Bridging GIS-based landscape analysis/modelling and 3D-simulation. Is this already 4D?

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1 INTRODUCTION

With the terms 'landscape analysis' and 'landscape modelling' we refer to a landscape level consideration of spatial entities. The North American approach of landscape ecology (Forman 1995) has provided the foundation of a spatial analysis at a landscape level. The key for us is the spatially explicit consideration of landscapes and their constituting entities opposed to a quantitative consideration of land use statistics ("12% of the landscape belongs to the class <urban, sub-urban>). The evolving landscape metrics, (Blaschke 2000) is becoming more widespread. It addresses landscape pattern which are based on the underlying geometry (shape, size, fractal dimension, compactness etc.) of landscape units or patches and their spatial arrangement, interspersion, juxtaposition, diversity etc. (Forman 1995).

Several studies have used remote sensing to map patterns of e.g. deforestation or to analyse the rates of land use change. These studies have proven useful for interpreting the causes of urbanization, deforestation etc. and the impact of such changes on the region. Monitoring of change (e.g. deforestation or reforestation) is frequently perceived as one of the most important contributions of remote sensing technology to the study of global ecological and environmental change (Roughgarden et al. 1991). Many researchers believe that the integration of remote sensing techniques within analysis of environmental change is essential if ecologists are to meet the challenges of the future, specifically issues relating to global change; however, in practice, this integration has so far been limited (Griffiths & Mather 2000). Considerable difficulties are encountered in linking, on the one hand, the biologies of organisms and the ecologies of populations to the fluxes of material and energy quantifiable at the level of ecosystems. In this paper, we concentrate on the methodological aspects of the delineation of landscape objects and touch the ecological application only superficially but we elucidate the potential of the proposed methodology for several ecological applications briefly.

After decades of GIS and remote sensing technological development, it should not be too difficult for an average user to identify land use pattern and landscape structure with the use of remote sensing data and auxiliary GIS data at an appropriate scale. But in reality it is. Clearly, we are receiving results in any case, but what do figures like "landscape diversity is 2.17" tell us? Only recently, such questions are raised, for instance at a European level focusing on the effects of the Common Agricultural Policy at the landscape level (http://europa.eu.int/comm/agriculture/publi/landscape). Whole groups of landscape ecologists and planners are working on these issues but so far, we are missing a sound methodology. The paper intends

- to demonstrate the potential of a new image processing methodology based on multi-scale image segmentation to delineate landscape elements,
- to provide a framework for bridging spatially explicit GIS-based landscape modelling and the potential of 3D object definition,
- to demonstrate the applicability of the methodology in practice for the sake of landscape visualisation and planning.

The first part briefly displays fundamental aspects of delineating landscape objects based on remote sensing data and auxiliary GIS data. The methodology of explicit multiscale definition of landscape objects is described as a heuristic procedure. In the second part, focusing on the implementation in practice, the terminology, steps and elements of the general delineation procedure are defined on behalf of the assessment of landscape simulation as an example. A small landscape simulation project demonstrates the implementation of the methodology in practice and its benefits, e.g., the improvement of the definition of the basic elements, or the promotion of an effective landscape change analysis methodology to support goal-oriented planning procedures, as a basic tool for valuation, planning, implementation and monitoring of landscapes. Then, we critically analyse if this is already "4-dimensional" landscape modelling or if this term is more likely to be a buzzword right now given the current state of the art.

2 METHODOLOGY

2.1 landscape analysis at a regional level

Landscape analysis is a valuable addition to the statistic land-cover classes which are more commonly studied by researchers when incorporating remotely sensed data analyses into landscape studies. GIS and remote sensing provide the necessary tools for this type of analysis. Although GIS may be regarded as technically mature, we still encounter methodological difficulties when representing landscapes digitally. Patches may be disturbance patches, remnant patches, environmental resource patches, introduced patches, or simply patchy entities on a map (Forman 1995). Patches may simply be landscape elements, such as roads, dwellings, forest patches, grassland patches, hedgerows, or fields. Patches could also be types of forest in a forested landscape (e.g. deciduous forest, recently-burned forest, conifer forest), or types of grassland in a prairie landscape. Patches of different age occur in landscapes subject to disturbances (e.g. fires, floods), where the age of the patch represents the time since it was last disturbed. Patches could also be the types identified by completing a classification of spectral data in a Landsat image, or in a scanned aerial photograph as used in this paper. In general, patches are simply the result of grouping pieces of the landscape into units whose members share a common set of attributes. But the delineation is not always intrinsically evident. A basic part of landscape analysis is characterizing the elements (i.e., patches) within a landscape. Numerous landscape metrics are used to evaluate structure; too many to cover in this paper. For simplicity, metrics can be categorized into four main groups - Patch Shape, Patch Size & Extent, Patch Connectivity, and Patch Dispersion (see Gustafson 1998, Farina 1998). The variety of landscape metrics and indices has lead to a discussion of their actual significance (Fry 1998, Blaschke & Petch 1999), although many examples have illustrated their usefulness in various applications, if carefully chosen and tested against hypotheses (Haines-Young & Chopping 1996, Dramstad et al. 1998, Lausch & Biedermann 2000, Luoto 2000). It is concluded that the need for a regionalisation and quantification of patterns and their changes is increasing.

The recognition of landscape units, in which there is a distinctive association of land cover and terrain, is a fundamental task in landscape ecology. In making such analyses a variety of data sources have been employed. These include map, air photo and field information. Increasingly, remotely-sensed satellite imagery have also been used, the particular advantages of these data being their repeated and large scale coverage and their digital format. It is often argued that these data are easy to integrate with other data sources for planning purposes and offer the prospect of several landscape analysis efforts over time leading to a monitoring of landscape change. Only recently, it is criticized that the 2-dimensional delineation of patches is too simplistic but there is no sound methodology for a '3-D patch definition' (simply speaking: incorporating height information) for larger areas or whole landscapes.

2.2 Introducing an object-oriented landscape analysis methodology based on image segmentation

While GIS may be regarded as a technically mature approach, the operational use of remote sensing is hampered today by the lack of a sound methodology to reliably and reproducibly gain information from raw data. Recently, object-oriented image processing approaches have been introduced based on image segmentation techniques, specifically a multiscale image segmentation approach was introduced and is available in a commercial software environment. Although image segmentation is not new, the idea to initially build objects based on assumptions of heterogeneity and shape information is still the exception in the remote sensing world. It is hypothesised that this methodology enables us to bridge 2-D object definition from remote sensing images and 3-D object building. The challenge and flexibility of the multi-scale segmentation approach lies in the defining of the semantic rules which relate the lower level landscape units or holons to higher levels of organization. In this way, we seek to overcome the subjectivity in the definition of objects of interest and we use the resulting objects together with height information for 3-D visualisation and simulation.

We use the methodology of segmentation base object modelling laid out by Burnett and Blaschke (in press) based on the theory of hierarchical patch dynamics paradigm (Wu & Loucks 1995). First, in a segmentation step, a fractal-based multi-scale segmentation algorithm developed by Baatz and Schäpe (2000) is implemented. The Fractal Net Evolution Algorithm (FNEA) has already successfully been applied in other studies (see Blaschke & Strobl 2001 for an overview) and is based on assessments of homogeneity and heterogeneity. In it, an iterative heuristic optimization procedure is programmed to get the lowest possible overall heterogeneity across an image. The basis for this is the degree of difference between two regions. As this difference decreases, the fit of the two regions is said to be closer. In the FNEA, these differences are optimized in a heuristic process by comparing the attributes of the regions (Baatz & Schäpe, 2000). That is, given a certain feature space, two image-objects are considered similar when they are near to each other in this feature space. In a second step, the semantic links between image objects are established based principles of object-oriented programming which allows to semantically express intrinsic spatial and spectral relationships such as: 'an object is constituted by certain subobjects", subobjetcs are element of super objects', 'sub-objects achieve certain classification rules from their respective super objects' and vice versa. This is just a very brief und maybe too short description of object-oriented image processing, for more details see Baatz & Schäpe (2000) or Blaschke & Strobl (2001).

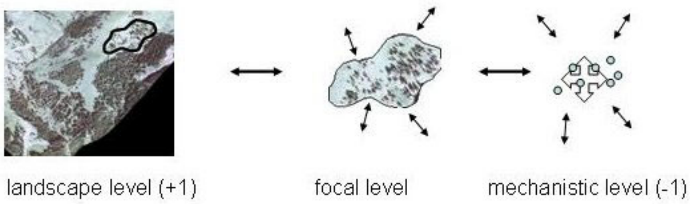

Fig. 1: Basic principle of multiscale, oo image analysis: Information is gained and explicitly expressed through objects, their respective super-objects (here only one level above the 'focal level' is shown) their respective sub-objects (here single trees) and specific characteristics of the subobjects such as their spatial arrangement, distribution, shape, size, spectral characteristics and many derived products from shape/area/distance relationships.

2.3 landscape modelling

The analysis of spatial pattern within a landscape, or landscape ecology analysis, is frequently divided into three components: (1) landscape pattern, (2) landscape function and (3) landscape change. Remotely sensed imagery can be used to provide information in all of these areas. This research focus on methodologies to incorporate information for components (1) and (3), which can indirectly be used to infer information about component (2). Such spatial analysis can be an effective way to analyze underlying ecological relationships within a landscape but the correlations of pattern and processes have to be proven carefully.

For instance, in many parts of the world direct loss of forest area is a primary concern. Forest fragmentation issues also assume vital significance in the context of maintaining the 'natural' variability in the size, shape and distribution of the mosaic of patches which exists within a landscape with little human influence. While in other parts of the world, e.g. Germany, forest loss is not a problem at all but the increasing fragmentation of remaining habitats through the building of roads, settlements and industry, this variability is believed crucial in affecting the flow of species and materials within a landscape (Forman, 1995). It therefore becomes important to quantify changes in landscape pattern, in addition to estimates of percentage change in area over time. The following case study addresses the use of landscape units to study spatial patterns of forest by calculating for each class a range of metrics such as mean patch size, mean patch shape, edge density, interspersion–juxtaposition, contagion, etc., from satellite-based land-cover classifications and analyses of land-cover change.

Analyses of how these patterns change over time will allow us to identify relationships between landscape patterns observed using land-cover classifications, and the processes driving the changes. In addition, the direct linkage of geographical information system (GIS) technologies with remote sensing and landscape ecology research allows us to integrate spatial land-cover patterns and ecological processes in a manner which is essential to the understanding of processes of change (Forman, 1995; Turner, 1990). Results of previous studies, e.g. Blaschke et al. (2001) emphasize the need to measure change quantitatively, to incorporate both landscape pattern and landscape change from satellite image analysis, and to integrate GIS information on the biophysical structure of the landscape. Information on biophysical and vegetation characteristics of the landscape shall be used to inform us about trends in pattern at the landscape ecological level, and to associate this with information on the planning processes leading to clearcutting, urbanization or reforestation.

2.4 landscape visualization

The general advantage to be able to interactively visualize a landscape can be regarded as common sense. The state of the art in computer graphics is far beyond the scope of this paper. The combination of geographic data and multimedia is much younger and culminates in expression like “Geo-Multimedia” (the slogan of this conference). Multimedia has involved the integration of computing, video and communications, reflected in the convergence of what had been discrete components of the entertainment industry. Multimedia Cartography is sometimes seen as the cartographic application of New Media, which includes a range of new delivery and display platforms, among them are the World Wide Web, interactive digital televisions, mobile Internet technologies, interactive hyperlinked services, and enhanced packages that are linked to large databases – national or global. Future maps, when applied to the access of spatial information, will become computer interfaces and retrieval engines for spatial data. Map interfaces are increasingly intuitive and require little training. The increasing accessibility of geographical information leads to generation of more maps in a ‚map on demand’ manner. Geographical information product components can provide embedded map and image display, as well as access to spatial operations. More realistic presentations are created, with more user control, and generally innovation has spawned many exciting products (Cartwright et al. 2001).

GIS-based maps are relatively quick to produce, they provide powerful expressions of geographical stories and they allow users to experience geography in new ways. Graphics and geographical exploration media once thought impossible to produce and deliver, are consumed daily (Cartwright et al. 2001). The traditional function of maps as a spatial storage device is on the decline, whereas their communication function and analytical power are increasingly emphasized. Now the world of mapping involves simulation and the creation of Virtual Environments. Virtual Environments or Virtual Worlds result from the interaction between the cognitive level of humans, and the visual and audible images produced by computers. They offer facilities for advanced human/machine interaction through 3-D image presentation and the direct manipulation of (virtual) objects, and allow a more natural interaction with the inherently spatial data in a geographical information product (Cartwright et al. 2001). Fig. 2 shows a typical example of the use of photorealistic planning software loosely couples with GIS through data exchange.

Fig. 2: representation of a landscape and a fictive planning scenario. Photorealistic planning software loosely coupled with GIS

For typical landscape and urban planning endeavours and their respective scales, commercial software packages allow for an increasingly realistic 3-D (GIscience would call most of the underlying data models ‘2.5 D’) representation of the reality and planning visions. These visions are usually a mixture of existing spatial entities and modified versions of it plus additional spatial entities minus some entities to be replaced by others. Visualisation software aims to produce a picture of future versions of landscapes as realistic as possible. While commercial visualisation software is powerful and widely available, commercial GIS software has limited but increasing capabilities for realistic 3-D visualisation. On the other hand, visualisation software packages are, of course, not designed for a comprehensive analysis of e.g. the spatial arrangement of the proposed landscape scenario and the spatial relationships of the intrinsically underlying spatial entities constituting the (future) landscape. This is the motivation for the following case study: to fill the gap between virtual reality techniques which are readily available on individual plot/stand level or on individual building level and a landscape visualisation with precise geographic information based on real world coordinates.

Computer visualizations range from simple 3-D perspective diagrams to complete virtual realities. Four distinct categories of visualization techniques can be identified (Berry et al. 1998): geometric modelling, video imaging, geometric video imaging and image draping. Recent developments opened some ways to perform these visualisations to users in a classic GIS environment, e.g. ArcView’s 3-D analyst, although professional simulations in various natural resource applications are not satisfactorily supported. Geier et al. (2001) provided an overview of low-cost systems for the visualisation of landscapes with a focus on vegetation representations. They distinguish between internal and external modelling of plants. For both options these authors distinguish between the CAD and GIS worlds. They lay out consistently the typical advantages and disadvantages of both plant modelling strategies (internal and external) and both spatial data handling worlds. Consequently, they associate GIS based land use data with 2D information and later combine it with DEM or DTM information, respectively. Although the field of combining computer graphics visualisation techniques and GIS based ‚real coordinate data’ is relatively new, we are tempted to call it the ‚classic way’.

2.5 Case study: visualisation based on image analysis products

For a case study in the area of Tübingen, Germany we started to extend the view described in section 2.4. We utilized a remote sensing/GIS method as described by Blaschke et al. 2001 or Blaschke 2001 and recently developed to a sound methodology (Burnett and Blaschke, in press) for the visualisation and analysis of landscape scenarios in a forest dominated landscape in Baden-Württemberg. The data stem for a master thesis at the University of Tübingen (Tiede 2002), the imagery is kindly provided from the Forest Service Baden-Württemberg. Fig 4 and 5 are based on aerial photography from the year 2000, resampled to an average ground resolution of 50cm. The photographs were taken in early 2000 to investigate the damages of the storm Lothar (26.12.1999) and are not optimal for the purpose of landscape visualisation and simulation but the additional GIS data are comprehensive and detailed. The used DEM was created by D. Tiede (Tiede 2001) and results in a relatively accurate 5m DEM with average z-value errors of less than half a meter.

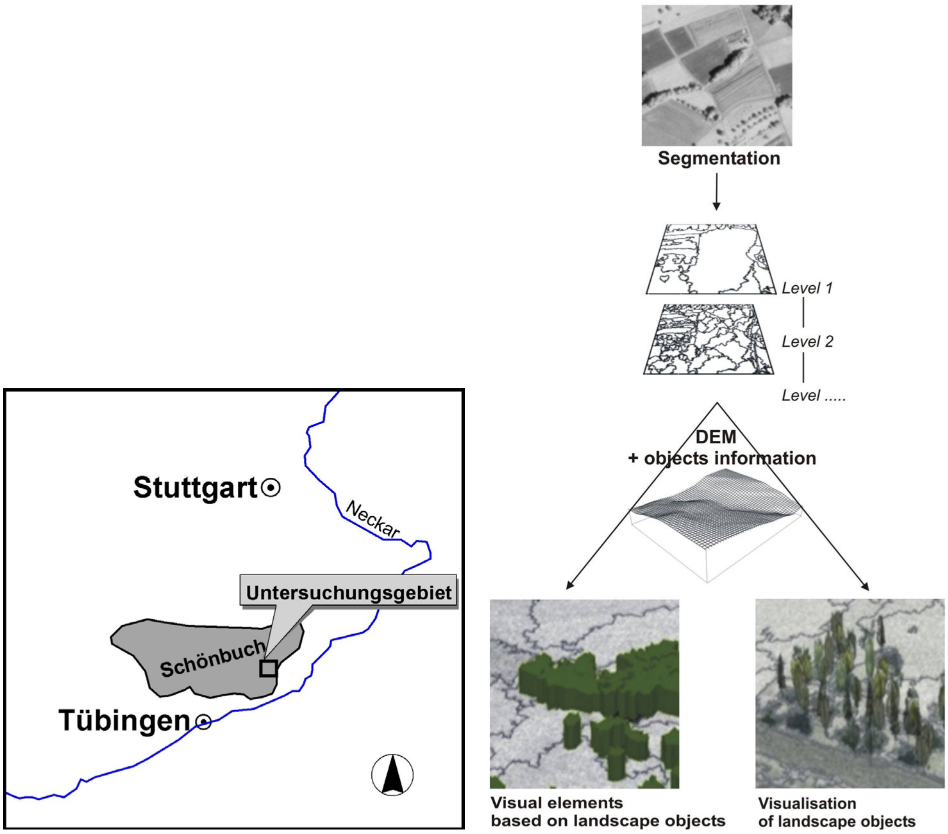

Fig. 3: Study area near Tübingen, Baden-Württemberg, Germany, and the 2-tired processing strategy, juxtaposing object-based entity modelling and 'geometric modelling' which builds on 3-D geometric representations of individual landscape features.

According to the nomenclature in Burnett and Blaschke (in press) we refer to 'whole' forest patches in the Tübingen case study area as the focal (level 0) patches. Single bushes, islands of clear-cut, meadows and other homogeneous sub-areas comprise the –1 level. This can be said to be a mechanistic level because they do not correspond to our focal scale and level of detail but help us to analyse and express quantitatively the complexity of the focal patches. The level +1 is the landscape, consisting of a mosaic of forest patches and open land such as meadows. Semantic rules are formulated in a commercial software environment (eCognition). Height information is encountered by integrating external forest data at for sub-stand units but not for individual trees. Typical heights range from 8 to 15 m, although some trees look higher due to relief variations. Individual trees in figure 4 are between 10 and 15 meter in height whereby different species at chosen. The two different ways of integration und visualisations are highlighted in figure 2.

3 RESULTS AND DISCUSSION

The aim of this paper was to examine how remote sensing and GIS data can be processed in an integrated RS/GIS object-based methodology in order to characterize landscapes, and to test how the results derived from this data source can be combined with visualization techniques. Two strategies were highlighted: block representations of objects based on sub-objects and virtual trees created on corresponding patches and their respective DEM information. In both cases, all steps are performed within the GIS software world (ArcGIS plus extensions and scripts).

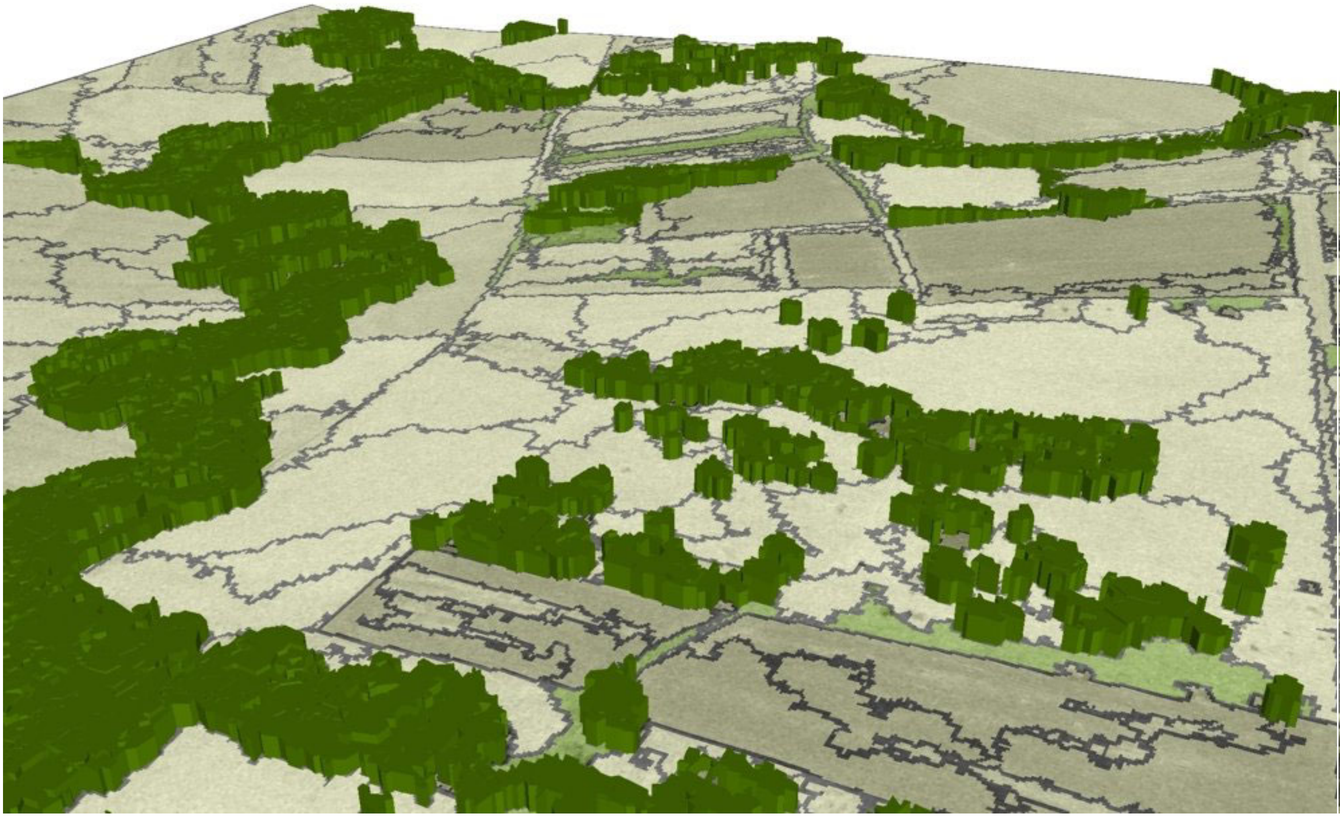

Fig. 4: example of the object-based landscape modelling superimposed on the 'patch level' segmentation of the image data

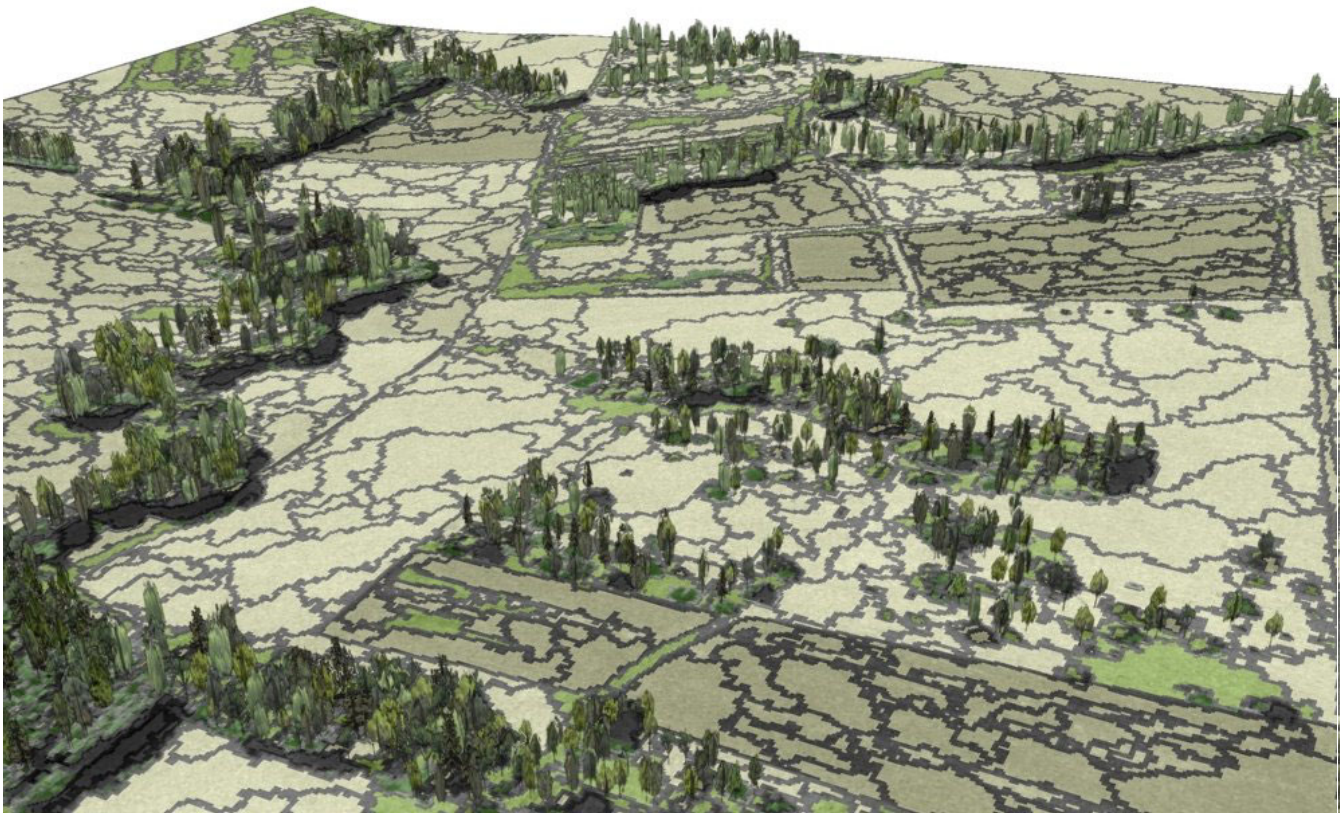

Fig. 5: example of the geometric (individual feature-based) landscape modelling superimposed on sub-patches (sub-objects)

For the visualisation and landscape planning tasks, we are still faced with substantial research questions (cf. Lehmkühler 2001, pp. 244), some of them regarding data availability in the required accuracy and standardisation issues. Nevertheless, it is concluded, that the graphical aspects are relatively well developed although a foundation of a sound methodology for expert involvement, participatory planning etc. is still missing. Especially when correct locations and view angles or view sheds are relevant, the computer graphics world is limited. The GIS based software extensions allow for exact an exact locating of flight paths, view angles or calculations of visually affected areas.

While it is widely agreed that it is possible to produce photo-realistic views of planning areas, currently only GIS-based solutions can characterize a landscape ecologically or functionally if additional digital spatial data of ecological parameters and land use structure are available. The general way of integration is to assign scanned photographs of appropriate plants to the ecological data of the GIS. Beyond that, the integration of clouds as well as other atmospheric effects and any three-dimensional objects is possible, although the GIS solutions challenge computer resources enormously. The latter restriction should not limit the development of a respective methodology since computer power is increasing rapidly coinciding with decreasing costs.

The little case study was very limited due to data restrictions but we believe that the relevance of this study for further landscape ecology investigations lies in the potential use of the methods examined for landscape survey and evaluation beyond visual simulation. The methodology described and tested in this study can be used as a basis for landscape characterization and landscape level simulations. Beyond the basis it offers for this type of application, it also has several implications for those concerned with the general assessment of landscape and other ecological resources. These implications concern the design sampling frameworks for environmental survey, and the development of more reproducible methods for landscape evaluation. For instance, expressions like "highly structured", "monotone landscape", "fragmented" can be expressed utilizing the derived landscape objects and respective sub-objects through their topological, arithmetic and spectral relationships. Rarity can be assessed in terms of the proportion of sub objects of a given type occurring within a higher level object. Extent of a given block is also easily assessed. The geographical relationships between classes, in terms of the Euclidean, environmental, and functional gradients present can also be explored using the landscape classifications and the vulnerability to changing land management practices determined.

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