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Facilitating well-informed trade-off decision making on land use change: Integrating rules and indicators of ecosystem service provision into procedural 3D visualization

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Abstract: Collaborative planning processes between science and a variety of public and private stakeholders are seen as prerequisite for more sustainable landscape and urban development. New planning tools are required enabling the stakeholders to make collaborative decisions under uncertainties taking into account multiple dimensions and values, alternative development possibilities and performance indicators. We present a generic modelling and 3D visualization framework for communicating relationships between the natural and built environment combining the approaches of multi-criteria decision analysis and procedural 3D visualization. Focussing on urban pattern’s potential for ecosystem services provision on parcel level, we demonstrate the approach of integrating rules and indicators into the procedural urban model implementing ESRI’s CityEngine system. Testing the preliminary tool with selected stakeholders suggests that the generic procedural system is suitable for interactive assessment of urban patterns and communication of trade-offs. A set of core indicators should be identified and linked to the 3D visualizations in order to further reduce complexity.

Keywords: Urban ecosystem services; urban typology; generic patterns; GIS-based procedural 3D visualization; multi-criteria decision analysis.

1 INTRODUCTION

1.1 Challenges of integrating ecosystem services into planning processes

Ecosystem services’ values are not yet effectively incorporated in actual planning and design processes, although awareness of administrations on these important resources is rising and indicator inventories measuring the performance of ecosystems are emerging (e.g., Staub et al. 2010). Particularly in regions with urban agglomerations continuous interactions among people and socio-economic and ecological variables generate increasingly complex and unsustainable environments and multiple trade-offs have to be made (de Jong and Spaans 2009). There is a need for new tools supporting better integration of the ecosystems’ services into planning and enabling effective trade-off decision-making for balancing social, ecological and economic aspects of landscape and urban design (de Groot et al. 2010).

Furthermore, comprehensive visualizations of the interrelationships between natural resource indicators and societal demanded values and the respectively resulting urban structure are needed for an effective analysis and evaluation by the relevant stakeholders (Opdam et al. 2002; Termorshuizen and Opdam 2009). This calls for the development of a new approach integrating indicators into visualisation tools (Wissen Hayek 2011).
1.2 Transdisciplinary urban collaboration platform

In the scope of an applied research project a framework for a transdisciplinary urban collaboration platform was established. The platform is supported by scenario simulations, procedural 3D visualizations and sustainability indicators to continuously accompany the development of urban systems in a collaborative “simulation of change-analysis-cycle”. The overall goal is the development of a collaborative planning platform, in which stakeholders of all planning levels and disciplines analyse the current urban situation, develop scenarios and assess those alternative urban development patterns (Figure 1). Through iterative assessment and adaptation of the virtual urban patterns on local and regional scales, sustainable urban patterns can be identified in a transdisciplinary dialogue. This dialogue is characterized by cooperation between non-academic stakeholders and science, mutual learning and knowledge integration (Scholz 2000).

The tool supporting the collaborative process is combining the outputs of two modelling approaches: (1) Complex behavioural modelling providing reasonable results to policy scenario inputs (www.urbansim.org), economic causalities, and relations between land use patterns and traffic congestion (MATSim, www.matsim.org). (2) Geometric modelling, implementing ESRI’s CityEngine system (www.esri.com/software/cityengine). The latter implements a rule-based generative approach to quickly produce and visualize 3D urban environments of any size (Halatsch et al. 2008). Furthermore, it is interfacing with Arc GIS allowing for a visualization of simulation results of urban development scenarios in 3D (Xu and Coors 2012).

![Figure 1. Framework of the transdisciplinary urban collaboration platform.](image)

1.3 Aim and scope

The paper aims at providing a framework for integrating criteria for securing the quality of ecosystem services and corresponding indicators into the transdisciplinary urban collaboration platform. Based on the preliminary implementation results we discuss the potentials of this framework for accelerating knowledge exchange between relevant actors and as a tool to support planners, architects, policy makers and concerned parties in identifying conditions under which the ecosystem services can be provided with the required degree of quality.

2 CASE STUDY AREA AND URBAN DEVELOPMENT SCENARIOS

The transdisciplinary urban collaboration platform is established in a suburban region in Switzerland - the Limmattal. This is the valley of the river Limmat extending over 24 km from east to west from Zurich city centre to the city of Baden (Figure 2). It comprises an area of 18'561 hectares, about 165'000 inhabitants and 118'000 employees. The region experiences high migration rates, with an estimated increase of about 30'000 people and 20'000 jobs by 2030 (Wissen Hayek et al. 2011). It is a typical suburban region challenged by the negative effects of
urban sprawl, directly perceivable by aesthetic degradation, loss of environmental quality, identity and reduced quality of life (Schumacher et al. 2004). Implementing Formative Scenario Analysis (Scholz and Tietje 2002) four shell scenarios for the regional level in the year 2030 were developed (Wissen Hayek et al. 2011). These qualitative scenarios are amongst others characterized by different levels of urban density and quality and distribution of green spaces. We focused on visualizing and indicating the relationship between the green space pattern’s potential provision of ecosystem services and the urban density. The relationship was illustrated for an urban residential district in the Limmattal’s city of Schlieren.

### 3 METHODS

#### 3.1 Interactive modelling and 3D visualization framework

The 3D urban modelling and visualization framework (Figure 3) aims at integrating parameters and indicators of ecosystem service provision into 3D visualizations. The integrated visualization tool shall enable stakeholders to assess the potential quality of urban green spaces’ services in alternative scenarios. By interactively changing the services’ weights, alternative green space patterns are modelled and visualized. The intention thereby is to support comprehension of the relationships between the natural and the built environment in- or decreasing urban qualities. Two different modelling approaches are linked: (1) A multi-criteria decision analysis (MCDA) is carried out taking into account spatially explicit location conditions and spatial structures for an optimization of green space distribution at district level implementing a trade-off model. (2) The resulting maps of the MCDA with land use information for each parcel are further processed in a rule-based procedural 3D urban model. This model is applying ecological rules of ecosystems’ constraints and benefits defining the distribution of green space elements on parcel scale.

![Figure 3. Framework for integrating rules and indicators of ecosystem service provision into 3D visualization enabling stakeholders to interactively assess the potential quality of urban green spaces’ services in alternative scenarios.](image-url)
3.2 Relevant urban ecosystem services, indicators and rules

From a landscape and urban planning perspective, Hengsberger (2012) characterized in our case study suburban green spaces providing relevant ecosystem services as (1) connected, diverse in structure and (semi)natural habitats for flora and fauna, (2) unsealed areas, (3) areas that are publicly accessible on a fast and secure way, and (4) readable and distinctive spaces allowing for identification.

Relevant indicators that are suitable to measure these qualities of the green spaces are, e.g., the amount of native vegetation species and structural diversity, the amount of unsealed areas, the connectivity and accessibility of green spaces, and the vegetation age as well as impressive single trees, which contribute to scenic beauty and the identification of the people with their urban environment (Sattler et al. 2010; Whitford et al. 2001; Maas et al. 2009).

Rules for an ecosystem service’s provision of the required type and amount of landscape elements as well as their distribution are available in form of comprehensive scientific knowledge on relationships between spatial patterns and the provision of ecosystem services (e.g., Georgiou and Dimitriou 2010; Gobster 1995; Lizée et al. 2011). However, this knowledge is scattered across the literature. Further, it is not in a suitable form for implementation in landscape development scenarios, which are characterized by inherent uncertainties and rather generic development patterns (Song et al. 2006; Walz et al. 2007). By generalizing this ecological process knowledge, it can be integrated into generic design pattern rules guiding urban planning and design (Nassauer and Opdam 2008; Wissen Hayek et al. 2010).

3.3 Urban Typology

Urban typologies are commonly used by urban planners for defining flexible frameworks in urban development (Schirmer & Kawagishi 2011) and securing a minimum quality of urban development (McManus et al. 2010). In this context, design codes can offer powerful guidance by specifying the components of a development (such as building and green space types) and how these relate together in order to generate, e.g., on masterplan level, an envisioned urban quality (Alexander et al. 1977; Carmona et al. 2006). These design codes are suitable to integrate rules for urban quality from diverse stakeholders’ perspectives as they are a means to structure needs and explore solutions collectively. Thereby, building and green space types are defined and specifications of these types are given providing rules for their design (see e.g., CATS 2009).

We defined 10 building types in our case study area, identified corresponding green space types and mapped their generic pattern as well as rules guiding their current design. Figure 4 shows exemplarily how we link a generic pattern and rules of the building type “Single-family house” with the relevant ecosystem services and indicators of this type. This is the interface for integrating constraints and benefits of ecosystem services into the modelling and 3D visualization chain on parcel level.

![Figure 4. Generic urban pattern type “Single-family houses”, rules for landscape elements, relevant ecosystem services and indicators for their quality.](image-url)
3.4 Procedural 3D visualization of generic patterns linked with indicators

ESRI’s CityEngine system (see Section 1.2) was proved to be a valuable tool for encoding typological rules to shape grammars, which generate 3D geometries of the urban layout at various scales (Halatsch et al. 2008). The generation is based on an attributed shape grammar called CGA shape grammar (Müller et al. 2006). Each lot (parcel) is assigned a shape grammar rule set consisting of production statements in the form:

\[
\text{Predecessor} \rightarrow \begin{cases} \text{Successors 1} & \text{case Condition1} \\ \text{Successors 2} & \text{case Condition2} \\ \text{Successor N} & \text{else} \end{cases}
\]

In order to model and visualize the generic urban pattern types (see Section 3.3), we encoded the patterns and their specifications to CGA shape grammars following the approach of Wissen Hayek et al. (2010). We defined attributes, which is the vegetation elements, their specific species, height and width. In the grammar, we determined the rules for their amount and distribution according to the lot’s (parcel’s) building type. Executing the parametric shape grammar, a resulting spatial 3D design alternative is generated, which satisfies the basic pattern’s description.

A reporting function allows for summing up areas and items by attribute in the generated scene. In this way, we calculated a set of indicators comprising the amount of inhabitants in the district (total people), urban density (people / ha), amount of unsealed area (m²), percentage of unsealed area (per cent), costs for the green space infrastructure (CHF), maintenance costs for the green spaces (CHF), tree population (amount of trees). The parameters in the shape grammar rule can be altered interactively, e.g. by increasing the urban density (people / ha), which in turn leads to new patterns (e.g. higher and/or additional buildings) and respective indicator values.

3.5 Pre-test of the procedural 3D visualization linked with indicators

It was intended to get feedback on the preliminary state of the supporting tool as work in progress and the test was not designed as representative study. The results of integrating ecosystem services into the iterative scenario visualization and assessment cycle were evaluated in qualitative interviews with five different stakeholders. These stakeholders were representatives of experts with different expertise (e.g. planners, environmental engineers), planning departments, different associations (community; youth; protection of the environment), and house owners. In a standardized setting, the stakeholders were presented the procedural visualizations and corresponding indicators of the current state and four different scenarios representing alternatives of urban densification on a district level derived from the regional shell scenarios (see Section 2).

4 RESULTS

The resulting procedural 3D urban model (Figure 5) provides a representation of the study site in form of generic urban patterns with rather high level of detail and allows for an interactive modification of the model parameters. The slider bars given on the right side can be moved to increase or decrease the costs for the green space infrastructure, the population density or the building type. In turn, the updated 3D visualization shows the resulting urban pattern. Additionally, the according indicator values are updated and given in the reporting window on the bottom right.
4.2 Stakeholder’s feedback in the pre-test
The selected stakeholders explored the procedural urban model and gave their feedback on the suitability of the interactive 3D visualizations and indicators for supporting the comprehension of relationships between patterns and their potential of ecosystem services’ provision. In the analysis we focused on the transparency of the rules presented with the procedural visualization system, the suitability of the quantitative indicators and the provided level of detail.

Stakeholders were interested in the basic data of the model in order to check the credibility. As it is based on statistical data of the demographic development and GIS data, they trusted the model. The stakeholders explained their preferences for certain scenarios by referring to the indicators and the visual urban pattern’s appearance. Regarding the rules, however, the interface of ESRI’s CityEngine system seemed to be too complex to present them in a transparent way. Stakeholders did not deal with them intensively.

The amount of indicators provided was criticized to be confusing. Furthermore, the stakeholders asked for other relevant indicators such as the green space area per person, accessibility to green spaces (private or public), connectivity of green spaces, energy consumption, and building maintenance costs.

The high level of detail was preferred by most stakeholders since it increased their imagination of the scenarios and, in particular, the building heights. However, it triggered also discussions on design details that hindered the intended evaluation of the relationships in the scenarios. Since the procedural model and its basic rules are rather simple, a lower level of detail was said to be more suitable to convey this abstract character and might be sufficient for strategic decision-making.

4 CONCLUSIONS AND RECOMMENDATIONS
For a more sustainable urban design, planners and decision-makers need to identify and understand the relationships between the natural and the built environment enhancing urban qualities. We presented a generic procedural urban modelling and 3D visualization framework for facilitating the communication of these relationships to stakeholders of planning processes, focussing on the urban pattern’s potential for ecosystem services provision.

The generic approach, which is based on an urban typology of building and green space types, is straightforward to integrate generalized rules of process-pattern-relationships into the interactive modelling and visualization system of ESRI’s CityEngine. Since types are used, the abstract and simplified character of the scenarios and thus the uncertainty inherent in the resulting urban patterns was understood by the stakeholders of the pre-test. In addition, 3D visualizations with high level of detail might be not important if testing the ecological and economic effects of changing parameter’s weights is the task. However, it has to be ensured that easy perception of parameters such as building heights is possible.
The demand for a low level of detail in combination with rough indicators make the suitability for implementation of the tool clear: the information provided is rather useful for very early phases of strategy development than deliberating concrete design alternatives. The data are appropriate for discovering possible opportunities or threats on a general level through analysing alternative urban patterns. The urban pattern's potential for supporting different ecosystem services correlating with the urban density and costs for green space maintenance were quantified by a set of indicators. Stakeholders used these indicators for individual trade-off decision-making on the preferred scenario. However, the provided indicators seemed to be not the most relevant ones. The results suggest that a rather small set of significant indicators from economic, ecological and social perspectives would make the relationships better comprehensible. This core indicator set linked to the 3D visualizations could facilitate quick perception and communication of risks to ecosystem services due to pressures for change. Taking into account the restricting time schedule of participatory workshop settings to examine and interact with the information (Salter et al. 2009), this can ensure delivering a practical tool for testing policies, strategies or projects in an early planning phase.

The preliminary tool is as yet implemented on the parcel level and only for single land uses. For informing land management decisions and negotiating resource use, an understanding of interactions between multi-functional land uses the land's potentials for supporting different ecosystem services as well as other urban qualities is required. Therefore, in the next step, further building and green space types are encoded to CGA shape grammar and the multi-criteria decision analysis on district/regional level is set up. The final tool will allow for informed trade-off decision-making in larger groups of heterogeneous stakeholders taking into account the impacts of their normative values on all the relevant ecosystem services, including social and economic aspects.

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