ANIMATED REPRESENTATION OF UNCERTAINTY AND FUZZINESS IN DUTCH SPATIAL PLANNING MAPS

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ABSTRACT:

This paper concentrates on developing methods to effectively visualize uncertainty and fuzziness in animated representations by various combinations of graphic and dynamic visualization variables, and selecting or developing a method by which the usability of uncertainty and fuzziness displays in spatial planning maps can be evaluated. As a case study, provincial level spatial planning data of Noord-Brabant, the Netherlands were used. A conceptual framework for animated representation of uncertainty and fuzziness in Dutch spatial planning maps was proposed. Subsequently, the animated representations were designed and implemented in a prototype. For the usability study, the prototype was evaluated in a focus group session and a task and questionnaire session. The results show that animated representations can be recommended to make spatial planners better aware of uncertainty and fuzziness in Dutch spatial planning maps than by using current visualizations.

1. INTRODUCTION

Spatial planning is a matter of policy by which the government gives conscious direction to spatial development and it also guides the process. Spatial planning in the Netherlands takes place within the administrative organization at three hierarchy levels i.e., national, provincial and municipal levels. The national level provides the global plan of the Netherlands. Detailed planning is done at municipal level where zoning plans are produced. The Dutch Ministry of Housing, Spatial Planning and the Environment promotes the digitizing of spatial plans into geographic datasets (DURP initiative). It aims at digital, exchangeable and comparable spatial plans (Vullings et al., 2007). Therefore, there is a transition going on in which plans at all planning levels will be digitally stored and made available for users. Many municipalities and provinces have already achieved digital plans for new spatial plans. The initial idea is that when plans are digitized and exchangeable, comparison of them will not be a problem. However, the first experiences show that not all planning objects are comparable because some of them are uncertain or fuzzy. Uncertainty and fuzziness limits the preparation and use of digital spatial plans if they are not dealt with in a right way. To overcome these limitations, the GeO3 project "Omgaan met onzekere planobjecten bij monitoring en analyse van ruimtelijk beleid" (dealing with uncertain planning objects to facilitate monitoring and analysis of spatial policy) has been initiated in 2005. The objective of GeO3 project is to study various properties of uncertainty in spatial planning objects, to define them and to suggest solutions to deal with them. The GeO3 project has already delivered a framework for dealing with the uncertainty in spatial planning (Vullings et al., 2007). Improved visualization is one of the solutions that is suggested to deal with the uncertainty and fuzziness.

The problems of uncertainty and fuzziness which the improved visualization can deal with occur mostly in the plan preparation phase at lower than national levels, particularly at municipal level. One problem is that planners are not able to correctly judge how some planning objects that are continuous in reality influence options for possible future types of space (or land) use. This happens because these continuous features are conventionally represented by crisp boundaries on the map. For example, noise in reality consecutively decreases away from the noise source. The wind and other natural factors influence how the noise spreads around the source. But noise in spatial planning maps is usually expressed by a solid and crisp noise contour around a noise source at one noise level only. Therefore, the planners are not able to understand their real impact. The second problem is created by cartographic symbols that incompletely define planning objects in spatial planning maps. The location, boundaries, orientation, size and/or shape of these objects are not well defined, and can therefore not be judged exactly. A typical example is a zone or arrow symbol to indicate roughly how an ecological transition zone should be extended, but its exact location, shape, size and sometimes direction are uncertain. Therefore, some spatial planning decisions which are made by spatial planners are based on uncertain information. The presence of the problems above imposes research challenges on visualization of uncertainty and fuzziness in spatial planning maps. By providing information about data uncertainty and fuzziness in an explicit visual way, spatial planners will be better aware and informed about the uncertainty and fuzziness, and are then able to better evaluate which options are available for future space use.

The basic method of visually representing uncertainty and fuzziness is based on the direct application of Bertin's (1983) graphic variables and their extensions (e.g. MacEachren, 1992). The original set of graphic variables includes location, size, (colour) value, grain (texture), colour (hue), orientation and shape. Still, other variables have been suggested as an addition to the original variables of Bertin, for example: colour saturation, crispness, transparency, resolution (MacEachren,

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1992). Another way to improve the effectiveness of uncertainty and fuzziness representation is by applying dynamic visualization variables. Six of these variables have been originally elaborated by Dibiase et al. (1992) and MacEachren (1994), Blok (2005) concluded that two of them (rate of change and synchronization) can better be seen as effects (e.g. of interactions with other dynamic variables) and four dynamic visualization variables are display date (or moment of display), duration, sequence (or order) and frequency. In cartographic animation data are represented by graphic variables in the spatial dimensions of the maps. In addition, dynamic visualization variables are applied in the temporal dimensions (display time) of a running animation. The combination of graphic and dynamic visualization variables can provide some animated cartographic symbols, e.g. moving or blinking symbols, which will be used to represent uncertainty and fuzziness in this paper.

Visualization of geographic information uncertainty and fuzziness has been a subject of increasing attention from researchers since the beginning of 1990s. Applying appropriate visualization techniques could provide more understandable (spatial and temporal) information of fuzziness and data uncertainty (van der Wel et al., 1994). A number of visual methods have been suggested and used for the visualization of uncertainty and fuzziness. Some methods start with Bertin's graphic variables. MacEachren (1992) considered *colour saturation* as "the most logic one to use for depicting uncertainty". He proposed to use saturated hues for map elements with a high level of certainty, while correspondingly less saturated colours for less certain information, while Brown & van Elzakker (1993) also argued that colour saturation is important, in addition to attribute information in a bivariate map (containing data and its uncertainty) . They also discussed the practical limitations of the use of saturation to signify uncertainty, such as low saturated colours may be difficult to distinguish from each other. Van der Wel et al. (1994) used a continuous scale of grey tones (i.e. colour *value*) to visualizing fuzzy class boundaries on a map. The result creates a perception of focused and less focused areas which can correspondingly be understood as certain and less certain areas. Davis and Keller (1997) concluded that the best way to statically represent uncertain information is using colour hue, colour value, and texture. Jiang et al. (1995) proposed a modified HLS (hue, lightness, saturation) colour system to display nominal categories by hue, data values by saturation and uncertainty by lightness variations, and it was applied in fuzzy overlay operations for visualizing fuzziness. Hengl (2003) presented a similar method using hue, saturation and intensity (lightness) colour models to represent uncertainty associated with spatial prediction of continuous and discrete variables in soil and landform mapping. Among the above researches, the three dimensions of colour (i.e. hue, value and saturation) play an important role in representing uncertainty. Some approaches to visualizing information uncertainty are centered on the use of extensions of graphic variables. MacEachren (1992) addressed the potential of three other graphic variables to depict uncertainty: crispness; resolution and transparency, where more transparent means lower level of uncertainty. In contrast with transparency, Drecki (1999; 2002) proposed an opacity method because he argued that it was more logic to consider opaque objects as the certain one. Therefore, in his opacity method, the highly transparent objects indicate uncertainty while less transparent objects are considered as certain ones. Blurring is the "removal of spatial high frequency details from information" (Russ, 1999; Brown, 2004). An example of

application of blurring was provided by Pang et al. (1997) in which motion blurring was used in animation to indicate the range of motion paths. Blurring is recognized as an effective method for signify uncertainty, because viewers intuitively associate such visual representations with data uncertainty (Brown, 2004; Griethe & Schumann, 2006). Therefore blurring is often applied in current researches (e.g. Pang et al., 1997; Botchen et al., 2005). The above four methods employ different visual variables i.e. crispness, resolution and transparency to signify uncertainty. All of them indicate immediate and intuitive contrast between certain and uncertain information with the variation in these visual variables. Although these methods can not provide precise values of uncertainty, the user can distinguish different levels of uncertainty. They are suitable to consider as alternative methods in this research to depict uncertainty and fuzziness in spatial planning maps.

To represent uncertainty in an animated way, methods like blinking and other animation techniques are developed. Several authors have explored the potential of animation to represent aspects of uncertainty. A typical example of animation is the blinking effect which is created by employing frequency or duration of the display time of map features, usually proportional to their fuzziness or uncertainty. Frequently blinking objects on the screen can be used to indicate high uncertainty values while more stable displayed information represent less uncertainty values (Fisher, 1994). Fisher (1993) illustrates a complex blinking effect by giving an example of soil grid cells which change their colour according to the proportion of being assigned to one of the existing soil classes. While Fisher's methods focused on direct representation of uncertainty using frequency, others have emphasized indirection representation of uncertainty through animated sequences of realizations. MacEachren (1992) used sequential alternating presentation as a method for presenting uncertainty. Ehlschlaeger et al. (1997) focused on animated visualization of the impacts of elevation certainty. The focus is on optimal path calculations based on an array of 250 possible DEM configurations. This animation presents sequences of complete realizations rather than animated sequences of one category at a time. Bastin et al. (2002) proposed a sequences animation to depict fuzziness of categorical data classification. While the representation of uncertainty using animated cartographic symbols has received some attention, Shepard (1994) proposed a range of animated symbols that exhibit 'time-varying symbolism behavior' (i.e. animated cartographic symbol behavior). Symbol behaviors include blinking or motion/positional change, to visualize geographic data. Although he did not apply the time-varying symbolism behavior in the uncertainty or fuzziness domain, his framework seems potentially useful. Animated cartographic symbols were applied and evaluated in this research as well. In addition to graphic and dynamic visualization variables, interaction can be applied. A known example is the "clickable map" where uncertainty can be represented by mouse interaction such as clicking (van der Wel et al., 1998). Howard and MacEachren (1996) proposed uncertainty representation by means of users interaction. More recently, Lucieer et al. (2004) utilized interactivity to develop an exploratory visualization environment to enable the analysis of classification of remotely sensed imagery and related uncertainty. The techniques presented above provided an overview of the visualization of uncertainty or fuzziness. The decision on which of these techniques to choose strongly depends on the intended goal.

The remaining part of the paper is organized in six Sections as below: Section 2 defines the concept of uncertainty and fuzziness in Dutch spatial planning maps; how uncertainty and fuzziness aspects can be visually represented is described in Section 3, animated cartographic symbols in relation to uncertainty and fuzziness aspects of the planning objects are addressed in Section 3.1. Section 3.2 attempts to establish a conceptual framework for the use of animated cartographic symbols to represent uncertainty and fuzziness aspects in spatial planning maps. Section 4 analyses the evaluation and results. First, Section 4.1 highlights the case study data used in this research. Section 4.2 describes the initial prototype design. Section 4.3 first summarises the evaluation results of the prototype in the focus group session, then analyses the usability results and finally discusses the results from both evaluations. Section 5 outlines the main conclusion.

2. UNCERTAINTY AND FUZZINESS IN SPATIAL PLANNING MAPS

The terms uncertainty and fuzziness are often confused. The aim of this Section is to remove possible confusion about intermixed terminology by defining the concepts in the context of Dutch spatial planning maps. The definition of uncertainty given by the GeO3 project is "the acknowledgement that one does not know the situation of a system exactly because of imperfect or incomplete information" (Vullings et al., 2007). Uncertainty corresponds to a lack of knowledge about an object, a fact that is usually caused by limitations of the observation. The spatial planners are uncertain about the real situation of planning objects in spatial planning maps due to imperfect visual representations in the map by symbols that do not indicate what the (level of) uncertainty is, therefore they are unable to deal with it properly. Fuzziness is "a type of imprecision in characterizing classes that for various reasons cannot have, or do not have sharply defined boundaries." (Burrough, 1996). Fuzziness is usually an inherent property of the geographic phenomenon itself. It means that the considered object or phenomenon cannot be precisely represented, such as a noise boundary and a coastline.

For the two sources of uncertainty and fuzziness in spatial planning maps (which are incompletely defined planning objects and discretely defined continuous phenomena, i.e. fuzzy objects), five uncertainty and fuzziness aspects can be distinguished in the geometric domain (see Figure 1). These are location, boundary, orientation, size and shape. Uncertainty and fuzziness exists in these five aspects. The five geometrical aspects of uncertainty and fuzziness are all applicable to line symbols. It means that spatial planners need to deal with these uncertainty and fuzziness aspects when they prepare spatial planning decisions for planning objects represented by line symbols. Orientation as an aspect of uncertainty and fuzziness is not applicable to point and area symbols and to fuzzy point planning objects because orientation does not have influence on them when spatial planners prepare planning decisions. Although line and area symbols can also be used to represent fuzzy planning objects, this research focused on point sources of noise, conventionally represented by (crisp) *point* symbols only.
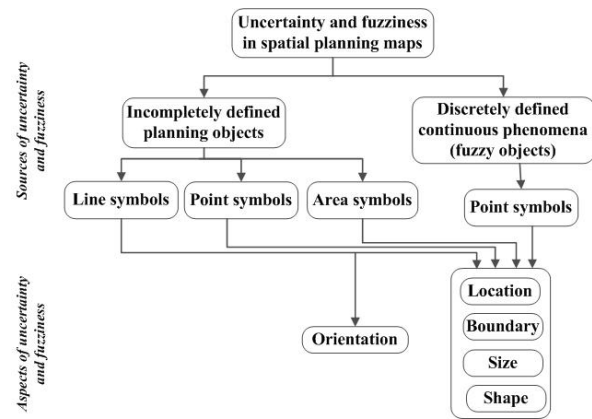

Figure 1. A taxonomy of uncertainty and fuzziness in Dutch spatial planning maps in the context of this paper

3. CONCEPTUAL FRAMEWORK

3.1 Animated cartographic symbols

In static maps, cartographic symbol appearance is controlled by the use of graphic variables. In animated maps, the graphic variables may be made to vary in display time by means of using dynamic visualization variables to reflect attributes of the features (Shepard, 1994). Changing basic graphic variables including location, size, value, grain (texture), colour (hue), orientation and shape and their extensions including colour saturation, transparency and blurring can be used to represent animated cartographic symbols. Five aspects of uncertainty and fuzziness in spatial planning maps (location, boundary, orientation, size and shape) are distinguished in Section 2. Some animated cartographic symbols are suggested to deal with each of these aspects (see Table 1). From a design perspective, an effective animated cartographic symbol depends on ways in which the dynamic visualization variables are linked to graphic variables (Blok, 2005). In this research, moment of display and order are the dominant dynamic visualization variables.

Uncertainty and fuzziness aspects	Animated cartographic symbols using change in the graphic variables in display time		
Location	Location change	Size change	
Boundary	Colour saturation change, Value fade	Transparency change	Blurring
Orientation	Orientation switch		
Size	Size change		
Shape	Shape morphing		

Table 1. Animated cartographic symbols using change in the graphic variables in display time to represent aspects of uncertainty and fuzziness

3.2 Conceptual framework

A conceptual framework for using animated cartographic symbols to represent uncertainty and fuzziness in Dutch spatial planning maps is shown in Figure 2. The components included in the conceptual framework are the graphic and dynamic

visualization variables, animated cartographic symbols and the aspects of uncertainty and fuzziness. Combining these components results in an animated representation of uncertain and fuzzy planning objects. A combination of the graphic and dynamic visualization variables can create animated cartographic symbols and effective animated cartographic symbols can be used to represent five aspects of uncertainty and fuzziness of planning objects. A planning object which may have some or all of the aspects of uncertainty and fuzziness can be represented by a combination of animated cartographic symbols. For example, a fuzzy point planning object includes locational, boundary, size and shape uncertainty. Locational uncertainty can be represented using locational change, boundary uncertainty can be indicated by boundary blurring, while size and shape uncertainty can be represented by size change and shape morphing. Therefore, it is expected that the combined effect of these animated cartographic symbols together can reveal the uncertainty information of the fuzzy point planning object.
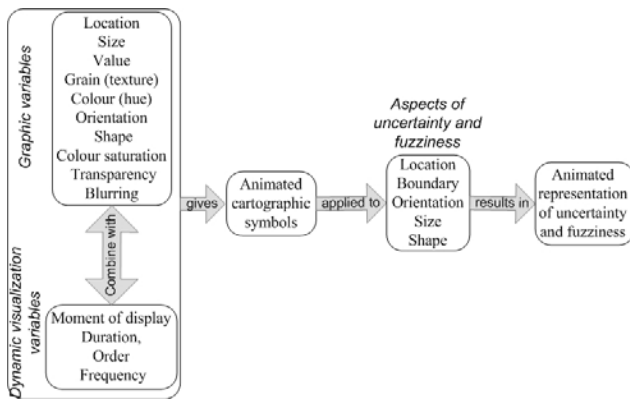

Figure 2. A conceptual framework for animated representation of uncertainty and fuzziness of planning objects

4. EVALUATION

4.1 Case study

The case study area is the province of Noord-Brabant which is located in the south of the Netherlands. The first plan map: main environment structure ("plankaart 1: ruimtelijke hoofdstructuur") of the Noord-Brabant regional plan of 2002 (Streekplan Noord-Brabant 2002) was chosen as case study data in this research (see Figure 3). A subset of layers was selected as examples of uncertain or fuzzy planning objects (see Table 2), the selection was made such that the sources and aspects of uncertainty and fuzziness conceptually defined in Section 2 are both involved. The uncertainty and fuzziness information was extracted and summarized from the Noord-Brabant regional plan text (Noord-Brabant, 2002). In addition, the three map layers that are emphasized in Figure 3 impose some limitations on implementation plans in reality:

- GHS_nature and GHS_agriculture (GHS stands for Groene HoofdStructuur, or Main Green Structure). They should not be occupied by other planning objects because their boundaries and surface are strict;
- AHS_landscape (AHS stands for Agrarische HoofdStructuur, or Main Agricultural Structure). AHS landscape areas sometimes might be mixed with other

planning objects. In such cases, nature and landscape values should be preserved, or else compensated.
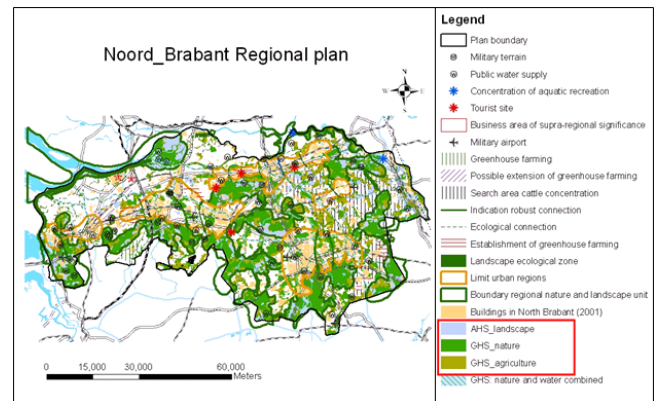

Figure 3. Overview of the Noord-Brabant regional plan 1

Sources of uncertainty and fuzziness		Case data layers
Incompletely defined planning objects	Point	Aquatic recreation
	Line	Landscape ecological zone
	Area	Greenhouse farming
Discretely defined continuous phenomena	Point	Noise area and boundaries

Table 2. Examples of uncertain and fuzzy planning objects used in this research

4.2 Prototype development

A prototype for the animated representation of uncertainty and fuzziness of planning objects was designed and implemented based on the concepts indicated in the conceptual framework. The aim was to use the prototype for demonstration and testing of the animated representations of different planning objects to improve their usability. The appearance of the prototype is represented in Figure 4. Two map display windows were designed in the prototype. The top left window is a map window for the representation of the regional planning map of the province Noord-Brabant. When a user clicks on uncertain or fuzzy planning objects, their animated representations are displayed in the right window (the animated representation window) at a larger scale than in the map window. Therefore, the animated cartographic symbols can be better and more accurately displayed. The uncertainty information window at the bottom was designed to display detailed uncertainty information in text about the planning objects. Examples of point, line and area symbols that represent incompletely defined planning objects and point symbols that represent discretely defined, continuous phenomena were selected for animated representation in the prototype (see Table 2). For each case, two or three animated cartographic symbols were designed, taking into account their uncertainty information and the limitations of GHS nature and agriculture and AHS landscape (as indicated in section 4.1). A control panel which included BACK and NEXT buttons was designed to facilitate usability testing. In addition, some animated instructions to be displayed in the map window were designed to guide users through the usability tasks later on.
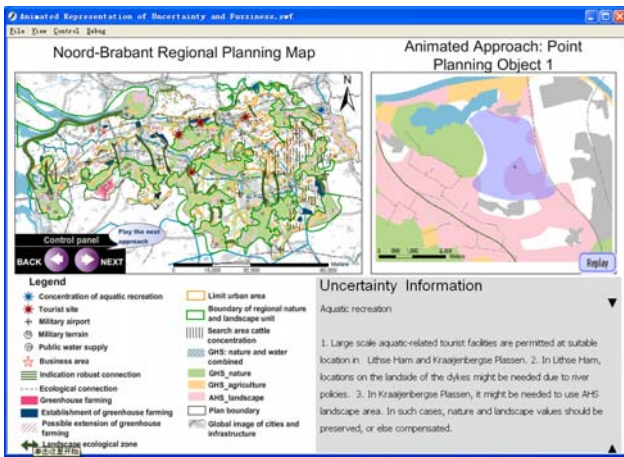
Figure 4. The display of the prototype window

4.3 Evaluation results and discussion

The usability of uncertainty and fuzziness display in spatial planning maps was evaluated after the prototype was developed. The evaluation was done in two phases. The first evaluation was a focus group session which was selected as an evaluation method because it is effective and fast for getting first impressions about the prototype design. A goal of the focus group evaluation was to obtain feedback on a first design of the symbols. In the focus group session, six domain experts evaluated the effectiveness of the symbols in the context of their domain. Most experts mentioned that transparency is a useful graphic variable to design animated cartographic symbols because the degree of transparency does not obscure other planning objects in the spatial planning maps. The experts could not indicate what their preference was in case of alternative visualizations for a planning object, because they believed that selection of the different methods should depend on the tasks and user requirements. Finally, the question if such an animated representation could support experts to be better aware of, and informed about, the uncertainties, was addressed. All experts agreed that it would support spatial planners to be better aware of the uncertainty and fuzziness.

After the focus group session, all reported wishes/suggestions provided by domain experts were added to/changed in the prototype. Subsequently, a task and questionnaire session was held to learn about the effectiveness, efficiency and the degree of satisfaction of the animated representations in the prototype. Nine participants from ITC, from the fields of urban and regional planning (6) and geovisualization (3) participated. The questionnaire (consisting of mainly closed questions and additonal options to explain answers) was considered for the second session because it can be easily summarized and it gives some quantitative results. The main goal was to assess the usability score of the proposed animated representations. The scenario of the test tasks was broadly described: an expert involved in spatial planning needs to consult spatial plans in the preparation phase of a regional implementation plan. He/she wants to become aware of the uncertainties and fuzziness of the objects (e.g. be warned in case of a fuzzy boundary) to evaluate the impact on the execution of the spatial plans. The scenario was accompanied by a number of tasks to be performed. The tasks were formulated to assess the different animated representations of the four types of planning objects mentioned in Table 2.

The usability results are shown in Table 3. Analysis of the results and users feedback reveal that the difference of usability scores of different approaches for the same planning objects is very small. There is no obvious preference. In addition, one participant mentioned that he got confused about the point planning objects. He expected, for example, that aquatic recreation was a point object and did not understand why the symbols showed it as areas in the animated representation window. This confusion was caused by the fact that a planning object that is represented by a point symbol (e.g. a star) in a map that does *not* show uncertainty and fuzziness is represented as area symbol in the prototype to signify the space available for such a planning object. Therefore, point, line or area refers to the symbols on conventional planning maps, not necessarily to the planning objects themselves. Such confusion should be avoided in future research.

According to the literature (such as Nielsen, 1993), an optimal number of participants for a usability testing is 3-5. Although 9 participants are used in this research, it is not enough to really quantify the results and make them statistically valid with only 9 test participants. Therefore, more participants are suggested for further research. Furthermore, if realistic planning tasks with detailed plan regulations could be employed to test the usability of the uncertainty and fuzziness representations, these tasks may help the participants to better understand the animated representations, and therefore more realistically assess the animated representations.

Planning objects types	Animated approaches number	Number of answers	E	EF	S	Average score
Point planning objects	1	7	3.29	3.57	3.29	3.83
	2	6	3.83	3.83	3.5	3.72
Line planning objects	1	7	3.71	3.86	4	3.87
	2	7	3.14	3.14	3.14	3.14
	3	9	3	2.89	3.2	3.03
Area planning objects	1	8	4.13	4	3.88	4.00
	2	9	3.33	3.33	3.22	3.29
Continuous planning objects	1	6	3.67	3.67	3.33	3.56
	2	6	3.17	3.5	3	3.22

Table 3. Averaged numerical results of the usability of individual animated approaches for each type of planning object (E= Effectiveness, EF= Efficiency, S= Satisfaction). The maximum possible score in each case is 5

5. CONCLUSIONS

The focus of this research was on the use of animated representations to display uncertainty and fuzziness in Dutch spatial planning maps. The research has limited itself to animated representations by means of the combination of graphic and dynamic visualization variables. Investigation into animated cartographic symbols and evaluation of their use in a prototype by different kinds of domain experts in spatial planning and visualization has been performed to meet the research objectives. The results show that all the suggested animated cartographic symbols that were tested gained moderate or higher than moderate effectiveness, efficiency and satisfaction. It means that the combination of the suggested

variables can be recommended to aid spatial planners in making better decisions, but some finetuning might still be necessary.

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