

Integrating Natural Resource Indicators into Procedural Visualisation for Sustainable Urban Green Space Design

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1 Introduction

Environmental aspects are often not properly integrated or even neglected in urban development planning, which can have rather long-term negative social and economical impacts (GRÊT-REGAMEY ET AL., 2008). 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. Further, methods need to be developed, which integrate this information into the urban design process (NASSAUER AND OPDAM, 2008). Finally, 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 (LANGE AND HEHL-LANGE, 2006; OPDAM ET AL., 2002; TERMORSHUIZEN AND OPDAM, 2009), which calls for the development of a new approach integrating indicators into visualisation tools (ANDRIENKO ET AL., 2007; WISSEN ET AL., 2008).

Innovative procedural modelling methods for the automatic creation of large-scale 3D city models offer unprecedented opportunities to understand and encode urban patterns. They allow us to easily produce multiple design alternatives based on design rules leading the simulation procedure (MÜLLER ET AL., 2006; HALATSCH ET AL., 2008). While grammars shaping the urban environment have already been defined, the contribution of the natural environment to urban qualities has not yet been encoded and integrated into a procedural modelling approach for sustainable city planning.

We explore the use of shape grammar driven procedural models for effectively linking natural resource indicators into the urban design process. This paper documents the development and first tests of the approach on the example of urban green space pattern design for the Swiss Village Abu Dhabi in MASDAR, an ecocity of the future. The approach presented in this study provides a starting point for more complete, comprehensive, sustainable urban planning, and a useful tool for better informed and participatory decision-making.

2 Methods

2.1 Case study area

As a symbol of Abu Dhabi's efforts to achieve sustainable development and environmentally sensitive socio-economic growth, the government of Abu Dhabi initiated MASDAR City, a new urban district of Abu Dhabi comprising an area of 6.5 km². This ecocity of the future with high population density (approx. 135 people per ha) is designed from scratch and will be only dependent on renewable energy. Located in the core zone of MASDAR, a Swiss Village with a size of 12 ha is planned, in which Swiss companies shall promote Swiss technology, design and quality (SVA, 2009). Although targets for environmental aspects such as numbers of indigenous species nesting on site are given in the guidelines for MASDAR city, directly relating applicable rules for appropriate urban green space design are missing. In order to support the Swiss Village Abu Dhabi Association in the design process of the Swiss Village, environmental rules shall be made applicable by integrating natural resource indicators into the urban design process.



Fig. 1: Location of the Swiss Village in Masdar City, Abu Dhabi, United Arab Emirates (map source: SVA, 2009)

2.1 Natural resource indicators

Urban systems offer a range of services provided by open areas such as space for recreation, climate regulation, water purification, wildlife habitat, and carbon sequestration that contribute to human well-being (BOLUND AND HUNHAMMAR, 1999; TRATALOS ET AL., 2007; TZOULAS ET AL., 2007). These are defined as ecosystem services, i.e. 'benefits people obtain from ecosystems' (MEA, 2005). We choose these natural resource indicators because the functions ecosystems provide are relevant and understandable for people. Furthermore, they can be expressed in quantitative and qualitative terms (e.g. required area size or landscape elements for the provision of functions) and thus offer possibilities for integration of relationships between ecological processes and spatial patterns into procedural urban modelling in the form of rules.

We identified relevant urban ecosystem services of green space patterns in MASDAR city and choose two ecosystem services for testing the modelling approach: provision of habitat and maintenance of favourable climate, which we will here briefly name cooling services. Climate is one of the most important topics in MASDAR City, whose subtropical climate is characterised by high temperatures regularly exceeding 40°C up to 50°C in the summers (May-October). Thus the vegetation's evaporation and/or shadowing are relevant ecosystem services for cooling and a pleasant micro-climate. With regard to the habitat function explicit objectives are given in the guidelines of MASDAR City in form of defined target numbers of species that should find their habitat within the city. Especially the Desert Hare (*Lepus capensis*) and birds, such as the European Roller (*Coracias garrulus*) are target species (ENVIRONMENT AGENCY-ABU DHABI, 2008).

2.2 Modelling approach

The strength of working with patterns was stressed by ALEXANDER ET AL. (1977) in "A Pattern Language". This language consists of entities called patterns, with each of them describing an environmental problem (e.g. accessible green) and a general solution to that problem (e.g. build public open spaces within 3 minutes' walk). All given solutions are stated solely in form of an instruction on the main components and spatial arrangements, still allowing for an infinite variety of precise styles. One solution to a single problem makes up a single design pattern.

For organizing the relationships between various design patterns a grammar is needed. Furthermore, for creating patterns that are functionally and symbolically adequate rather than looking plausible, it is necessary not only to describe essential properties of a pattern but to give rules to construct new designs (STINY AND MITCHELL, 1980). STINY AND GIPS (1971) advocated the use of parametric shape grammars for design based on generative specifications that allow algorithmic (generic) production, analysis and evaluation of alternative designs. They used the terms "pattern" and "shape" interchangeably. Parametric shape grammars are characterised by parameters and associated shape transformation rules. Thus, as a result various alternative patterns may be produced that all belong to the language defined by one grammar (STINY AND MITCHELL 1980).

In our proposed approach we draw upon these theories that are recently applied in architectural urban design using a novel attributed shape grammar suitable for applications in computer graphics (ULMER ET AL., 2008) and use it for integrating environmental aspects. We divided the workflow in three main phases (Fig. 2): (1) Model authoring, (2) 3D Green space generation, and (3) Stakeholder's evaluation of the design pattern. Model authoring comprises the generation of rules of pattern design and translation into the shape grammar. Hereby we followed the logic of NASSAUER and OPDAM (2008), who propose to link the scientific knowledge on landscape ecological pattern-process relations with the design of landscape patterns (process:pattern:design). This was done by first identifying relationships between spatial patterns and the provision of ecosystem services, then integrating this process knowledge into general design pattern rules, and finally applying the pattern rules as designs on the case study site. Green space generation, i.e. the visualization of green space patterns with the CityEngine system (Procedural Inc.,

<http://www.procedural.com>), comprised applying the shape grammars on urban open spaces in the case study site.

In a further step the structure of the resulting patterns will be analysed and values of the two selected ecosystem services will be calculated for the resulting urban green space design. Finally, the 3D visualization and the two natural resource indicators will be presented to stakeholders for evaluation. With the feedback of the stakeholders, the design rules can be altered, which in turn will lead to new green space patterns and indicator values. In this way an iterative enhancement of the green space design takes place. In this article we focus on model authoring for green space generation.

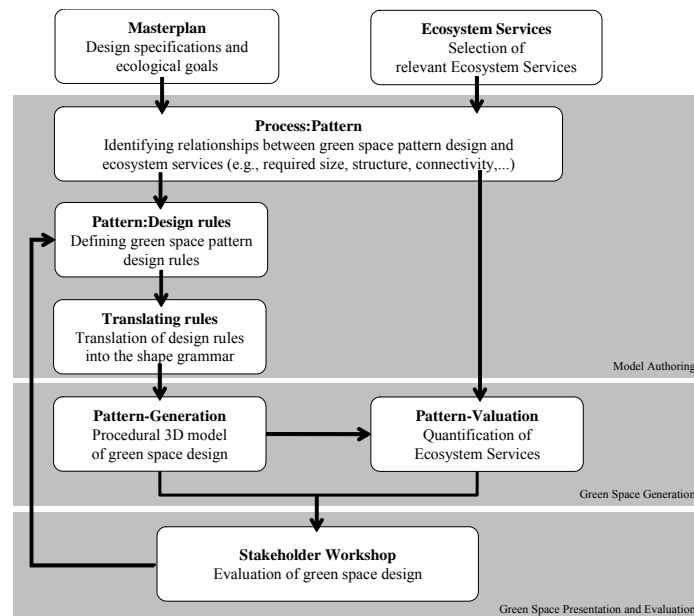


Fig. 2: Workflow on integrating natural resource indicators into procedural visualisation of urban green space design

3 Model authoring

In order to generalize ecological knowledge for deriving applicable design rules, relationships between the required landscape elements and structures and the provision of the selected ecosystem services, cooling and habitat, were identified.

3.2 Cooling effects of the vegetation

Many functional benefits of trees increase as leaf surface area increases, e.g. photosynthesis, transpiration or noise reduction, and the shadow cooling the surrounding area (FAHMY ET AL., 2010). Based on research findings we used the crown width of trees as one input parameter for green space pattern generation, which allows quantification of the cooling service (MCPHERSON, 1992; FAHMY ET AL., 2010).

3.1 Habitat variables

Environmental variables, describing suitable habitats of focal species, can be used to predict potential sites for these and many other species as they can represent landscape characteristics that will encompass the needs of many other species (MÖRTBERG ET AL., 2007). Required basic habitat characteristics derived from literature for both focal species, the Desert Hare and the European Roller, are given in Table 1.

Tab. 1: Explanatory variables of habitat characteristics used for defining suitable green space pattern designs for focal species

Focal species	Land cover type Types of habitat fulfilling the species' needs for nesting, perching, forage	Structural landscape parameters Required landscape structures	Patch size Necessary amount of habitat for one individual	Home range
European Roller (<i>Coracias garrulous</i>)	Forest Temperate Shrubland Mediterranean-type, shrubby vegetation; Subtropical / Tropical Dry Grassland Temperate; Artificial (BIRDLIFE INTERNATIONAL, 2008)	Old trees, nest-boxes or holes in building walls for nesting; Hedgerows for perching (ANGELSTAM ET AL., 2004)	300 ha in a network of inter-connected patches within the home range (ANGELSTAM ET AL., 2004)	300 m from the nest (rarely up to 1.5 km) Home ranges are partly over-lapping (ANGELSTAM ET AL., 2004)
Desert Hare (<i>Lepus capensis</i>)	Shrubland Mediterranean-type, shrubby vegetation; Subtropical / Tropical Dry Grassland Subtropical/Tropical Dry; Desert – Hot; Artificial (DREW ET AL., 2008)	Shrubs for sheltering from summer sun and predators (DREW ET AL., 2008)	5-20 ha No barriers as hares are sensible to landscape fragmentation (DREW ET AL., 2008)	10-300 ha Home ranges are partly over-lapping (FLUX AND ANGERMANN, 1990)

4 Shape grammar for green space generation

The selection of vegetation species for urban green space design was based on the determined requirements concerning habitat functions, particularly focussing on species of possible land cover types. Then the selected vegetation species had to be distributed in order to fulfil the structural needs of the focal species (see Table 1) as well as to meet design specifications of the master plan. This was done by organizing the determined landscape features to basic design patterns that define major design solutions (BEIRÃO ET AL., 2008; ULMER ET AL., 2007). These basic design patterns formed the required input for the procedural modelling. The patterns were encoded to rule sets structured in shape grammars. For urban green space pattern generation we used CGA shape grammars that are implemented in the CityEngine system (see ULMER ET AL., 2007; HALATSCH ET AL., 2008). The main advantage of this system is that it can quickly produce and visualize in a three-

dimensional view urban environments of any size based on the CGA shapes. The latter are grammars producing patterns by sequentially applying rules for spatial distribution of features (HALATSCH ET AL., 2008). Each lot (parcel) is assigned a shape grammar rule set consisting of production statements in the form:

```
Predecessor → [case Condition1:] Successors 1 [case Condition2:]
Successors 2 [else:] Successor N
```

The successors can be composed of several shape operations and query statements as shown in the example rule set and the resulting tree distribution pattern in Figure 3.



Pattern_trees.cga

```
attr tree_distance = 3.5 // defines the tree distance
treeMinHeight = treeMaxHeight*.85 // min. tree height = 85% of
max. tree height
attr treeMaxHeight = 9 // max. tree height
tree_h = rand(treeMinHeight,treeMaxHeight) // assign min./max.
height randomly
tree = "treemodel.lod0.obj" // tree 3D model
tree_jitterT = floor(rand(2,7))*0.1 // locate trees with slight
deviation from centre point

Start --> TreeAreaZ // initial rule that forwards to TreeAreaZ

TreeAreaZ -->
split(z) {~tree_distance: Tree SoilType(1)}*
// split the area according to the defined
tree distance and go on with rule Tree
and rule SoilType(1)

SoilType(ST) -->
case ST==1 : color(soil2C) A. report("Area.Grass",
ceil(geometry.area()))
else: color(soil1C) A. report("Area.Undefined",
ceil(geometry.area()))
// query SoilType, assign color and finish
rule. Report area

Tree -->
60%: t('tree_jitterT,0,'tree_jitterT) // translate/move
the placement origin
s(0,tree_h,0) // set height
r(0,rand(0,360),0) // random rotate
i(tree)report("Instance.Tree", 1) // insert tree 3D
model and report the placed instance

else: NIL
```

Fig. 3: Top: A vegetation model distribution pattern. Bottom: This CGA grammar can be read as hierarchical implementation of a set of comprehensible rules applicable on the given area to produce the tree distribution pattern as shown in the visualization on top

A resulting spatial design alternative from applying the parametric shape grammar, which satisfies the basic pattern's description set up for Swiss Village Abu Dhabi, is presented in Figure 4. The reporting of the resulting green space design given in Tables 2 and 3 provide figures on the area size of the different land use types and distributed landscape elements.

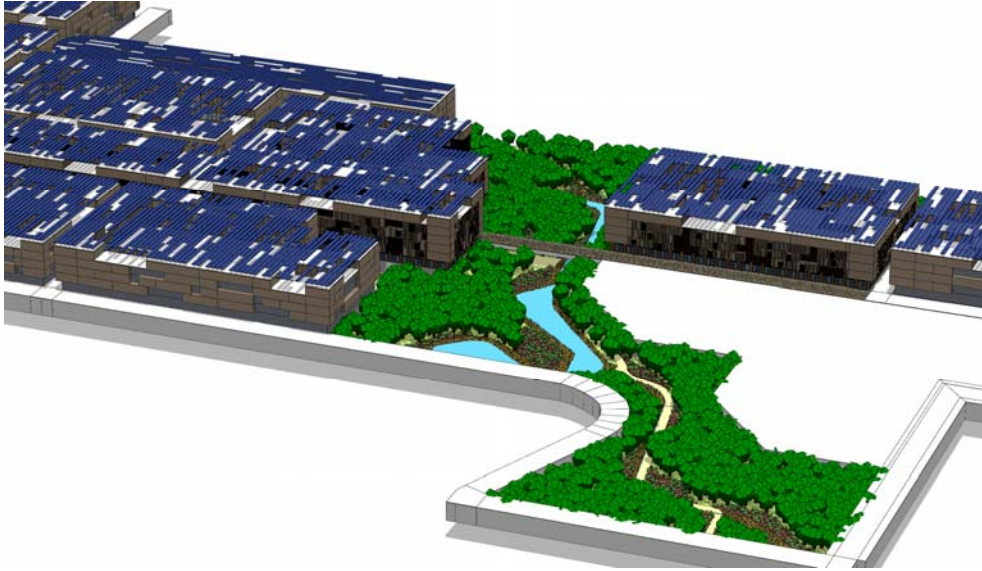


Fig. 4: Procedural visualisation of urban green space design in the Swiss Village Abu Dhabi based on a parametric shape grammar

Tab. 2: Reporting table of the area size and percentage of the different land use types produced by the shape grammar (Figure 4)

Report	Number of Area types	Area type (%)	Sum area (m ²)	Sum Area (%)
Area	30448	100	57847	100
Area.Grass	2237	7.3	24585	42.5
Area.GravelA	16900	55.5	16900	29.2
Area.GravelB	11289	37	11289	19.5
Area.Sand	12	0	2016	3.4
Area.Water	10	0	3057	5.2

Tab. 3: Reporting table of the type, number and percentage of landscape elements distributed by the shape grammar (Figure 4)

Report	Number of Instances	Instance (%)
Instance	13719	100
Instance.Bush	1692	12.3
Instance.Grass	8417	61.3
Instance.Stone	2269	16.5
Instance.Tree	1341	9.7

5 Conclusions & Outlook

In the presented study we showed how generalized ecological process knowledge can be integrated into design rules, which are applicable in procedural modelling of urban open spaces. Due to the use of parametric shape grammars it is possible to transfer and, if necessary, adapt the rules to other areas. Whereas rules such as habitat functions for indigenous species are rather region specific, rules concerning the cooling function can be applied easily on urban areas in other regions. Further rules should be prepared in order to make ecological knowledge more applicable in urban planning. However, in future more complex relationships, e.g. between the shading of buildings, vegetation needs and functions and the green space pattern design should be explored.

In the next step, we will analyse the resulting patterns according to their provision of the selected ecosystem services and assess how far important ecological requirements were taken into account. This will provide the basis for altering the rules and optimising the design. The integrated model will be an assessment tool that can be used to test urban design alternatives on the ecological functioning as a starting point for architects.

6 References

- Alexander, C., Ishikawa, S. & M. Silverstein (1977): *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press, New York
- Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A. & S. Wrobel (2007): *Geovisual analytics for spatial decision support: Setting the research agenda*. International Journal of Geographical Information Science 21(8): 839-857
- Angelstam, P., Roberge, J.M., Löhmus, A., Bergmanis, M., Brazaitis, G., Dönn-Breuss, M., Edenius, L., Kosinski, P., Kurlavicius, P., Lärmanis, V., Lūkins, M., Mikusiński, G., Račinskis, E., Strazds, M. & P. Tryjanowski (2004): *Habitat modelling as a tool for landscape-scale conservation – a review of parameters for focal forest birds*. Ecological Bulletins 51: 427-453
- Beirão, J., Duarte, J. & R. Stouffs (2008): *Structuring a Generative Model for Urban Design: Linking GIS to Shape Grammars*. Proceedings of eCAADe 26 Conference 2008, 929-938
- BirdLife International (2008): *Coracias garrulus*. In: IUCN 2009. IUCN Red List of Threatened Species. Version 2009.1. www.iucnredlist.org.
- Bolund, P. & S. Hunhammar (1999): *Ecosystem services in urban areas*. Ecological Economics 29: 293–301
- Drew, C., O'Donovan, D., Simkins, G., Al Dosary, Al Khaldi, A.M., Mohammed, O.B., Al Nuaimi, A.S.M., Al Mutairi, M.S., Al Habhani, H.M., Sami Amr, Z., Qarqas, M. & M.A. Abu Baker (2008): *Lepus capensis*. In: IUCN 2009. IUCN Red List of Threatened Species. Version 2009.1. www.iucnredlist.org.
- Fahmy, M., Sharples, S. & M. Yahiya (2010): *LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt*. Building and Environment 45: 345-357

- Flux, J.E.C. & R. Angermann (1990): *The Hares and Jackrabbits*. In: J.A. Chapman and J.E.C. Flux (eds.), Rabbits, Hares and Pikas – Status Survey and Conservation Action Plan, IUCN/SSC Lagomorph Specialist Group, 61-94
- Grêt-Regamey, A., Bebi, P., Bishop, I.D. & W. Schmid (2008): *Linking GIS-based models to value ecosystem services in an Alpine region*. Journal of Environmental Management 89: 197-208
- Halatsch, J., Kunze, A. & G. Schmitt (2008): *Using Shape Grammars for Master Planning*. In: J.S. Gero (ed), Design Computing and Cognition DCC'08, Springer, 655-673
- Lange, E. & S. Hehl-Lange (2006): *Integrating 3D Visualisation in Landscape Design and Environmental Planning*. GAIA, 15 (3): 195-199
- McPherson, E.G. (1992): *Accounting for benefits and costs of urban greenspace*. Landscape and Urban Planning 22: 41-51
- MEA, Millennium Ecosystem Assessment (2005): *Ecosystems and Human Well-being*. Synthesis. Island Press, Washington DC
- Mörtberg, U.M., Balfors, B. & W.C. Knol (2007): *Landscape ecological assessment: A tool for integrating biodiversity issues in strategic environmental assessment and planning*. Journal of Environmental Management 82: 457-470
- Müller, P., Wonka, P., Haegler, S., Ulmer, A. & L. Van Gool (2006): *Procedural Modeling of Buildings*. Proceedings of ACM SIGGRAPH 2006/ ACM Transactions on Graphics (TOG), ACM Press, 25 (3): 614-623
- Nassauer, J.I. & P. Opdam (2008): *Design in science: extending the landscape ecology paradigm*. Landscape Ecology 23: 633-644
- Opdam, P., Foppen, R. & C. Vos (2002): *Bridging the gap between ecology and spatial planning in landscape ecology*. Landscape Ecology 16: 767-779.
- Stiny, G. & J. Gips (1971): *Shape grammars and the generative specification of painting and sculpture*. IFIP Congress 1971. North Holland Publishing Co
- Stiny, G. & W.J. Mitchell (1980): *The grammar of paradise: on the generation of Mughul gardens*. Environment and Planning B 7: 209-226
- SVA, Swiss Village Abu Dhabi Association (2009): *Swiss Village in Masdar. The green business hub for Swiss companies*. Swiss Village Association Brochure, July 2009. <http://www.swiss-village.com>
- Termorshuizen JW & P. Opdam (2009): *Landscape services as a bridge between landscape ecology and sustainable development*. Landscape Ecology 24: 1037-1052
- Tratalos, J., Fuller, R.A., Warren, P.H., Davies, R.G. & K.J. Gaston (2007): *Urban form, biodiversity potential and ecosystem services*. Landscape and Urban Planning 83: 308-317
- Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Ka'zmierczak, A., Niemela, J. & P. James (2007): *Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review*. Landscape and Urban Planning 81: 167-178
- Ulmer, A., Halatsch, J., Kunze, A., Müller, P. & L. Van Gool (2008): *Procedural Design of Urban Open Spaces*. Session08:City Modelling – eCAADe 25: 351-358
- Wissen, U., Schroth, O., Lange, E. & W.A. Schmid (2008): *Approaches to integrating indicators into 3D landscape visualisations and their benefits for participative planning situations*. Journal of Environmental Management, 89: 184-196