Algorithmic Landscapes Meet Geodesign for Effective Green Infrastructure Planning: Ideas and Perspectives

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Abstract: In this paper, we discuss the potential of incorporating algorithmic landscapes in Geodesign to enhanceGreen Infrastructure (GI) planning. In the first part of the paper, we identify the matches among all three subjects and how the methods may benefit from each other. GI planning is an ecological framework for environmental, social and economic sustainability. It aims to develop an interconnected network of green spaces that provide ecosystem functions and benefits for multiple values. As an interdisciplinary approach involving a variety of stakeholders, the challenge is to enable all to understand complex ecological processes and interactions on a landscape scale. Geodesign offers design strategies and procedural techniques for communication and understanding of the geographic context and emphasizes collaboration and co-design. Biophysical algorithmic landscapes can present intuitively appealing visualizations of complex data that enable all stakeholders to appreciate both the landscape and the underlying environmental and ecological patterns in their area of interest. Both GI planning and Geodesign attempt to formalise a very complicated process and the incorporation of more algorithmically based input would seem to fit well with this endeavour. In the second half of the paper, we present two examples of applications that have used algorithms for green planning. The first uses habitat suitability modeling to identify spatial potentials for ecosystem functions and services. The second uses assemblage modeling to integrate bio-physical data and generate an "all in one" map for use in regional nature conservation planning in Australia. Although neither presents a 'ready-to-use'-solution, they illustrate the potential of suitable algorithms for more formal integration in Geodesign processes. Geodesign in turn can support the communication strategy within GI planning through its emphasis on stakeholder involvement. Thus, the algorithmic approach together with Geodesign show capabilities for raising understanding and appreciation for ecological processes, functions and associated human benefits among the different stakeholders to support GI planning processes.

Keywords: Ecologically Oriented Planning, Green Infrastructure, Geodesign, Algorithmic Landscapes, GIS

1 Setting the Scene: How to Get the Horse before the Cart

1.1 What is Green Infrastructure Planning?

Although the term 'Green Infrastructure' (GI) is relatively new, its ideas are related to earlier concepts of urban planning (WRIGHT 2011) and conservation of biodiversity, such as habitat and wildlife networks and ecological corridors (AHERN 2007). The concept of GI emerged in the United Stated in the late 1990's in response to urban sprawl, with its negative effects on landscape and nature (ROUSE & BUNSTER-OSSA 2013). The intention was to integrate green "infrastructure' into spatial development as an "interconnected network of green spaces that conserves natural ecosystem values and functions and provides associated benefits to human populations" that could provide "the ecological framework needed for environmental, social and economic sustainability" (BENEDICT & MCMAHON 2002). In the meanwhile, it evolved

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very dynamically on different scales, putting emphasis on various objectives addressed by a number of disciplines, such as ecology and conservation biology, regional and urban planning, landscape architecture, water resource management and transportation (KAMBITES & OWEN 2006, TZOULAS et al. 2007, MELL 2010, SINNETT et al. 2015). Unchanged is the common understanding that GI "aims to create multifunctional networks of green spaces" with connectivity and multifunctionality as two inherent key principles (PAULEIT et al. 2017). It is understood as an integrated cross-sectoral spatial planning approach, comprising biodiversity planning, along with a number of different landscape functions and services such as water, climate, fluxes regulation as well as taking into account social and cultural benefits. As a prerequisite, the understanding of natural resources and the environment and their capacities to support ecosystems and their services are essentials for sound GI planning. Hence, successful GI planning needs communication strategies to raise understanding and appreciation of ecological processes, functions and associated human benefits among all the different stakeholders.

1.2 What is Geodesign and why is it Good for Green Infrastructure Planning?

According to MILLER (2012) the basic concept of Geodesign can be understood as design that relates to geographical context, i. e. the natural conditions of a site and its surroundings. This approach was used by earlier influential architects and landscape architects including Frank Lloyd Wright (1867-1959), Richard Neutra (1892-1970), Warren H. Manning (1860-1938) and Ian McHarg (1920-2001). The term "Geodesign" was introduced by STEINITZ (2012) to brand his conceptual framework that consists of design strategies and procedural techniques that essentially benefit from the integration of both Geographic Information Science (GOODCHILD et al. 1991, LONGLEY et al. 2011) and creative design. Because Geodesign is considered as an interdisciplinary approach involving different stakeholders in the design process it aims to provide methods and tools that promote collaboration and co-design.

As mentioned above, for successful green infrastructure planning, interdisciplinary approaches are needed that enable different professions and actors from government and the community to work together (PAULEIT et al. 2020). Hence, GI planning would likely benefit from Geodesign for the communication and understanding of the geographic contexts through Geodesign's promotion of collaboration in the spatial planning processes.

1.3 What are Algorithmic Landscapes and why are they Good for Green Infrastructure Planning?

The origin of the term 'algorithmic landscape' may be found in the field of digital art and computer simulation, particularly for the creation of artificial worlds in videogames and movies (LANGSTON 2012, DOLAN 2018). Basically, 'algorithmic landscapes' can be understood as landscape representations that have been digitally processed and manipulated, ideally reflecting spatial patterns of underlying landscape variables and processes in the most realistic manner (c. f. CURETON 2016). We may thus consider Alexander Humboldt's 'Tableau physique des Andes et pays voisins' as an earlier 'analogue' historical precursors of an algorithmic landscape (Figure 1). The painting synthesises spatial patterns and interactions of a number of environmental variables, such as elevation, soil, climate, vegetation, based on data from several years of field observations and measures during the years 1799-1803.

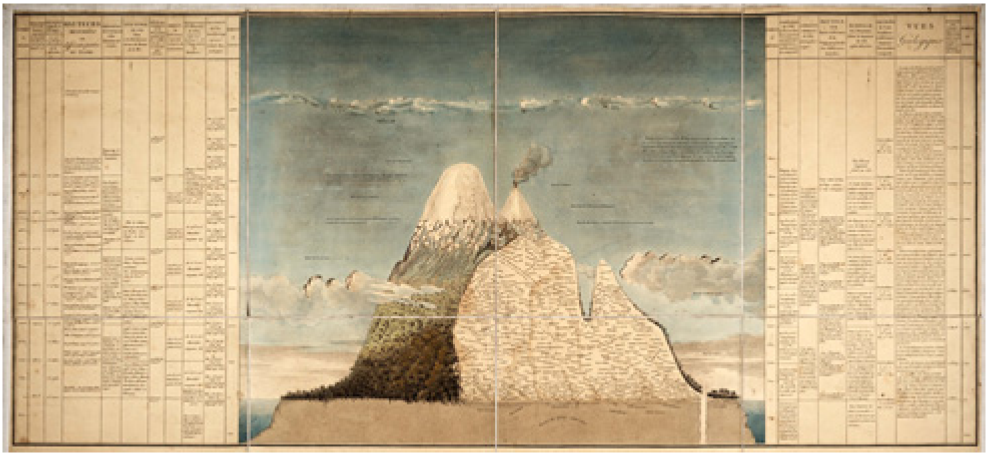

Fig. 1: Painting of the Chimborazo volcano is a formalised representation und interpretation of environmental phenomena by Alexander von Humboldt and Aimé Bonpland – possibly the first algorithmic landscape ever modeled (Source: Peter H. Raven Library/Missouri Botanical Garden, http://botanicus.org/page/1061689)

Recently designers in landscape architecture started experimenting with algorithms to support design concepts (CLAGHORN 2018). One of the more established applications in landscape architecture is the one of 'digital botany' used for high-end visualization of vegetation structures (PRUSINKIEWICZ & LINDENMAYER 1990, REKITTKE & PAAR 2006). At the same time, various landscape oriented disciplines have developed suitable algorithms to analyse and model patterns of spatial arrangements, topological relationships and networks, spatial growth, flow of energy, matter, and information as well as spatial interactions, behaviour, and response. Digital geographic information offers opportunities to analyse of complex systems and spatial implications of dynamic processes. As such potential applications of algorithmic landscapes can be very broad and manifold.

In this paper we focus on representations of the biophysical landscape that are generated by algorithms applied to real world data. Algorithmic-based methods have been developed in the past decades adding new perspectives to traditional expert-based, qualitative methods, integrating existing environmental models into geographical information systems (KEMP 1997). In the meanwhile algorithms have undergone a number of advancements to delineate and visualize landscapes (e. g. BELBIN 1995, HARGROVE & HOFFMAN 2005, KREFT & JETZ 2010). The application of biophysical 'algorithmic landscapes' provides insights into interrelationships between the biological and physical systems of the landscape, directly supporting ecological oriented planning and design (c. f. MCHARG 1969, MURPHY 2016). Thus, they can help all stakeholders to appreciate the landscape and its underlying environmental and ecological patterns in their area of interest, supporting GI planning.

1.4 How Do Algorithmic Landscapes Fit with Geodesign?

The Geodesign framework can be broadly divided in two phases: the descriptive/evaluative (representation/process/evaluation) and the prescriptive/planning (change/impact/decision) part (STEINITZ 2012). The two phases are strongly related to the dynamic interrelation of spatial patterns and ecological processes of the landscape and secondly, to how landscape planning, in turn, alters landscape patterns, processes and functions. As mentioned earlier, potential applications of algorithmic landscapes to support design processes may be manifold (CLAGHORN 2018). Potentially they can show how ecological processes interact across spatial patterns which is exactly what Geodesign needs for its change models.

"Representation models" are Geodesign's views of the inputs to its planning process and algorithmic landscapes are perfectly suited to delivering these. They can be used to communicate the reference geographic context, intuitively accessible to all participants and therefore conducive to cooperative and participative GI planning. This fosters local stakeholder appreciation of their landscape and its underlying environmental and ecological patterns and is inclusive of experts with from non-ecological disciplines. Hence, we would encourage the formal incorporation of algorithmic landscape models in Geodesign to address the following gaps as identified by STEINITZ (2012) and to enhance the current state of the art of Geodesign:

1) In representation models the application of Algorithmic Landscapes helps to deal with continuous, non-categorical information and fuzzy data. In particular, biophysical environmental phenomena usually do not have clearly defined characteristics with well-defined borders. They are usually characterized by environmental gradients and landscape variables with smooth transitions.
2) In process and impact models the application of algorithmic landscapes may help to understand interrelated systems, with complex attributes and interpret the interrelations in a simple and understandable manner according to the stakeholder interest.
3) In the change models algorithmic landscapes offer a formal repeatable analytical methodology, transferable to different contexts.

2 Application Study

2.1 Habitat Suitability Modeling Algorithms to Identify Spatial Potentials for Ecosystem Functions and Services

The second example uses algorithms for habitat suitability analysis. These support habitat-based conservation approaches, aiming to identify regions, areas or sites (depending on spatial scale) suitable for target species conservation. Such information is needed to support the planning of hubs, sites and links that are fundamental components of GI. Furthermore, these approaches can be used to identify spatial potentials for ecosystems and their services, highlighting areas with benefits for humans in general as well as those addressing the local stakeholders' interests.

The identification of spatial suitability for the development of GI components is essential for effective GI planning. Therefore, effective suitability mapping methodologies are needed. Modeling of habitat suitability, also often referred to species distribution modeling (SDM), environmental or ecological niche modeling offer a promising mapping approach using algorithms for sophisticated data exploration. The main idea of habitat suitability modeling is to estimate the spatial distribution of suitable habitat conditions, based on statistical relations between known distribution patterns and prevailing landscape and environmental parameters (AHMED et al. 2015). This approach is particularly efficient in areas where real occurrence data are missing, and helps to provide an overview of the distribution potential habitats and ecosystems. Many different algorithms and toolboxes have been developed (e. g. GUISAN & ZIMMERMANN 2000, HIRZEL & LE LAY 2008, PETERSON 2006). They have been widely used to answer ecological questions related to reserve design and conservation planning, impact assessment and resource management, ecological restoration and ecological modeling, risk and impacts of invasive species including pathogens, and to analyse effects of global warming on biodiversity and ecosystems (FRANKLIN & MILLER 2009).

Habitat suitability modeling can support planning processes in an effective manner, providing an analytical methodology that is transparent, repeatable and transferable, that can be integrated in Geodesign as process and impact models as well as change models.

In this application study, habitat suitability modeling was used to map the potential spatial distribution of low-intensity grassland systems (Figure 2). The relevance of these to the support of multiple functions for urban green infrastructure has been accessed (ROLF et al. 2018). With the support of the modeling process, spatial potential for low-intensity grassland farmland have been identified that could contribute to a number of services, These include the protection of biodiversity, the regulation of local urban climate and air quality problems due to abiotic connectivity and opportunities for recreation and human regeneration at the urban fringe for city dwellers.

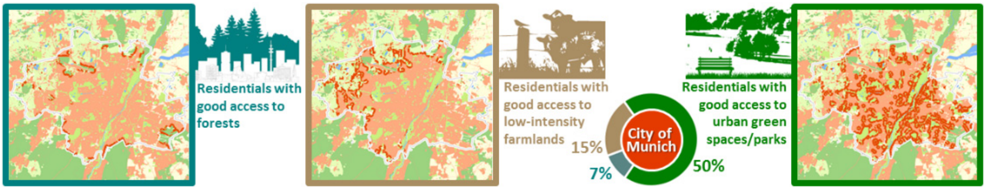

Fig. 2: Example of habitat suitability analysis used to identify potentials for low-intensity farmland (grassland systems) as multifunctional open green space for urban dwellers, in the City of Munich, Germany (adapted from ROLF et al. 2018)

2.2 Assemblage Modeling Algorithms to Summarise Comprehensive Biophysical Data

Our first example illustrates the principal use of algorithmic-based methods for summarising comprehensive biophysical data in providing the reference basemap for GI planning and facilitating the Geodesign collaborative approach. The same algorithms can adapted to mapping potential ecologically sustainable agricultural land-use.

Methods suitable for landscape character assessment are manifold (WASCHER 2005). Those driven by human ('expert') interpretation are vulnerable to subjectivity, whereas approaches that are based on more statistical, automated analysis – with or without interpretative refinement – are more transparent and meet the scientific rigour of repeatability and statistical reliability (JONGMAN et al. 2006, BUNCE et al. 2008). The latter are the "algorithmic" methods and take advantage of computation and "big GIS data". The latter are the "algorithmic" methods and take advantage of computation and "big GIS data". Algorithms that can handle multiple continuous environmental variables are needed to properly analyse these data and to summarise and map the spatial interplay among them.

In the 1980s, Australian national raster coverages of biophysical environmental variables were developed to support 'Environmental Domain Analysis' (EDA) as a geographically mapped multivariate cluster analysis of physical environmental regimes (MACKEY 1996). EDAs have since been undertaken in many different natural and cultural landscapes, including Northern America (COOPS et al. 2009), Europe (METZGER et al. 2005), New Zealand (LEATHWICK et al. 2003), Switzerland (BAFU GRID-Europe 2010). These have taken advantage of advances in technology and data quality. One of the latest is the European Landscape Classification (MÜCHER et al. 2010), using state of-the-art image processing technology to classify and segment high-resolution multi-band raster of various environmental variables, integrating climatic and topographical factors, soils, and land-use.

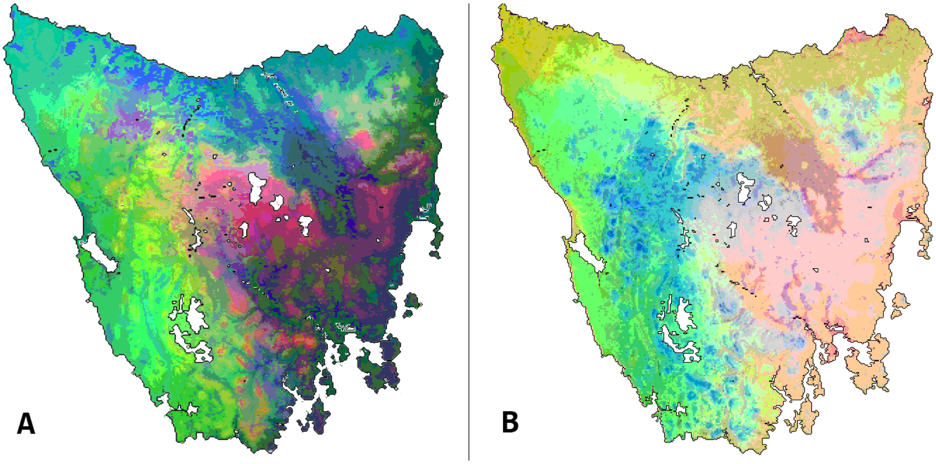

Fig. 3: A: Environmental Domain Analysis, B: Species Assemblage Modeling. Both are 'algorithmic landscapes' and are based on analysis of the same suite of environmental rasters. Scale: Tasmania is 300 km wide. Both maps have fuzzy boundaries. Perceived colour differences correspond to data differences for non-colour blind viewers. (adapted from PETERS & THACKWAY 1998).

A more bio-centered approach goes beyond EDA by using SDMs to delineate ecosystems rather than environmental domains (PETERS & THACKWAY 1998). Our example is taken from this work. Figures 3A and 3B are both algorithmic landscapes with the same suite of environmental variables as input. Figure 3A is the EDA produced using an algorithm similar to that of Mackey (MACKEY 1996). Figure 3B uses a different but not much more complicated algorithm. The map was developed from 65 bird SDMs considered together. Each SDM raster cell's value is the probability of the species being present. The SDM raster stack is the input matrix for a Principal Components Analysis (PCA). The output is a low dimensional representation of the spatial variance in species composition ("species assemblage space"). Thus, this modeling approach contains the combined species assemblage 'view' of the environmental data rather than a naive classification of them. One nice advantage of this algorithm is that each raster cell is located spatially as usual but has the orthogonal PCA species assemblage space coordinates as well. The three most informative of these can be projected into perceptually uniform color space. In this case, the regionalization phase did not use image segmentation algorithms because those available then could not handle mosaics. Instead the fuzzy ecosystem map was used by expert local biogeographers as a guide to drawing boundaries (collaboratively!). Providing a legend for these fuzzy maps is a challenge although locals seem to have little difficulty interpreting them. Recent advances in graphics processing will no doubt be helpful in providing interactive legends and the days of the paper map are probably coming to an end.

This 'species-oriented' algorithm can use SDMs trained on any spatial phenomena linked to the environment. For example, a cultural landscape in Central Europe was modeled from land use mapping, using landuses classes as "species". A landuse was considered sustainable from the point of view of local environmental regimes if its model was a good fit (PETERS 1999, ROLF 2012). Similarly, expert maps of potential natural vegetation etc. can be "reverse engineered" using this approach to discover the rules the experts probably used and perhaps to reveal their underlying assumptions.

The products of these landscape classification and visualization algorithms can provide the reference basis for GI planning in that they help planners and stakeholders to understand landscape as an interrelated dynamic process of biological and physical factors. Further, the models can be readily integrated in the Geodesign as 'representation' models and might also be appropriate inputs for change models.

3 Conclusion and Outlook

We have highlighted the strength of Geodesign for GI planning if based on sound scientific ecological data. The integration of our suggested algorithmic landscape approach can contribute to this strength by enabling the ecological information to be summarised for communication with stakeholders with limited specialist ecological knowledge.

We realize that the general approach is not new and that geographic information science already offers a number of different algorithms that appear to be suitable for integration in Geodesign processes. However, we also note that as yet, no 'ready-to-use' solutions are out there. We believe that the time has come to introduce these into the GI planning mainstream.

Nevertheless, the examples provided by this work illustrate how the use of sophisticated algorithms help to analyse complex ecological interrelations in the landscape. Such approaches help to handle comprehensive environmental data and offer opportunities to process them purposefully. In particular, the examples attempt to demonstrate the potential of algorithmic landscapes to provide the baseline mapping of underlying environmental regimes, relevant to local ecosystems that we see as vital for GI planning.

More research effort is needed to strengthen ties between geographic information systems science and design and to demonstrate the utility of the approach. Still, we believe GI planning stands to benefit from algorithmic models incorporated in the Geodesign framework when it comes to the identification of potentials for ecosystem conservation along with their services and human benefits.

Despite the limitations of this work we hope it has shed some light on these potentials and that it will encourage discussion to further evaluate the use of algorithmic landscapes as part of the Geodesign framework. We believe that algorithmic landscapes can contribute to Green Infrastructure planning directly but can be even more effective when delivered as part of the Geodesign process. When all three components of our suggested approach are combined, we can hope for effective communication to stakeholders of the complex ecological interrelations that need to be considered in the delivery of any viable GI plan.

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