of users to three different visualization types: colored raster cells, 2D-icon and 3D-icons. For that we developed a dedicated multi-layered visualization of current and future land use in the Netherlands, that may allow policy-makers to assess and compare land use scenarios. This Google Earth based visualization, abbreviated GESO, facilitates users by means of the three different visualizations of current and future land use. It is often assumed that 3D-visualization improves the cognitive understanding of scenario outcomes. There are many uncertainties, however, about the affective responses to 3D-visualization. A between-subject experiment has been designed to compare viewers' responses to the three types of visualizations on affective appraisals of the environment. 3D-icon visualization elicited the highest affective appraisals and positively influenced perception of the environmental quality. Moreover, the results demonstrated that 2D-icons and 3D-icons, compared with colored raster cells, did not improve the efficiency or accuracy of the participants in this experiment. The results provide evidence that the visualization type may influence the affective appraisal of the environment represented. The need for further research is discussed, especially regarding the question whether these types of visualizations may influence judgement and decision-making in environmental planning.

1. Introduction

As with many areas under the influence of urban conglomerations, the Dutch land area is subject to a continuous land use transition, especially in the direction of ongoing urbanization. According to studies conducted by The Netherlands Environmental Assessment Agency (PBL), the demand for housing area will increase by at least 120.000 ha, according a trend scenario, and at most 190.000 ha, according the increased spatial demand scenario, in the period 2010–2040 (Milieu-en Natuurplanbureau, 2007). These demands will have a high impact on other land uses, especially agricultural production and nature conservation, and will thereby influence the environmental and landscape quality in many ways. The PBL conducts scientific studies on future land use to support Dutch policy-makers at regional and national administrative levels who discuss sustainable development of the land, taking into consideration improvement of the mutual accommodation of space and society. The concept of mutual accommodation may contribute to improve environmental conditions and is able to respond adequately to environmental challenges such as food supply, CO_2 reduction, and offsetting a rising sea level.

1.1. The challenge of visualization

The results of studies such as those of the PBL are offered to policy-makers and stakeholders as reports, including maps showing current and future land use. The Sustainable Outlook is one of these reports that must be produced every 4 years (Milieu-en Natuurplanbureau, 2007). It is intended as a source of information that can serve in discussions on the impact of middle and long term (through 2040) land use changes and their environmental, ecological, and spatial effects. Land use transitions for the Dutch land area are based on the simulation of land use development using the dedicated modelling software Land Use Scanner (Hilferink & Rietveld, 1999). The Land Use Scanner produces geo-referenced raster data sets that cover the full extent of the Dutch land surface (41,528 km^2), presenting land use in the near future. Each raster cell spans 100 by 100 m and shows one land use class. The maps created from these datasets also cover the full extent of the Netherlands, are color-printed on A4-size, have legends of 10 land

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use classes, and present the land use classes according a specific scenario in a particular year.

The maps are created in the first place to support policy-makers in detecting and understanding land use changes and their impacts on the physical environment. Currently, a change in color hue in these maps only depicts the transition to a different type of land use. Consequently, impacts are difficult to interpret from these maps (Fig. 1). Changes, such as the effect of low-density residential development on open landscape, or the effects of scale enlargement in agriculture, need to be interpreted by the policy-makers themselves (Borsboom-van Beurden, Van Lammeren, Hoogerwerf, & Bouwman, 2006).

The PBL has noticed such usage difficulties arising from the maps (Borsboom-van Beurden et al., 2006). The main Sustainable Outlook map users, policy-makers on National and Regional administrative levels, comment negatively on the excessive amount of detail on the A4 paper size, the similarity of colors, and the fact that the maps cannot easily be compared with other maps in the report. Such comparisons are essential for placing contemporary land use classes and patterns side-by-side with scenario-based outcomes. Allowing users to easily detect changes between the current and future situations, as well as between various possible future situations, will improve interpretation of the maps, as well as the processing of information by users. Given the recent developments in three-dimensional (3D) visualization (e.g. Appleton, Lovett, Sünnenberg, & Dockerty, 2002; Paar, 2006), the PBL has started a number of projects to search for a better communication platform for policy-makers (see also Hudson-Smith, Evans, & Batty, 2005). The first project took off in 2004 and aimed at meeting two challenges. First, the nominal land use map was to be transformed into a 3D-visualization, based on the assumption that a 3D-presentation could tackle the observed problems. Secondly, such a 3D-visualization was to be made accessible by an interactive interface, using the latest geo-information technology.

Although 3D-visualization seems to offer many advantages (see Ant Ozok & Komlodi, 2009), which shall be outlined in the next section, the outcome of the technical development projects showed that its potential could not yet be fully realised at that time and "might even be a mission impossible" (Borsboom-van Beurden et al., 2006). A major difficulty was posed by the nature of the land use model output data (spatially coarse grid cell data, and long term changes) and the absence of visual information about spatial structure and coherence. The latter has been addressed in the landscape feature (LF) approach (Momot, 2004; Van Lammeren, Momot, Olde Loohuis, & Hoogerwerf, 2005) in which topographical information and landmarks (Al-Kodmany, 2001; Lynch, 1960) were included (Borsboom-van Beurden et al., 2006). This LF approach intended to enable the recognition of characteristic patterns of the Dutch land area according to principles of accuracy, representativeness, and legitimacy (Sheppard, 2001; Sheppard & Cizek, 2009). Thanks to the arrival of Virtual Globes (Butler, 2006), and the high resolution data layers available within them certain intentions of the LF approach have been actualized and are now at our disposal.

1.2. Articulation of the challenge

The above-stated expectation of the policy-makers is in line with most users and designers, who intuitively prefer realistic 3D representations of environments. This assumes that such a representation results in near-effortless comprehension and provides an accurate assessment of the environment that is represented (Al-Kodmany, 2002). This faith in realistic displays is, however, often misplaced, because for many tasks low-fidelity visualization tools offer superior functionality and performance (Hegarty,

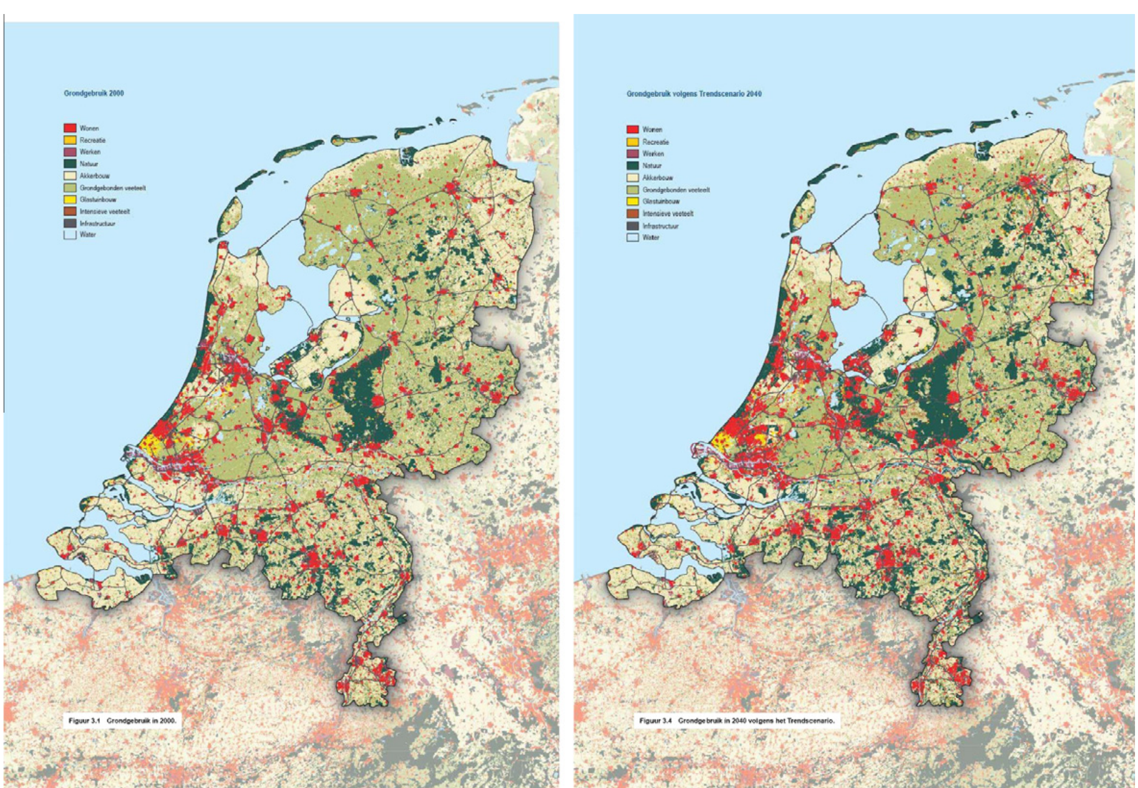

Fig. 1. The A4 land use maps – *left:* land use 2000; *right:* trend scenario land use 2040 (Milieu-en Natuurplanbureau, 2007).

Smallman, Stull, & Canham, 2009; Smallman & St. John, 2005). The basic principle of visual representation, however, is grounded by the proposition that any representation should be designed for the required tasks and offers the cognitive and affective information the user needs when performing these tasks (Mahdjoubi & Wiltshire, 2001; Rohrmann & Bishop, 2002).

3D-visualization is expected to offer better cognitive understanding of spatial relations (topology) and vertical dimensions (geometry) (Bos, Bregt, Bulens, & Lammeren, 1998) especially when users can navigate through the environment (Bleisch, Dykes, & Nebiker, 2008; Mülder, Säck-da Silva, & Bruns, 2007). Photorealistic representations, including material textures, illumination, and atmospheric conditions, seem to improve recognition, support understanding, and allow appraisal of aesthetic and affective qualities of the area (e.g. Sheppard, 2005). If the presentation better fits daily visual references (Bishop & Rohrmann, 2003), it will improve communication between stakeholders and elicit more detailed responses (Van den Brink, Van Lammeren, Van der Velde, & Däne, 2007).

The attractiveness of 3D-visualizations may also have unwanted effects. Whereas visualizations are supposed to be beneficial by removing ambiguity in interpretation by helping viewers to create a mental image of the represented area (Tress & Tress, 2003), there is evidence that 3D-visualizations are perceived as more trustworthy and convincing than other, traditional representations (Sheppard, 2001). This has raised questions, for example, about the ethics of using 3D-visualizations for the purpose of convincing the general public. Any biases in data interpretation engendered by the medium should also be considered carefully in the context of planning and decision-making.

This evidence reveals the need for user-centered studies addressing the question. What are the requirements for the representation of future land use in 3D-visualizations and for the usability of 3D-visualizations to support policy-makers in unambiguous, fast, and effortless interpretation? Many researchers have posed this question in the last decade (e.g. Fuhrmann et al., 2005; Mahdjoubi & Wiltshire, 2001).

Although studies into the effect of geo-information transfer and individual task performance are now increasing, the affective response of the user to the representation and interface is often neglected (Wergles & Muhar, 2009). The PBL has not taken this into account when starting up its more technically-oriented projects. Usability research on interfaces of interactive computer applications acknowledges the importance of aesthetics and the user's experience (Tractinsky, Katz, & Ikar, 2000). Appreciation of the interface and visualization may influence the user's cognitive, affective, and behavioral response (Sheppard, 2005) and may be transferred to a judgment of the system itself (Thüring & Mahlke, 2007; Tractinsky, 2004). Aesthetics alone could be an important determinant of user satisfaction and system acceptability, even overcoming poor usability experience and positively influencing the meaning of information (Hartmann, Sutcliffe, & De Angeli, 2008; Tractinsky, 1997; Tractinsky et al., 2000).

Assuming that the advantages of 3D-visualizations improve understanding of land use changes and increase the appreciation of the interface, this leads to the question how the response to a visualization technique affects the appraisal of the perceived, visualized environment (Sheppard & Cizek, 2009).

In this paper, we explore the affective appraisal and affective response of users to three different visual representations of land use. Affective appraisals are judgments concerning the capacity of the appraised objects to alter mood, expressed in terms such as pleasant, repulsive, and attractive (Russell & Snodgrass, 1987). If a change in the viewer's affect occurs as a result of the perceived affective quality of an object, we call this an affective response. Appraising an object (or environment) does not necessarily result in an affective response: the object only has the potency of changing one's affective state. So if a viewer appraises the represented environment as pleasant, it may influence her or his affective response; however, it may not depending on the context, task, the viewer's personal drives, and the degree of pleasantness (van der Spek & Houtkamp, 2008).

Different visual representations were created by using 2D referenced geo data and 2D computer display. Referring to Fig. 2, the visualization approach in our study is presented by the more contrasted area that includes bold fonts and black arrows. In our approach, we interpret 3D-visualization as the outcome of (geo)data transformation (Fig. 2, TII) into the visualized (geo)data. Such a transformation results in visual 'layers'. Each layer has its own reference, extent, and precision, presents the selected transformation variables such as graphic attributes (symbols, colors, and textures) and object representation (from 3D geometry into 2D planes) to represent the geo data based objects. The different combinations of graphic attributes and object representation lead to multiple types of visualizations. Moreover, the transformation could include more graphics such as additional 3D-objects and atmospheric conditions.

Another important stage is the transformation of the geo-visualization into a projection which may be viewed by a computer display (Fig. 2, TIII). The projection may vary from orthogonal, parallel to perspective and could be based on close or distant views (Verbree, van Maren, Germs, Jansen, & Kraak, 1999). Current interactive interfaces (display viewers) offer this full range. Finally, a 3D-experience may be supported via a transformation to display the view in such a way that the human parallax is triggered (Fig. 2, TIV), and the projection, whether 2D or 3D, offers depth cues that could give the viewer a 3D-experience (Ware, 2004).

2. Methodology

In order to explore the users' affective responses, we first developed an application to create data which could be used as a tool to

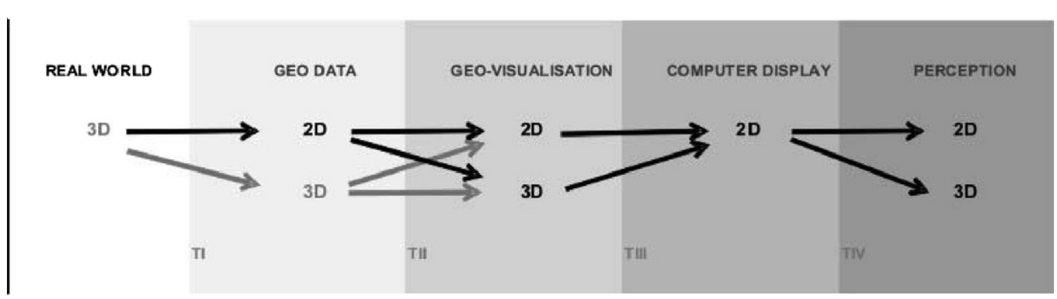

Fig. 2. Transformations in the Geo-Visualization process TI geo data acquisition; TII geo-visualization definition; TIII display rendering; TIV perception triggers in 2D and 3D (parallax and/or depth cues). The 2D and 3D representations in bold fonts and connections with black arrows represent the geo-visualization approach of this work.

acquire responses from users. Secondly, we defined an experiment to assess the affective responses of the users to, and usability of, three different types of visualizations. This section explains the GESO application, the data generated, the experimental setting, and the analysis of the user-based data.

2.1. GESO application and data

Since the launching of Google Earth (http://www.google.com/press/pressrel/google_earth.html), software to present the third dimension of geo data has been progressively developed. Virtual Globes (Google Earth, NASA WorldWind (http://worldwind.arc.nasa.gov/java/) and Microsoft Bing Maps (http://www.microsoft.com/maps/default.aspx) have found their way into the Web 2.0 society. These Virtual Globes offer an interactive interface, exchange of geo data via the Web and a link to 3D-object modelling (e.g. SketchUp (http://sketchup.google.com/) by KML and KMZ exports and Collada objects, respectively (Rodrıguez Lloret, Omtzigt, Koomen, & De Blois, 2008): an enormous potential for supporting geo-visualizations. In addition, the accessibility and availability of high-quality geo data guarantee the commitment to professional application of these virtual globes.

At the Netherlands Environmental Assessment Agency, high-quality geo data, such as the Actual Elevation Model of the Netherlands (AHN) (http://www.ahn.nl/viewer) and the National high resolution topographical data (top10Vec) (http://www.nationaalgeoregister.nl/geonetwork/srv/en/main.home), are a part of all data sets used in the Sustainable Outlook studies.

Given these current advancements, an application[1] has been developed to generate Google Earth 4.x (GE) dedicated files originating from the Sustainable Outlook study. Fig. 3 shows in the top row the visualizations that were created, labelled multi-layers, that users may view by using Google Earth. The bottom row of the figure shows the input data, the files that have been transformed to support our study.

The following use scenario depicts a possible application of the multi-layers; The user, for example a policy-maker, starts an Internet browser to find out the latest multi-layers of scenario outcomes. Via a web viewer, in this case Google Earth, the policy-maker is able to inspect and compare the intended land use changes via the multi-layers. Using free navigation options, the user will tender an impression of current and future land use. Current land use is presented two-dimensionally by recent (2005) high resolution aerial photographs (Fig. 3 multi-layer {a}), by colored raster cells (Fig. 3 multi-layer {b}), and three-dimensionally by 3D-shapes (Fig. 3 multi-layer {c}). Future land use is presented two-dimensionally by colored raster cells (Fig. 3 multi-layer {d}) and 2D-icons (Fig. 3 multi-layer {e}). The three-dimensional presentation of future land use is given by 3D-icons (Fig. 3 multi-layer {f}). Except for the aerial photographs, all other land use representations share the same color legend.

The user viewpoint initiates the visibility of a layer. On lower viewpoints, ranging from a human eye's viewpoint up to a viewpoint at 640-m altitude, 3D-shapes and 3D-icons can be seen. At higher viewpoints, such as bird's eye view (above 640 m), the 3D-icons change into 2D-icons and finally, above an altitude of 1800 m, into colors. Using interactive navigation, including toggling layers on and off and changing the transparency level, the user could detect changes and construe their impacts. We have to stress that the layers show all land uses for the full land area per year of interest and do not show the changed land use.

2.2. Experimental conditions and hypotheses

In order to examine the effect of representational characteristics on the affective appraisals of the viewer of the visual representations and of the environment, an experiment was designed in which participants performed tasks similar to those of policy-makers for whom the application is designed. In the experiment, three conditions were compared: 17 future land use classes were either represented by colored raster cells, 2D-icons, or 3D-icons.

Colored raster cells are abstract colored squares that are supposed to be effective for rapid comparison of land use transition over time. Color ensures preferential access to or retrieval from memory when distinct items must be rapidly remembered (Yao & Einhäuser, 2008), A shortcoming of the raster cells in this experiment is that the colors are not intuitive; for instance, pink represents industrial areas and yellow is used for orchards. Also, the combination of straight, flat squares is inharmonious with the photographic resolution of the underlying Google Earth visualization as well as the envisaged landscape pattern.

The series of 2D-icons developed for this study at the PBL maintain the same colors but indicate the land use functions with mimetic symbols that can easily be recognized. In visualization, the function of an icon is to act as a symbolic representation that "shows essential characteristics or features of a data domain to which the icon refers" (Van Walsum et al., 1996). The level of detail is purposely kept low, to make evident that the representation has no resemblance to the actual appearance of the future landscape (Fig. 4A). This is in line with the requirements for this tool, supporting strategic decision-making on regional and national levels.

In the third condition, 3D-icons were used showing a limited amount of geometric and symbolic detail to stress that the representation is iconic. The level of detail is purposely kept low, to make obvious that the representation has no resemblance to the actual appearance of the future landscape. The colors used were identical to the types of visualization in the first two experimental treatments. However, the height of the 3D-icons, especially in the categories for urban living, industrial areas, and business parks, gives a more realistic impression of the effect on the landscape from an aerial oblique view (Fig. 4B). The 3D-icons for this study were developed in cooperation with PBL. Both 2D- and 3D-icons were designed only to improve recognition of the land use type, without adding information, or suggesting how the area will actually look in future situations. The geometric detail that is provided by the 3D-icons is not related to how the future situation will be experienced by viewers in reality.

Based on evidence from literature (Mülder et al., 2007), we hypothesized that the participants would judge the more realistic

[1] GESO data were developed via the Geo Data & Model Server (GeoDMS). GeoDMS is an integrated spatial modelling framework with a calculation management engine and a declarative scripting language for the implementation of Planning Support Systems (PSS) and Scenario Evaluation Systems (SES). The GeoDMS consists of two components. The GeoDMS Engine, a generic set of dll's that control, retrieve, store and calculate the primary data and model results. This engine is programmed in C++. The GeoDMSGui, a generic client application that visualizes the primary data, the model results and the calculation logic with a set of primary data viewers. Furthermore it supports the user in extending/editing the model logic, importing and exporting new primary data and savings all these 'settings' in a new configuration. The GeoDMSGui is developed in Delphi. The GeoDMS became the technical basis of successors of SimEurope, such as the LUMOS Land-use Scanner, the EuroScanner, Lands, the NatuurPlanGenerator, GlowaElbe, and Elpen, and has also been used to implement many local and regional PSSs. The 3D-icons have been made in SketchUp (royalty-free software) and in 3DStudio Max. The latter data had been transformed into SketchUp models. The 3D-icons may be shared via the 3D-model database of the SketchUp community. Currently, the multi-layered data is not available via the GE web service. There are many opportunities to develop such a full web service by offering it through the open Google Earth community (http://bbs.keyhole.com/ubb/ubbthreads.php?ubb=cfrm) and an intranet such as Google Earth Enterprise license. Such a web service could be improved using the dedicated kml generation application that is available under a GNP GPL (open source) license (http://www.objectvision.nl/GeoDMS/default.htm). The 3dShapes data, generated by the GESO project partners, may be viewed by the website of Objectvision bv (http://www.objectvision.nl/Geodms/products/3dshapes.htm). However this version has been updated for use as web plug-in and is not fully comparable with the version used for our experiment.

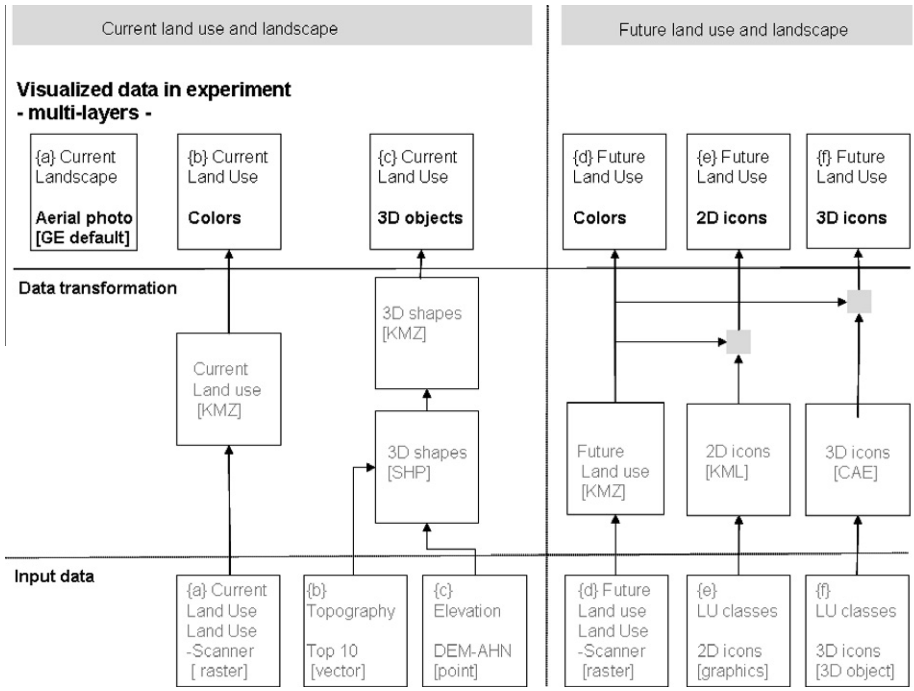

Fig. 3. GESO application data flow (TII of Fig. 2). The top row shows the generated multi-layers.

3D-icons more attractive than the colored raster cells and the 2D-icons. We expected that the representation with 3D-icons would be appreciated most and that this would transfer to the appraisal of the area itself.

In the experiment, the accuracy and efficiency of task performance were assessed as well. We expected that the 2D-icons and 3D-icons would improve the performance of the participants. In this paper, however, we only report on these results briefly where relevant.

2.3. Experimental setting

The experiment was conducted with 45 participants who were randomly divided over the three experimental conditions, in a between-subjects design. The participants had varying backgrounds. Eighteen participants were students of M.Sc. Human Geography and Planning. The other 27 participants were employees, mainly researchers, of the PBL. The mean age of the participants was 32.5 years (SD = 11.4), and 12 of them were women. All participants were shown to be experienced users of computers and 3D geo-visualization.

The experiment was performed in 2008 at two locations, an office at Utrecht University and at the Netherlands Environmental Assessment Agency, for students and employees, respectively. Desktop computers with 19" monitors were used at both locations, which were similar to the platforms used by policy-makers.

The experiment consisted of three parts (Table 1). The first part of the experiment measured the user's accuracy and efficiency in relation to the land use visualization. The participants performed a series of tasks that were representative of the actions of policy-makers when using the maps. These tasks were derived from a preceding study in which 12 policy-makers were interviewed thoroughly on how they used maps during the decision-making process (Colijn, 2008). The tasks were placed in the context of four task-scenarios, in which the participants were asked to explore locations for new industrial areas in a densely populated area and to consider the effects for other types of land uses. To resolve the questions included in these task-scenarios, participants needed to compare maps/layers of current and future land use and assess differences in distribution of land use types over time, thus estimating the area they cover. After each scenario, the participants were presented with a short questionnaire asking them to estimate which land use type covered the largest area in the current and future situations, and which land use types would suffer most as a result of proposed developments. We recorded the time a participant needed to complete each of the scenarios. After completing a scenario, participants also listed how often they had used the functionalities of the interface, such as zooming in or rotating. Examples of visualizations presented to the participants in the experiment are shown in Fig. 5.

The second part of the experiment focused on the appreciation and usability of the interface, and the aesthetic appreciation and recognizability of the type of visualization (raster cells, 2D-icons, or 3D-icons) that participants were shown in the experiment. On completing the scenarios, the participants first filled in a questionnaire consisting of 23 statements on the interface and general characteristics of the visualization, on a 7-point Likert scale with the option to note remarks. These included standard statements from the Computer System Usability Questionnaire – CSUQ – (Lewis, 1995) and cover system usefulness, information quality, interface quality, and overall satisfaction (Tullis & Albert, 2008). The statements were adapted to this application, referring to, for instance, navigation and orientation in the 3D environment.

Examples are provided in Table 1.

Next, for each of the 17 land use classes participants were asked to fill in a score to what extent they felt the used representation was: (1) easily recognizable and (2) aesthetically pleasing, on a 7-point Likert scale.

The aim of the third, and final, part of the experiment was to reveal the effect of the appreciation of the three types of visualizations on the affective appraisal of an environment. This is a process of which a viewer is not consciously aware but that may affect decision-making. Because the viewpoint in the GESO application ranges from high to low eye level altitude, we designed a series of questions that assessed the perceived quality of the area on a larger map scale. The participants were presented with

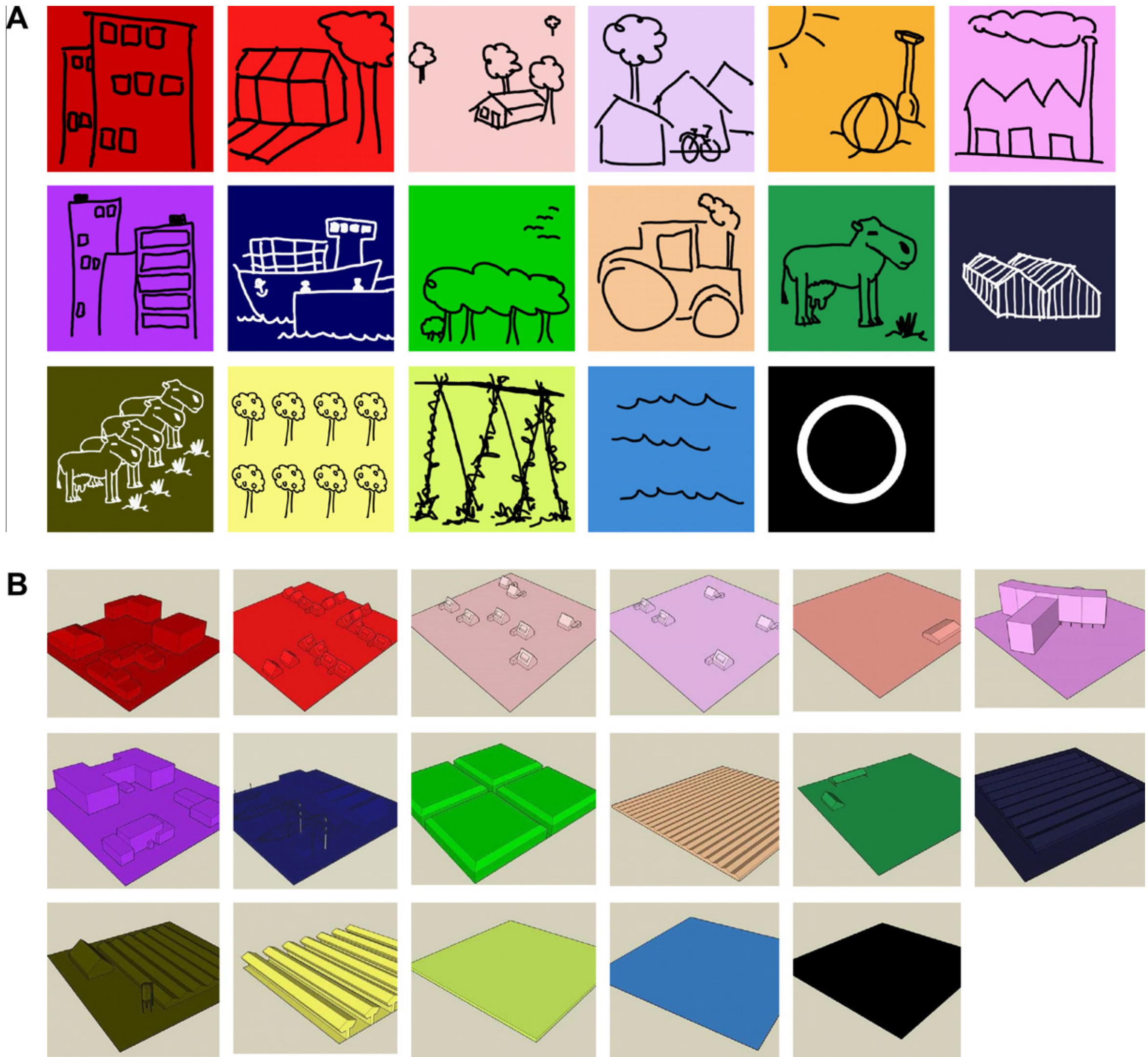

Fig. 4. 2D- and 3D-icons of visualized land use classes. The colors related to each land use class are exactly the same in every condition. (A) 2D-icons of future land use classes. (B) 3D-icons of future land use classes.

printed screenshots of seven environments (like Fig. 5B), again by the visualization type belonging to the experimental condition. We used printed screenshots so participants would not try to use the functionalities of the application, and for instance alter the viewpoint. The environments chosen were generic, meaning they did not represent any specific location in the Netherlands that might be known to the participants. The 50 questions relating to these environments were considered to affect individually-perceived environmental quality for living and recreational activities. They included air pollution, traffic noise, landscape characteristics, visual attractiveness, and public amenities (see Table 1). These questions were inspired by policy-objectives as given in the chapter two of the Dutch National Spatial Strategy (Ministeries van VROM et al., 2006), which range from safeguarding environmental quality and safety, conserving and enlarging available and accessible areas for outdoor recreation, preserving and increasing the variety between rural and urban landscapes, and improving the quality of life in urban conglomerations.

The participants were asked to answer the questions on the quality of the environments presented by scoring a 7-point Likert scale. The quality of the environment could not be deduced directly from the visualization. The participants had to construct a mental image of the environment and fill in gaps of information with their own knowledge and experiences. In research on the affective appraisal of real and virtual environments, semantic scales are generally used to assess the affective qualities of environments, for instance (Bishop & Rohrmann, 2003; Russell, Ward, & Pratt, 1981). These scales are valid when the viewer is located in the environment or perceives a representation of the environment as if located in the environment.

3. Results and analysis of responses

In this section, we focus on the results of the appreciation of the visualization and its effect on the appraisal of the environment (Colijn, 2008). We added certain results from the usability test concerning accuracy and efficiency, in order to give a contextual background to the findings on affective appraisal.

3.1. Part 1 of the experiment: efficiency and accuracy

Under all conditions, the number of correct answers was high, varying from 66% to 79%, which confirms that the GESO application supports the type of tasks evaluated here. 2D-icons and 3D-icons did not improve the accuracy or speed of the task performance significantly, compared to simple colored raster squares (Table 2).

Table 1
Outline of the experiment including examples of tasks and questions topics on the perceived quality of the depicted locations.

Experiment	Assessment of	Measuring instruments
Part 1	Task performance: accuracy and efficiency	Questions on results Questions on use of functionalities Time for task completion
Part 2.1	Appreciation and usability of the interface	23 statements on system usefulness, information quality, interface quality, and overall satisfaction, with a 7-point Likert scale Examples of statements: "It was simple to use this system." "When navigating I sometimes lost my sense of direction and location." "The names of the land use classes in the legend are easy to understand." "The visualization of current land use is easy to interpret." "The interface of this system looks nice." "The information as visualized in the environment seems reliable."
Part 2.2	Recognizability and aesthetic appreciation of the individual land use classes	7-point Likert scale for recognizability and aesthetic appreciation of each land use class
Part 3	Affective appraisal of the environment	Questions for seven environments: "How would you characterize the quality of this area for living/recreation/as a nature conservation area (depending on the area shown)?" followed by statements, with a 7-point Likert scale. Examples of statements: "The environment is spacious." "The environment is quiet." "The quality of the air is good." "The environment is attractive." "Shops and public services such as schools and public transport are easily accessible." (only used for assessment of living environment) "Recreational areas are plenty and nearby." (only used for assessment of living environment)

3.2. Part 2 of the experiment: appreciation of the interface and visualization

Participants in all conditions reported that the application was easy to learn (mean 5.9 on a 7-point Likert scale) and that the functionalities (rotate, zoom, and move) were easy to use (mean 5.1 on a 7-point Likert scale). In general, they were able to orient themselves in the 3D-environment sufficiently (mean 4.9). On the whole, the information represented in the visualization was deemed reliable (mean 4.6).

The appreciation of the interface, and of the visualization of the environment in its entirety, did not show significant differences between conditions. Only the visualization of future land use was considered more beautiful with 3D-icons, almost significantly ($F = 3.067$, $p = 0.057$).

Of the visualization techniques, the 3D-icons were appreciated most. Of the 17 depictions of land use, the 3D-icons scored higher 14 times (six times significantly). A post hoc Tukey test showed that the appreciation of the 3D-icons together was significantly higher than that of the colored squares ($F = 3.041$, $p = 0.046$). Fig. 6 shows the scores of the techniques over the three types of visualization.

When the scores for recognizability of all land use classes were summed, no significant differences between the three types of representations were found. A one-way ANOVA showed significant differences for only five land use categories. Post hoc Tukey tests resulted in a significantly higher score for the 2D-icons representing Recreation-day, Industrial area, and Glasshouse cultivation, and for the 3D-icons representing Sea harbour, and Stockbreeding-intensive.

The overall scores on recognizability and aesthetic appreciation of the three types of visualization are shown in Table 3.

3.3. Part 3 of the experiment: affective appraisal of the environment

Out of 50 items assessing the perceived quality for living and recreation, the condition with 3D-icons showed the highest scores for 30 occasions. The differences were rather small, however: Only in five cases was (ranging from urban to natural areas and form bird's eye perspective to ground level human perspective) there a significant difference ($p < .05$), and in two, the difference was nearly significant ($p \leqslant .075$). They concerned different aspects of four of the seven environments presented to the viewers. Twice the perceived quality of the area for living (a general judgment), and also twice the accessibility of public amenities scored higher in the 3D-icon condition. The attractiveness of the area, the spaciousness, and the perceived quality for recreation each scored higher in the 3D-icon condition once. The experimental group using 2D-icons scored significantly higher for only one item, whereas the colored squares not once. The 3D-icons also led to more convergence in the answers. The variance in the answers was significantly lower than in the other conditions ($F = 11.184$, $p = 0.00$). Furthermore, participants in the condition with 3D-icons used the option "cannot answer this question" less often (93 times under condition 1; 71 under condition 2; 63 under condition 3. The maximum number of answers for each type of visualization was 750).

4. Discussion and conclusion

On request of PBL, a Google Earth-based application has been developed to replace the A4-size hard-copy maps of their future land use studies. This application, abbreviated GESO, offers multi-visualization layers of current and future land use with two-dimensional and three-dimensional data of the complete national land area. Future land use classes may be viewed in colored raster cells, 2D-icons, and 3D-icons. As a reference to landscape features and patterns, the default Google Earth aerial pictures of the Netherlands were used as a visual background.

Appreciation of the GESO application in our experiment was high: the accuracy of the tasks performed, and the ease of use and high learnability of the interface reported by the participants, indicated that this is a valuable and reliable replacement for the printed maps that are currently in use.

Experimental results revealed a difference between colored raster cells, 2D-icons and 3D-icons with respect to affective appraisal. In this final section, we discuss these findings and propose an alternate outlook.

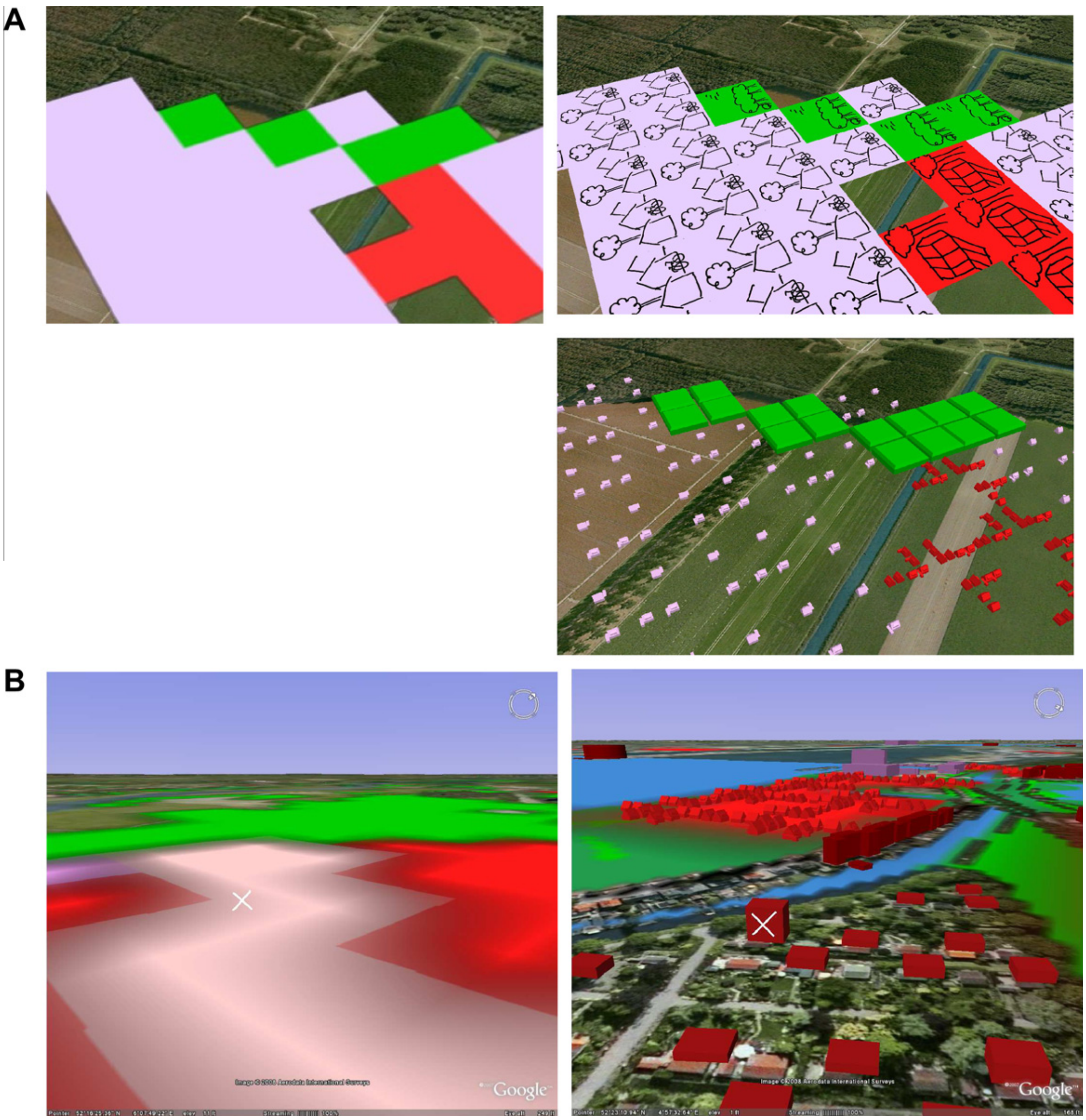

Fig. 5. Visualizations as used in part 3. (A) Impression of the three conditions: *upper left*: future land use by color hue of raster cells – condition 1; *upper right*: future land use by 2D-icons – condition 2; *lower right*: future land use by 3D-icons – condition 3, for environment 5 (recreational-residential living in a rural area). (see http://www.objectvision.nl/Geodms/products/3dshapes.htm). (B) Impression of hard copies as used during the experiment. Respondents have to visualize themselves on the location of the cross and give their opinion of environmental issues. Left picture shows environment 4 (residential living in an urban fringe) and the right picture environment 1 (residential living in a semi-urban area).

Table 2
Mean and standard deviation of the required time per task, in seconds.

Condition	Task 1	Task 2	Task 3	Task 4	Total
Color hue	360.2 (215.90)	277.3 (119.55)	307.0 (162.74)	172.0 (110.94)	1116.5 (531.1)
2D-icon	258.3 (105.95)	279.8 (91.42)	236.8 (85.50)	168.0 (58.20)	942.9 (296.6)
3D-icon	311.3 (116.42)	340.2 (129.34)	318.3 (204.66)	193.9 (79.30)	1163.7 (416.9)
Significance	0.21	0.25	0.32	0.68	0.34

4.1. Evaluation of the experiment

Evaluation of information visualization techniques is an intricate process. Most studies show weaknesses, for example, by substituting real and complex tasks and future users of the interface with simple tasks in laboratory experiments (Andrews, 2006). In this study, an attempt was made to approximate real usage with tasks designed to resemble the actions of policy-makers as much as possible.

The measuring instruments were designed specifically for this experiment. Although these methods included common techniques such as Likert scales, the questions used were specific to our goal, and the experimental results could not be directly compared to other empirical research in this field. Because the number

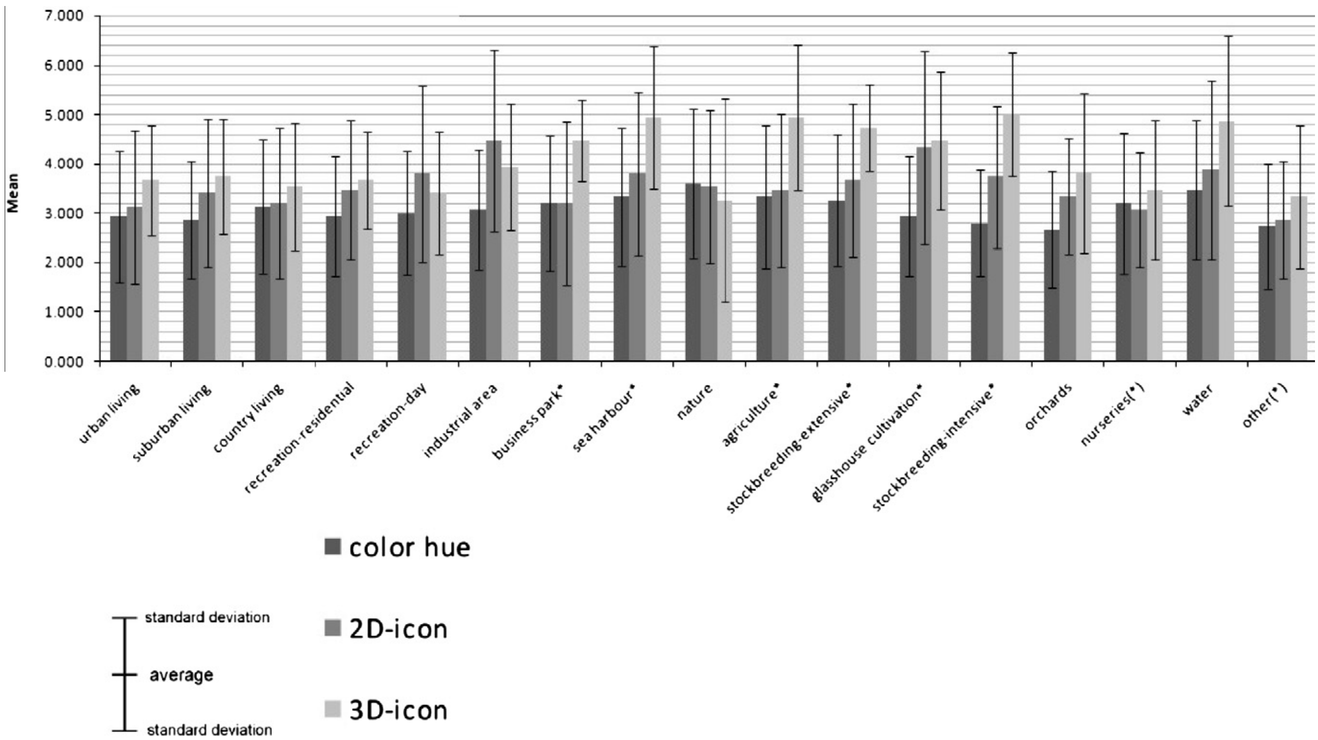

Fig. 6. Scores on the appreciation of the types of visualization in all three conditions. The bar charts present the mean and standard deviation per condition per land use class. The three conditions are positioned on the *X*-axis (cond. 1 = color raster cells; cond. 2 = 2D-icons; cond. 3 = 3D-icons) and the mean and standard deviation of the 7-point scale Likert scores on the *Y*-axis. *Significantly higher scores for the 3D-icons, p < .05, two-tailed, are marked with* *. *Significantly higher scores for the 3D-icons, p < .05, one-tailed, are marked with* (*).

Table 3
Mean of all scores on recognizability and aesthetic per condition on a 7-point Likert scale.

Condition	Recognizability	Aesthetic appreciation
Color hue	4.67	3.09
2D-icon	4.88	3.55
3D-icon	4.58	4.07

of participants was relatively small (15 in each condition), a second series of experiments with more participants would increase the validity of the results.

Although the participants of the experiment had knowledge of cartography, geography, and planning issues, they may have responded differently than real policy-makers when using the tool in an actual working situation. Other studies have shown that the meaning and understanding of visuals may vary greatly depending on the knowledge domain, the roles, and the tasks that the users perform (MacEachren et al., 2005). Participation by sufficient numbers of policy-makers in future experiments is probably not feasible, but a study applying techniques such as observation and interviews may produce valid results that help us interpret and contextualize our experimental findings.

Nevertheless, the results of the experiment show that representation has an effect on the appraisal of a viewer, which is relevant in many actual situations.

4.2. 2D vs. 3D in relation to affective and cognitive responses

2D-icons and 3D-icons, compared with colored raster cells, did not improve the efficiency or accuracy of the participants in this experiment. This seems a logical consequence of the fact that the 2D-icons and 3D-icons did not score significantly higher on recognizability than the colored squares. In the application, visualization elements were relatively large, and participants could zoom in and out, navigate and rotate, allowing them to take positions which were optimal for viewing the maps. The color differences were apparently clear enough for the number of land use types presented. The GESO application offers quite a different presentation and functionality compared to the maps in A4-format that are currently in use at the PBL. In the latter, it is difficult to assess color differences, and much effort is needed to compare maps.

The higher appreciation of 3D-icons may be explained by the expectations of viewers. The 3D-icons 'blend in' better with the Google Earth visualization and are thus more aesthetically pleasing. They add expected variations in height, thereby increasing the degree of similarity to the geometric detail of the photographs offered by the Google Earth. Less abstract, or more 'realistic' representations are generally preferred in visualizations, even when they are not required for the tasks at hand, such as in this case (Hegarty et al., 2009; Smallman & St. John, 2005).

The perceived quality of the environments for living and recreation was higher in the condition with 3D-icons. This may be an effect of the 'transfer' from the appreciation of the visualization technique, to the perceived environment. The answers of participants in the condition with 3D-icons showed less variation than in the other conditions. The greater correspondence of the participants' assessments may be explained by the role of 3D-icons in helping viewers to create a mental representation of an area, activating relevant knowledge and eliminating uncertainties in the viewers' mind (Appleton & Lovett, 2003). The uniformity in assessments is not an indication per se of the correctness of the predictions, however.

Our conclusion from this experiment is that visualization technique influences the perceived quality of the visualized environments. This perceived quality includes features of the environment that cannot be deduced from the visualizations directly, but that are construed by the viewer from memory images and associated affect. This effect should be considered in the design of visualizations for strategic government policy, as well as for other purposes.

4.3. Importance of affective qualities of visualizations for policy-makers

According to Sheppard (Sheppard & Cizek, 2009), every new powerful technology has the potential of misuse. Because virtual globes are universally accessible, the chances of misuse are great, and miscommunication can easily occur. "The realism, perspective views, and social meanings of the landscape visualizations embedded in virtual globes invoke not only cognition but also emotional and intuitive responses, with associated issues of uncertainty, credibility, and bias in interpreting the imagery." (Sheppard & Cizek, 2009).

In research on decision-making, the importance of affective response is being increasingly recognized. According to the theory of Slovic, Finucane, Peters, and MacGregor (2007), representations of objects and events in people's minds are "tagged" with affect to varying degrees. In the process of making a judgment or decision, all of the positive and negative tags consciously or unconsciously associated with the representations interfere with rational arguments. As Slovic et al. (2007) stated, "Using an overall, readily available affective impression can be far easier—more efficient—than weighing the pros and cons or retrieving from memory many relevant examples, especially when the required judgment or decision is complex or mental resources are limited." Our experiment shows evidence that the representation may bias the affective appraisals of a viewer, which in turn may influence judgment and decision-making.

4.4. Research outlook

So far, the GESO application has been used to evaluate affective and cognitive responses to three types of visualizations that represent future land use. Following the proposition that any representation should be designed for the tasks in hand and offers the cognitive and affective information the user needs when performing the tasks, we advocate ongoing field experiments on affective responses to two- and three-dimensional visualization. These experiments should be conducted with well-defined target groups and preferably in the domain of wicked problems in spatial planning and design (Ohl, 2008) with a high impact on society, such as environmental planning, in relation to urban and landscape planning. Such research not only provides findings on the affective and cognitive meaning of different types of graphic representations, but also simultaneously fuels the debate on aesthetics and ethics by its examples and applications.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.compenvurbsys.2010.07.001. These data include Google maps of the most important areas described in this article.

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