Plausibility validation of computer generated landscape configurations for use in spatial planning

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ABSTRACT: In this paper, a validation approach is presented to test the plausibility of computer-generated landscape configurations for use in collaborative spatial plan-making processes. Based on user-defined landscape typologies, the computer is able to create geo-referenced plan alternatives at the landscape component detail level. This is expected to be useful, to enable discussion among multiple actors about plan alternatives, at a more comprehensable level of plan visualisation. A validation experiment based on real data (topographic map 1:10000) is designed to prove that the generated landscape configurations are plausible alternatives for hand-made configurations. Plausibility of configurations is unraveled into subjective and objective plausibility. The experiment form is: a design quality test, a representativeness test and an evaluation dimensions test.

1 INTRODUCTION

Nowadays, contemporary strategic spatial plan-making in the process of drawing up regional development plans in the Netherlands, is largely about participation, collaboration and communication. (Däne & van den Brink 2007). Governmental planners and interdisciplinary professionals, private organizations and representatives of civil society rely on each other to develop high quality spatial plans. The challenge is to reconcile all conflicting interests into a realistic development vision (Spaans 2006).

Not many incentives in digital planning support and land-use modelling have focused on supporting this complex communicative and collaborative plan-making process effectively (Geertman and Stilwell 2003a, Vonk 2005). In this specific phase of the wider planning process, focus is primarily on the collaborative development of a variety of plan alternatives to be decided on in politics.

Based on practical experience, we think digital planning support tools should be developed to facilitate and structure information flows between the various actors in such a setting. Important requirements are that all actors can operate, express and explore their ideas and opinions at their spatial level of interest. Furthermore, that a common flexible graphical 'language' is available to promote mutual understanding on proposed developments (top-down as well as bottom-up) and their implications. This visualisation should be specifically tailored to the requirements for each separate phase of the plan-making process.

Some incentives have mainly focused on sketch planning tools to support early phases of scenario building with as final graphical result 'sketchy' (GIS-based) maps (Geertman and Stilwell 2003b, Hopkins et al. 2004, Harris 2001). Others addressed the use of virtual reality and CAD-environments to support bottom-up development proposal visualisation and management (Hatna 2007, Kwartler and Bernard 2001). We bridge the gap by developing a framework for efficient and effective multi-level and multi-discplinary plan-making and evaluation (Slager et al., 2007).

One of its core components is the Landscape Generator (LG) which produces locational landscape configurations, taking user-defined landscape typologies as input (Slager et al. in prep). In contrast, where other land-use methods and models often have predictive purposes, the LG here has only limited intentions to be predictive or prescriptive. Its output is a means to support efficient communication of landscape development on the most comprehensible level of detail. Its purpose is to 'step' through scale levels, by efficiently producing future configurations acceptable for the actors as initial position for the next level of detail to be discussed on. Or to give them a detailed view of how the landscape might transform when the intended developments are realized.

With the LG landscape components, like buildings, trees and other land cover are in proportions (according to typology) and with a certain logic dispositioned in an area a-priori demarcated by the user. After allocation, the system offers functionality to easily adapt the landscape configuration to additional user demands. Most advantageous of this approach is that actors can flexibly create and communicate strategic development alternatives at different scales, with accompanying detail level. Furthermore, several GIS-based analytical evaluation models need this input level of data to produce plan performance output.

Besides, the intrinsic nature of the LG makes it possible to carefully validate the simulated output. Contemporary land-use models act on different, often more abstract spatial levels and validating its output has always been a difficult task. (Batty & Torrens 2005)

In this paper, we present a specific experiment to validate the plausibility of generated configurations, keeping in mind its before mentioned use. Validation (McCarl 1984) refers to activities designed to determine the usefulness of a model or method:

1) whether it is appropriate for its intended use(s);
2) whether the model contributes to making "better" decisions, and;
3) how well the particular model performs compared to alternative models.

As common in scientific research, our focus is primarily on "validity in use". This article is organized in five sections. Firstly, the validation approach in this study is presented. In the second section, the design of the validation experiment is elaborated on in detail. Thirdly, more information is given on technical means and execution of the experiment. Fourthly, several statistical approaches are suggested, where finally in the discussion section, use and necessity of this validation approach is argued.

2 VALIDATION APPROACH

2.1 *Landscape configuration validation*

This section outlines the approach applied to validate the developed spatial plan-making method. (Slager et al. in prep.) Sargent (2007) identifies three major methods for verification and validation of simulation models in a model development process (see figure 1):

1. conceptual model validation; in which is tested if the theories and assumptions underlying the conceptual model are reasonable for the intended purpose of the model;
2. computerized model verification; in which is tested if the conceptual model is correctly implemented into a computer program;
3. operational validation; in which is tested if the model's *output behavior* has *sufficient accuracy* considering its *intended purpose* over the *domain* of the model's *intended applicability*.

This paper focuses on the operational validation. Validation of the methodology is performed on *its output*: in this case the generated landscape configurations. The *intended purpose* is to generate plausible landscape configurations on pre-defined locations, based on a user-defined landscape typology. The test analyses whether generated landscape configurations are *sufficiently accurate* to be considered plausible situational elaborations in the (early) design phase of a strategic spatial plan-making process. A configuration is in this case considered plausible, if it is accepted as starting configuration of an user-introduced development idea. The configuration can ultimately serve as input for GIS-based analytical evaluation models which need input at this scale level and which produces indicative values for plan quality. It's *intended applicability* is restricted to dimensions of a real-world study area in the Netherlands, user-defined locations (and its size) and the allocation of user-defined and catalogued landscape typologies. In the validation of the plausibility of landscape configurations, concepts of turing tests, internal validity tests and statistical validation are used and combined.

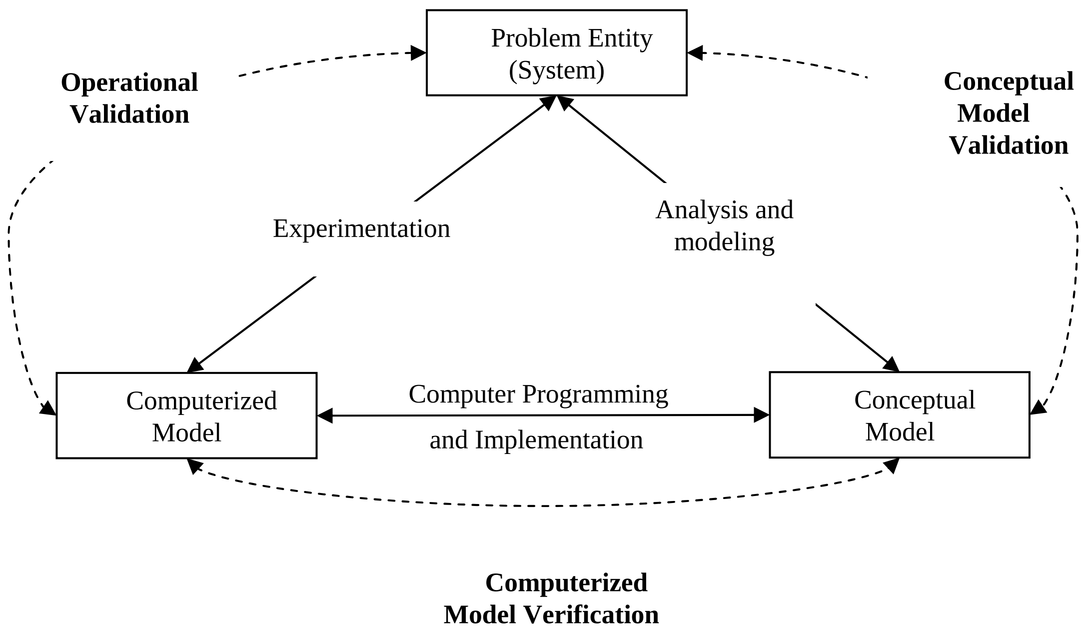

Figure 1. Simplified version of the modeling process and corresponding verification and validation (after Sargent 2007)

2.2 *Plausibility tests*

Three particular research questions to be answered in this validation approach are:

1. To what extent does the subjective plausibility of computer-generated landscape configurations differ from the subjective plausibility of expert-made configurations?
2. To what extent does the objective plausibility of computer-generated landscape configurations differ from the objective plausibility of expert-made configurations, in case restrictive criteria are imposed?
3. Along which (objective measurable) dimensions do respondents evaluate landscape configurations?

This paper is arranged following these three questions.

Firstly, in this validation approach we investigate the subjective plausibility of the generated configurations, using assumably plausible expert-made configurations. Here, we are particularly interested in the capability of the developed method to produce landscape configurations of equal quality as experts. Out of a short description about an imaginary intended development (composition), a limited amount of experts (hereafter named *producers*) is asked to make suitable configurations, keeping in mind the intended use. Based on a (subjective) interpretation by the modeler, resulting configurations are categorized on similar characteristics, and 'translated' into an equal number of parameter sets to be used as input for the computer-generated configurations.

Perceived quality judgment in this case is mainly performed by face-validation through experts (hereafter named *consumers*). They are considered independent and are completely free to choose their own (subjective) criteria to perform their judgment.

On a simplified 1-dimensional visualisation of the plausibility space for a particular assignment (see figure 2), the *producers* indirectly define the range of plausible configurations by their delivered configuration. With this first part in the experiment we investigate whether generated configurations fall within this range, without further identifying possible criteria used by the consumers.

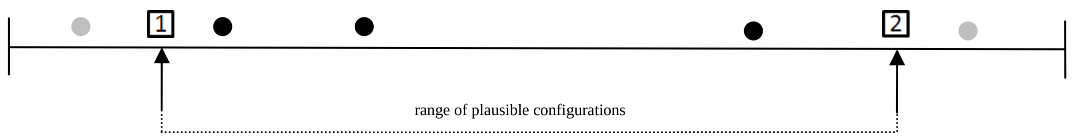

Figure 2. Plausibility space for a particular assignment; numbered square (1) represents an expert (producer) configuration and as such the border of plausible configurations, a closed dot (●) represents a (subjective) plausible computer-generated configuration and a grey dot (●) represents a (subjective) implausible configuration

Secondly, we investigate the objective plausibility of the generated configurations, using assumably plausible expert-made configurations.

Here, we are particularly interested in the capability of the developed method to produce representative landscape configurations fitted into the environment as experts. Meanwhile, we try to get more insight into which (objective) criteria the *consumers* use to evaluate the landscape configurations.

The LG produces configurations which satisfy the parameter values set. Main adjustable parameters available are presented in table 1.

Adjustable parameters	**Effective level**
1. total proportional area	landscape component
2. amount of instances	landscape component
3. individual exact area	instance of landscape component
4. individual proportional area	instance of landscape component
5. maximum exact perimeter	landscape component
6. individual maximum exact perimeter	instance of landscape component
7. individual minimum and maximum exact aspect-ratio of boundingbox	instance of landscape component
8. individual minimum and maximum exact percentage of boundingbox filled	instance of landscape component
9. individual minimum percentage of edge connection to other landscape component	instance of landscape component

Table 1. Adjustable parameters to produce landscape configurations

Using a configuration image (see for an example figure 3) from the intended landscape typology, the *producers* are asked to make their most representative configurations, keeping in mind the intended use. In this case the *producers* are much more restricted in comparison to the first part of the experiment. Parameters used for computer-generated configurations are directly derived from the image, independent from *producers* contributions.

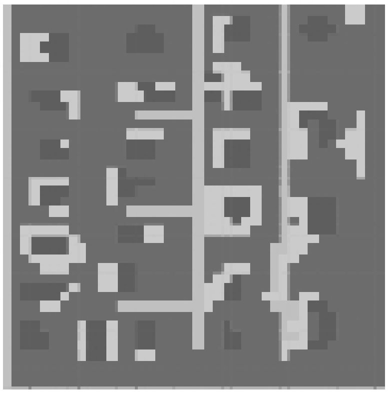

Figure 3. an example of configuration image from a green villa district typology

Again, on a simplified 1-dimensional visualisation (see figure 4) of the plausibility spaces of a particular assignment specified for each criterion (for LG parameters), *producers* implicitly define the range of plausibility.

It should be kept in mind that multiple criteria to some uncertain extent are correlated. With this part of the experiment we investigate whether generated configurations fall within the range specified for each criterion.

Thirdly, we investigate which evaluation criteria are used. *Consumers* are afterwards asked to indicate which criteria (selective from parameters listed above) they used to evaluate the configurations; this indirectly gives information about the weights *consumers* assign to each criterion in their evaluation. It is essential to do this afterwards, since informing them on these criteria in advance certainly will bias output.

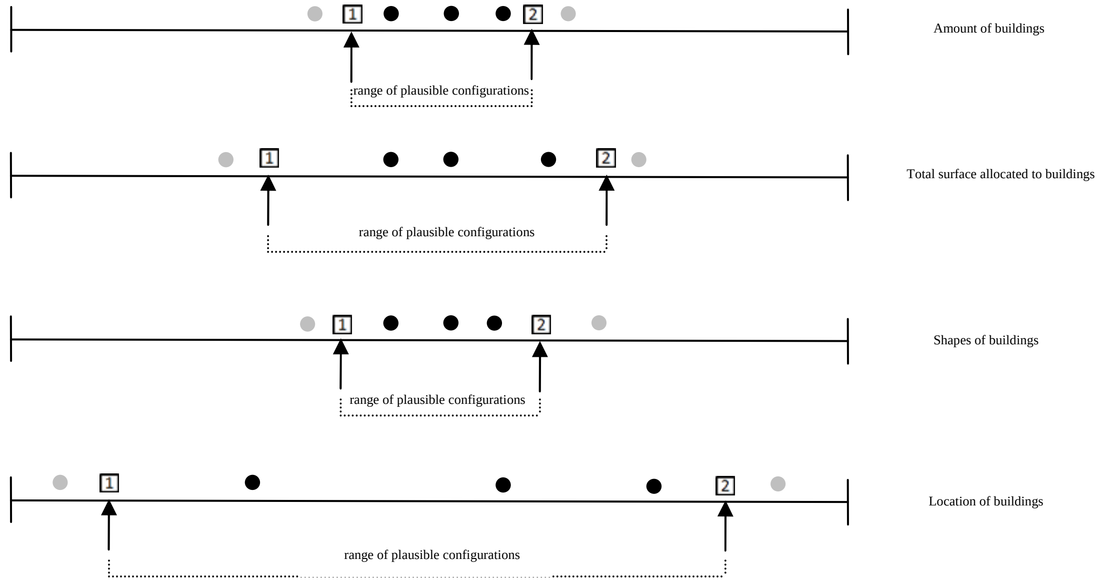

Figure 4. Plausibility space for a certain assignment, specified for more criteria (for example buildings)

3 DESIGN OF VALIDATION EXPERIMENT

After discussing the general validation approach, in this section we elaborate on the setup of a specific experiment yet to be performed by *consumers*. Necessary preparations at the *producers* side to 'fill' the experiment with content are discussed.

The intended experiment consists of an internet-based inquiry, which is divided in three subsequent blocks of assignments. Each block is again related to one of the research questions earlier posed in section 2.2. (see figure 5)

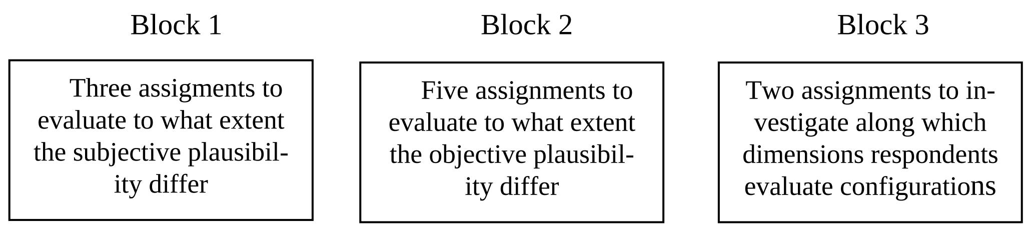

Figure 5. Setup of experiment: three blocks of assignments

Before we consider preliminary activities for each block, we elaborate on the experiment context. To keep experimental conditions as close to the domain of potential applicability, a study area is chosen with the same extents as used in a real-world planmaking process.

3.1 *Study area*

The study area is a polder landscape at the border of the highly-urbanized "Randstad"-area in the Netherlands. The area is situated in the centre of the country between the cities of Muiden in the North and of Weesp in the South (figure 6). In this study area, four potential locations for development (consisting of one or more cadastral lots) are further selected. These locations are distinct in their local surroundings, their size and their specific shape. Only these four locations are used in the experiment assignments as entities with potential developments. The developments to be tested are defined by landscape typologies.

Figure 6. Study area situated in the centre of the Netherlands (left); four potential development locations (right)

3.2 *Landscape typologies*

Besides testing a variety in locations, another important variable experimental condition is the choice of landscape typologies. In our methodology the availability of a structured library with landscape typologies is a vital component. A basic set of these typologies is available, which covers a sufficient part of the landscape physical layout variability present in a western-European landscape.

This basic set is structured along three visual parameters of physical landscape, quantitatively expressed as proportional hard space cover (hardscape), proportional soft space cover (softscape) and proportional tree space cover (treescape). Further specification of the layout typologies is dependant on specific use in a plan-making processes. For the purpose of this experiment, typologies are further specified on landscape layout patterns, e.g. density of components like buildings or trees, on adjacency between landscape components or on presence of specific building typologies. In figure 6 this basic set is presented. An important consideration is the scale to which the typology is applicable to. For that reason, each specified typology contains a parameter specifying a surface range to which the type validly can be allocated.

3.3 *Block 1: Design quality test*

Three *producers* create in the scope of a prize contest, for three assignments, one or two suitable landscape configurations. These lie according to them within the range of the proposed landscape configurations (see figure 2). The *producers* themselves define on which grounds they design. In addition to a basic description of the intended landscape (see section 4 for an example), they receive information about the specific region as well. After a subjective interpretation process by the *producers*, they individually determine further specification of the compositional description into a locational configuration. The *producers* receive for each assignment an A4-printed scaled topographic map with a white background at the location to be configurated. After sketching, the result is digitized, referenced, manually converted into pixels (using photo-editing software) and once again verified by the *producer*. With three *producers* making two configurations each, a maximum of six expert-made configurations for each assignment are collected. The contributions are carefully analysed by the modeler(s) and categorized according to similar main characteristics.

HSR	SSR	TSR	#	Layout	TSR	#	Subtype	#	Subsubtype
80-100	0-20	n / a	1	**Business park**	n / a	1.1	Industrial terrain		etc.
						1.2	Greenhouses		
80-90	10-20	n/a	2	**City centre**	n/a		etc.		etc.
60-80	20-40	n /a	3	**High rise residential (apartments)**	n /a		etc.		etc.
40-60	40-60	n / a	4	**Low rise residential (houses)**	n / a	4.1	Terraced houses		etc.
						4.2	Semi-detached houses		
20-40	60-80	n / a	5	**Villa district**	n / a		etc.		etc.
1-20	80-99	< 10	6	**Farmland**	< 3	6.1	Open Farmland	6.1.1	Maize farmland
								6.1.2	Pasture farmland
					3 - 10	6.2	Half-open Farmland	6.2.1	Maize farmland and wooded banks
								6.2.2	Pasture farmland and tree clusters
		10 – 90	7	**Estate**	10 - 50	7.1	Park estate		etc.
					50 - 90	7.2	Forest estate		etc.
0	100	<10	8	**Field**	<3	8.1	Open field		etc.
					3 - 10	8.2	Half-open field		
		>10	9	**Forest-and nature area**	> 10	9.1	Swampy vegetation		etc.
						9.2	Roughness		
						9.3	Forest		

Figure 7. Specification of landscape typologies available for this experiment; HSR = Hardscape Ratio, SSR = Soft scape Ratio and TSR = Treescape Ratio

The parameter values (see table 1) for the LG are deduced manually from these categorie. The LG produces for each assignment an equal number of configurations which in a degree fulfill the conditions defined by the experts. Finally, the whole set of configurations is converted into the same visualisation format and configured into the inquiry.

Noteworthy to mention here, locational road infrastructure will not be part of the configurations to be judged (and thus are converted into grass), since a road generation heuristic is not yet implemented in the LG.

3.4 *Block 2: Representativeness test*

The *producers* create in the scope of a representativeness test for each of the five assignments, one or two landscape configurations which according to them optimally represent the proposed landscape typology. The experts interpret the typology, however in their configurational design they are more restricted now due to the configuration of the representative landscape typology. Like in the assignment for the prize contest, experts receive means to draw effectively. With three *producers* making two configurations each, a total of six expert-made configurations for each assignment is collected.

Parameters of the LG (again see table 1) are set equal to objective landscape values deduced from the landscape typology image. The LG produces for each assignment an equal number of configurations. Finally, the whole set of configurations is converted into the same visualisation format and configured into the inquiry.

3.5 *Block 3: evaluation dimensions test*

In the third block of assignments is investigated along which dimensions the *consumers* evaluate the configurations. They are confronted with their own rank order of configurations for a certain assignment, where after they should indicate from the list with objective criteria used in LG parametrisation (see table 1), at least three specified criteria on which they based their rank order.

4 EXECUTION OF THE EXPERIMENT

In this section we elaborate on the execution of the web-inquiry by *consumers*. The specific assignments for the *consumers* in this experiment are described.

At least 50 professional experts (*consumers*), employed at governmental organizations, planning institutions and planning agencies are selected to participate as respondents in this experiment. They are appointed to evaluate sets of expert-made and computer-generated configurations. However, they receive no information about this difference in production. Although, participatory spatial planning processes aim at actors with a different level of expertise, we are particularly interested in the opinions of experts, because it is assumed when experts significantly judge configurations being plausible, laymen will as well. In the experiment setup a balance is sought in order to avoid fatigue, stereotyping and inefficiency of the respondents, but to acquire a statistically robust set of data. (Coxon, 1982)

4.1 *General socio-economic information*

Since it can be expected that *consumers* will have their own (subjective) grounds of judgment, we introduce at the last page of the inquiry at most 10 short sociological questions; e.g. name, organisation, their function in the organisation, indication of experience with spatial plan-making processes (none, little, average, much), gender, age, level and type of education, years of experience, focus on rural or urban design. This information may be useful to explain patterns in the results and give some indication of experiment validity.

4.2 *Inquiry structure*

In total, the experiment consists of 10 assignments. As shown in table 2 the first three assignments are part of the *prize contest* (block 1), assignment four to eight are part of the *representativeness test* (block 2). According to Batty & Torrens (2005), good model-building involves testing the model in such a way that it can be validated in a context that is independent of that for which it has been initially developed. By using a number of more or less (because within certain distance) independent locations and independent landscape types, this methodology can be applied in many contexts which are independent for which it has been initially developed.

Table 2. Assignments applied in experiment (between brackets the landscape typology id of figure 6)

Assignment #	Location #	Landscape type	Test type
1	1	business park (1.1)	Prize contest
2	2	four park estates (7.1)	Prize contest
3	3	greenhouses (1.2)	Prize contest
4	1	wet terrestrical nature area (9.1)	Representativeness
5	4	water-robust low-rise residential district (4..)	Representativeness
6	4	forest estate (7.2)	Representativeness
7	3	green villa dstrict (5)	Representativeness
8	3	maize farmland and wooded banks (6.2.1)	Representativeness
9	4	forest estate (reflection on assignment 6)	Dimensions of evaluation
10	3	green villa district (reflection on assignment 7)	Dimensions of evaluation

Before discussing the assignments in more detail, first the main user-interface of the web-inquiry is presented (see figure 8).

4.3 *User-interface*

The interface is almost identical for each of the first eight assignments. The differences in user-interface between the tests is the absence of an image of the landscape typology in the prize contest. The web-inquiry interface consists of three main components: 1) an ordering window, 2) an assignment description in Dutch and 3) a navigation window. In the ordering window, *consumers* can effectively drag-and-drop a configuration along a slider bar, ranging from best suitable to least suitable. The navigation window is available for navigating around in the neighbourhood of the location. By double-clicking the configurations in the ordering window, the configuration is presented in more detail in the navigation window. The navigation window contains user-friendly zoom and pan functionality, to offer the respondents a easy look on the surrounding map.

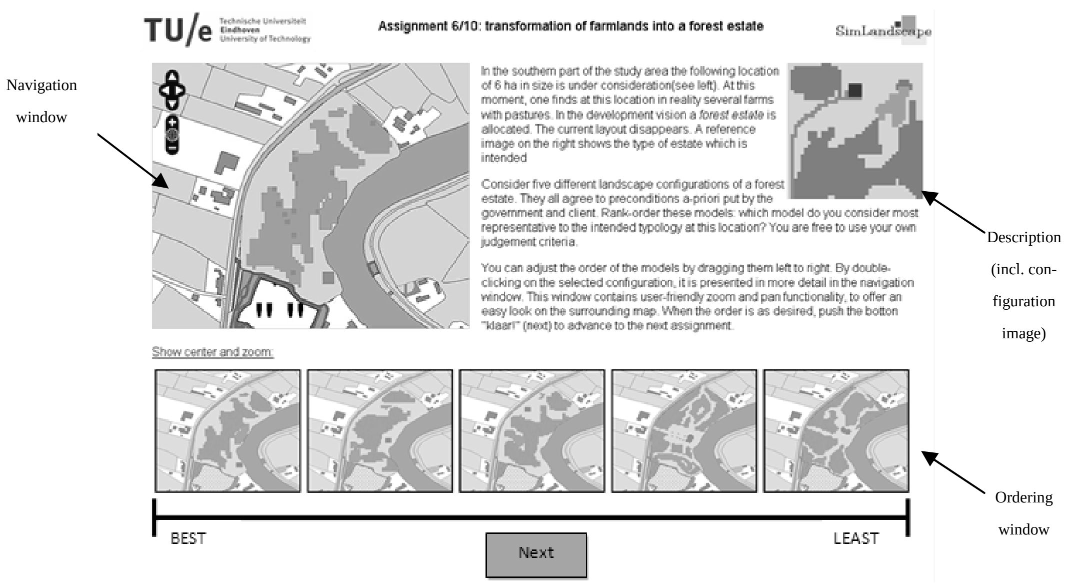

Figure 8. Screenshot of the main user-interface of the internet-inquiry: 1) ordering window; 2) assignment description and 3) a navigation window

4.4 *Block 1: Design quality test*

In the first block of the experiment we recall that it is investigated if subjective plausibility of computer-generated configurations differ from the subjective plausibility of expert-made configurations. For in total three combinations of location and landscape (description), *consumers* are invited to rank order, like in a prize contest, five landscape configurations on their suitability at that location. They are free to use their own (subjective) criteria in their judgment procedure.

The respondents receive information on the name of the intended landscape, a short description about functional properties of the landscape and compositional information about proportional abundance of each landscape component.

The following example illustrates an assignment description (in italic assignment specific texts) for : "In the *southern* part of the study area this location of *9* hectares in size is situated. In the current situation one can find a couple of farmlands here. In the development vision a *small business park* is planned. The current layout will change into a *businesspark with mainly small and medium-sized company premises*. *More than 80% of the surface is either built space, or hard space, less than 20% should be green*. C onsider five different landscape models of a *business park*. They all agree to preconditions a-priori put by the government and client. *Rank-order these models: which model do you consider most suitable at this location.* You are free to use your own judgment criteria."

The respondents receive no information about the exact location of the study area, since it is assumed it will bias evaluations significantly. Two or three (randomized per assignment and respondent) of the presented five landscape configurations are randomly drawn from the collection made by experts, two or three remaining from the collection produced by the landscape generator. These five configurations are presented to the *consumers* in a random starting order. The respondents are not informed about the origin of any of the landscape configurations.

4.5 *Block 2: Representativeness test*

In the second block of assignments it is investigated if objective plausibility of computer-generated configurations differ from the objective plausibility of expert-made configurations, but now with restrictive criteria imposed. For in total five combinations of location and type, respondents are invited to rank order, five landscape configurations on their representativeness for an intended typology. Respondents are free to use their own (subjective) criteria in their judgment procedure.

Two or three (randomized per assignment and respondent) of the five landscape configurations are made by experts, two or three remaining by the landscape generator. In contrary to the prize contest block, respondents receive besides information on the name of the intended type a standardized image of the intended typology. The specific question is significantly different than in the design quality test:
"Rank-order these models: which model do you consider most **representative** to the intended typology at this location?" Again, the respondents are not informed about the origin of any of the landscape configurations.

Assignment 7 is a special case. So far, road network features at the locations are not considered in the experiment. However, a road creating heuristic is developed in the methodology, but not yet implemented. *Producers* have been asked to produce an alternative configuration with their own road layout, and one configuration with an a-priori road layout. The landscape generator produces for each assignment an equal amount of configurations based on a-priori road layout and for an equal amount configurations the road layout is added afterwards. *Consumers* in this special case, receive only configurations including road structures. The question remain unchanged.

4.6 *Block 3: Dimensions of evaluation*

After completing these eight assignments, only two assignments remain for the respondents. The user-interface considerably change for these last two assignments. (see figure 9). The resulting order of assignment six entered by a respondent is retrieved and presented in the upper part of the screen. After this reminding, the respondent is asked to indicate according to the list of objective LG parameters (see table 1) which were most influential in their judgment of plausibility of configurations. The respondent should indicate at least three criteria. The same procedure applies for assignment seven. Note: in figure 8 the order of configurations is identical to the order set in figure 7.

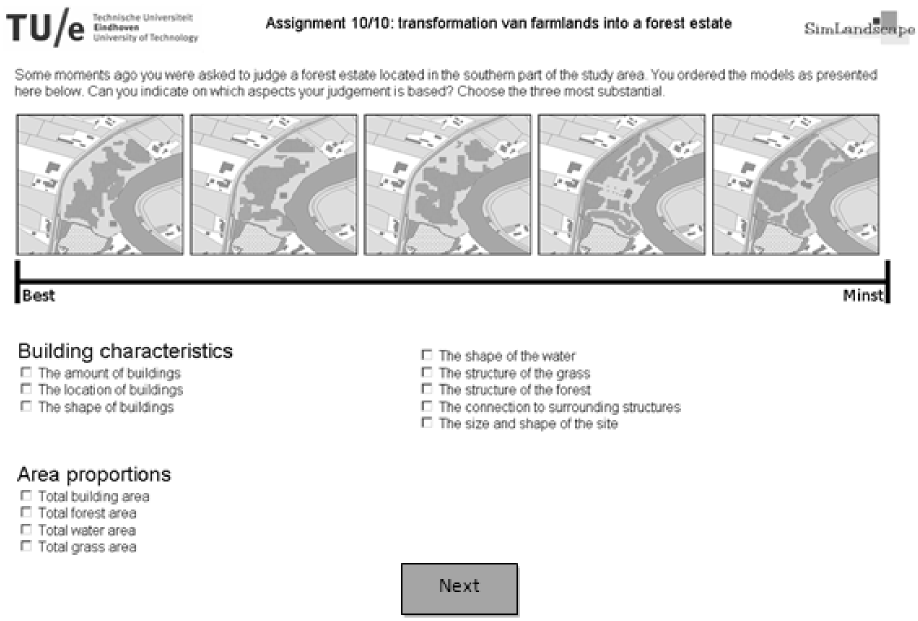

Figure 9. Screenshot of evaluation of dimensions assignments

5 STATISTICAL ANALYSIS

The validation results are statistically analysed by means of: 1) descriptive statistics, 2) sign test and 3) multi-dimensional scaling.

Descriptive statistics like graphical displays, tabular descriptions and summary statistics give insight into the basic features of the acquired data. Interesting basic features can be analysed at individual and aggregated levels. Besides statistics (like mean or median) on best and least valued configurations for each assignment. One can for example also think of statistics calculated on level of experience.

The sign test will test the hypothesis there is no difference between plausibility of expert-made and plausibility of generated configurations.

Multi-dimensional scaling is a statistical technique to reveal potential empirical relationships in data, by means of representing the data as a set of points in space. (Coxon, 1982) Ordinal data, retrieved in this experiment can be expressed in how similar or how dissimilar different configurations are valued. By placing this data in a 2D-space in such a way, that distances of the reference points represent the rank order of the original data as close as possible, potential empirical relationships may be revealed by the existence of visible axes (dimensions). Subsequently, these existing dimensions have to be labelled using information from the third block of assignments of the experiment in which the respondents are required to identify the criteria they used in their judgment.

6 DISCUSSION

In this paper we presented a validation approach to test plausibility of computer generated landscape configurations for use in participative spatial plan-making processes. By separating subjective and objective plausibility in the test, we are able to identify whether the landscape configuration generator sufficiently produce useful output. Furthermore, we try to get insight whether the set of adjustable parameters in the generator is sufficient to. In several previous presentations and accompanying discussions the term plausibility in this research was under continuous attention. With this landscape configuration methodology we are not aiming at producing the best or pseudo-best solutions, we aim at producing the solutions out of the whole solution space present under certain parameters imposed, that satisfy a minimum subjective threshold to be considered as plausible. Plausible to be used as starting point of discussions on development ideas in participative spatial planning processes.

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