



Landscape generator: Method to generate landscape configurations for spatial plan-making



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ARTICLE INFO

Article history:

Received 20 March 2012
Received in revised form 28 January 2013
Accepted 29 January 2013
Available online 26 March 2013

Keywords:

Spatial plan design
Plan generation
Multi-objective function
Heuristic optimization

ABSTRACT

Current spatial planning tools focus mainly on land use evaluation and not on spatial plan design. Automated generation of spatial design intends to bridge the gap between graphical design and geographical information systems. We propose a new method that generates spatial plans with a high level of detail and realism. A simple set of rules is derived by the modeler from a landscape type that serves as a reference. These rules are implemented by spatial functions with a landscape type specific objective. In a multi-objective optimization algorithm a landscape plan is generated for a specific lot that meets the objectives. The modeler controls the plan generation process through an objective task list which determines the priority of the objectives. Examples show that the landscape generator is capable of generating plausible spatial plans in reasonable computing time. More specifically, they show that the landscape generator performs best with low configurationally structured reference projects and performs less with high configurationally structured reference projects. The manual construction of the objective task list could be further improved by pre-structured objectives dependent on landscape designer's preference.

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1. Introduction

Spatial plan-making mainly comprises plan design and plan evaluation. Plan evaluation is effectively supported by many GIS tools. Plan design however relies upon creative thinking and therefore automation of plan design is much harder to support by computer tools. On the low end we find CAD and graphical design software (e.g. Adobe Photoshop), but these programs are merely electronic sketch tools and do not capture any spatial design knowledge. On the high end we find land use allocation models, but these are focused on maximizing land use suitability, ignoring compositional and configurational plan properties. So far, only some dedicated sketch and edit instruments have been developed, useful for design and allocation of primarily economic functions at a single spatial resolution and abstraction level. Some examples of such systems are: SketchGIS (Geertman, 2002), INDEX (Allen, 2008) and CommunityViz (Janes & Kwartler, 2008). Since based on GIS technology, plan design software development, however, is more focused on specifying and calculating spatial indicators for policy analysis than on providing effective instruments for spatial design. To enable effective design and modeling of plausible future spatial plan variants, we propose a method for automatic generation of landscape configurations using a user-defined landscape type.

A landscape type is described by quantitative compositional and configurational landscape metrics of a site. Notice the difference with land use type, whereas the latter is described by land use functions. The landscape type metrics are calculated from a (sub)set of landscape components (e.g. agriculture plot, water body, grass plot, tree plot, building and infrastructure) that constitute that landscape type. Compositional metrics are easily quantified and refer to the variety and occurrences of landscape components within a landscape, while configurational metrics are more difficult to quantify and refer to the spatial character and arrangement, position, or orientation of landscape components within a landscape (McGarigal, Cushman, Neel, & Ene, 2002).

Automatic generation of landscape configurations is mainly part of the research field called 'generative modeling'. Before we discuss our method in more detail, we present a brief overview of the state-of-the-art in generative modeling. In spatial planning literature, three important more or less distinct fields of research are identified which offer directly or indirectly approaches for developing automatic generation of landscape configurations:

1. Procedural modeling (e.g. landscape grammars).
2. Spatial multi-objective optimization modeling (e.g. genetic algorithms).
3. Cellular automata and multi-agent systems.

Shape grammars, introduced by Stiny and Gips (1972), contain a vocabulary of primitive geometric shapes and rules which specify

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how the shapes can be arranged in relation to each other. Procedural modeling techniques as shape (landscape) grammars are able to produce, or support the creation of detailed and appealing landscape visualizations (see e.g. Mayall & Hall, 2007). Due to this level of modeling, the process of inference to identify relevant objects and mutual relations in reality is complex, highly subjective and time-consuming, mainly due to a large number of objects and relations to be modeled. Moreover, the ambiguous character of the relations between objects provide large difficulties in identifying objective and generic rules.

Multi-objective optimization modeling in spatial planning problems, as linear integer programming (IP), genetic algorithms (GAs) and simulated annealing (SA), have a strong theoretical base and are applied frequently in spatial planning literature to provide 'the most favourable' landscape and plan layout in terms of minimal development costs. More recently, spatial shape criteria are included in the multi-objective functions devised (Aerts, Eisinger, Heuvelink, & Stewart, 2003; Duh & Brown, 2007; Stewart, Janssen, & van Herwijnen, 2004; Xiao, Bennett, & Armstrong, 2002). The research objectives in these studies however, are often restricted to a level of layout planning with less detail (e.g. allocation of land-use with a resolution of 25×25 m or larger) than the objective stated in this research. A direct consequence is that shape criteria are in general terms of compactness and solely defined at the land-use class level. Furthermore, in example case studies, the number of land-uses to be allocated and the site to be modeled is kept relatively small. These features are enough to provide a proof of principle, but not to deal with realistic planning challenges.

Cellular automata (CA)-models have proven to produce complex global patterns with comparable self-organizing properties as real urban growth. Due to its simplicity, it is a popular approach in modeling of urban dynamics in time and space. The neighborhood concept and transition rules are effective modes to incorporate geographical theories in the model. Where CA-based approaches are popular to model land use change at the local level, multi-agent systems (MASs) directly mimic human reasoning and decision-making behaviour driving land use dynamics. MAS are often combined with other modeling techniques (e.g. CA, heuristic methods as GA, logit models). In the latter case there is an overlap with the multi-objective optimization approach. CA and MAS provide robust frameworks to realistically model subject and object interactions in space and time (e.g. Ligtenberg, Beulens, Kettenis, Bregt, & Wachowicz, 2009; Saarloos, Arentze, Borgers, & Timmermans, 2005; Sante, Garcia, Miranda, & Crecente, 2010). However, although analytically correct these models may not always generate a plausible plan at the level of the individual landscape components.

The aim of our research is the development of a landscape generation tool with the following properties:

- Automatic generation of plausible landscape configuration. Plausible means here that the generated plans are considered as good as manually crafted plans by professional planners.
- The generated plans provide sufficient level of detail (scale 1:1000) and realism to support evaluation by experts as well as laymen.
- Generation of a great variety of plausible plans with a simple set of rules entered by the modeler.
- The plans are generated within minutes to support interactive planning processes in new development projects.

Automatic generation of a plausible landscape configuration, based on the properties of a user-defined landscape type is not effectively supported by one of the existing approaches for generative modeling. Therefore we present a new method and its prototype implementation named Landscape Generator. The core of this

method is a heuristic multi-objective optimization algorithm that operates on a cell-based representation of the spatial plan. The application domain is interactive spatial-plan making of realistic plans by multiple stake-holders. The outline of the paper is as follows. First, we describe the spatial functions we use in the landscape generator. In Section 3 we explain the flow of the generation process. In the following section the method is exemplified by a hypothetical case study. A demonstration of the functioning of the method for plausible landscape configurations is presented and discussed in Section 5. Finally, conclusions are drawn on the results and the proposed method.

2. Multi-objective optimization

2.1. Multi-objective utility

A central concept in the method is the use of a multi-objective utility to determine the global distribution of particular landscape components over an allocation site. Remind that not the land use suitability, but compositional and configurational metrics of the whole landscape type is the focus of our method. The multi-objective function consists of a landscape proportion function for each landscape component and one or more other spatial functions that can be used to control the spatial configuration. In turn, a spatial function is based on a spatial metric with a target value. The spatial metric is related to a quantitative landscape property of a landscape component to be allocated on a lot. A landscape component can have zero or more instances inside a lot. A *landscape component instance* is the occurrence of a landscape component and it consists of a cluster of one or more adjacent cells (C_{xy}) with similar component values. Each cell is described as a vector $C_{xy} = \{i, f\}$, where x and y correspond to the spatial location index of the cell in the grid, i corresponds to the landscape component value and the binary value f indicates that a cell is fixed (0) or enabled (1) to change. The cell size is set to 6 m in our model. This dimension has proven to be adequate for a variety of building shapes and vegetation (Vries, Til-laart, Slager, Vreenegoor, & Jessurun, 2012).

The multi-objective utility is defined by

$$U : \Sigma f_o(s)$$

where

The compositional and configurational-specific multi-objective utility (U) is compiled from seven spatial functions (f). In general a spatial function is of the form

$$f_o(s) = |\text{spatial metric}_o - \bar{\lambda}_o|$$

where spatial metric_o is calculated from the landscape type properties and $\bar{\lambda}_o$ is the target value. When a spatial function is included in the multi-objective utility, it is assigned an index o (where $o = 1, \dots, n$). This index represents the priority of that particular spatial function in the multi-objective utility (objective task list). The index determines in which order the individual spatial functions will be optimized.

2.2. Spatial functions

In the landscape generator, seven spatial functions are used in compilation of the multi-objective utility (see Table 1). Each spatial function is based on the objective quantitative metrics found in FRAGSTATS software (McGarigal et al., 2002). FRAGSTATS is also used to calculate the target values $\bar{\lambda}_o$ from the user-defined landscape type reference. The spatial metric depends on one or more of the following spatial variables: (i) landscape component, (j) instance of landscape component i , and (k) other landscape component. Furthermore, each spatial function $f_o(s)$ contains a specific

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