Ecosystem Services, Smart Technologies, Planning Support Systems, and Landscape Design: A Framework for Optimizing the Benefits of Urban Green Space Using Smart Technologies

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Abstract: Urban green spaces and natural areas are common objects of landscape design. These areas provide vital services to urban residents including climate and water regulation, disaster mitigation, and recreational opportunities (among other benefits). While contemporary landscape architects are well aware of the importance of these and other ecosystem services, their understanding of the ecological principles on which these services are based is limited and usually based on empirical or qualitative sources. Consequently, quantitative analysis including ecological processes and assessments on how ecosystem services are impacted by design decisions can be absent from typical landscape design workflows. In this study, we propose a quantitative analytical framework based on 'smart' approaches that combine planning support systems, landscape stress analysis, and ecological modeling in support of landscape design and decision making. The analytical framework is tested on a potential community development project to illustrate how designers can benefit from easy access to such information via planning support system models.

Keywords: Impact analysis, Planning Support Systems (PSSs), Geodesign, land-use modeling, ecosystem service

1 Introduction

The term ecosystem services refers to the benefits that humans accrue directly from a healthy and functional ecosystem. This useful construct has helped define the value that ecosystems provide to human populations (COSTANZA et al. 1997). Its use in typical landscape design processes however, has been limited. A general reductionism in ecological and environmental sciences has been noted as one possible explanation (CRESWELL 2009). The complexity and narrowness of the field has generated fragmented (and a somewhat distributed) knowledge set which designers may find difficult to access and utilize in day to day design activities. In addition, ecologically based studies are typically set in well-preserved ecosystems that are both far from densely populated areas and disconnected from the typical anthropocentric landscape design project (VAN LIEROP 2011). To promote landscape designs that more readily consider and apply established ecological principles and useful constructs such as ecosystem service analysis, scattered ecological datasets must be integrated and translated into a design centric philosophy in a language that landscape architects can understand and easily access.

New efforts in data sciences and information and communication technologies (ICTs) is providing a means to establish such an integration. The approach uses system models, machine learning and other manipulation techniques to allow large amounts of data to be pro-

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cessed and communicated in highly efficient ways. These smart technologies may both overwhelm and help support landscape designers. It can more readily connect designers with a vast, numerous and discrete set of new data and scientific findings. Without translation or manipulation however, these enumerate bits of data can overwhelm decision making and design. This was a common problem in early periods of smart city implementations, where the "smartness" of a city was measured by the amount of ICT infrastructure (big data) with little or no context awareness or connections to natural or social systems. Although vast amounts of data were generated, these systems had little connection or impact on actual decision making. According to CARAGLIU et al. (2011) it took years to establish an anthropocentric approach to smart cities that is centered on human needs and interactions.

The last decade has witnessed the rapid development of these smart tools that exhibit great potential for helping to optimize urban services planning and maintenance. In the field of landscape architecture however, the application of smart approaches is still a nascent idea. While sensors and other data collection devices have been installed in urban open spaces, how such data might help in landscape design is challenging. One consideration is that design and planning can be highly divergent processes that emphasize different values and outcomes. As a result, most planning support tools have not been fully utilized in landscape design activities. Process oriented approaches such as GeoDesign have been established to help designers benefit from state-of-the-art planning support system information. The key is that designers are able to understand whether their design decisions are viable and desirable from a planning perspective (WARREN-KRETZSCHMAR et al. 2012).

Some literature suggests that a smart approach is more than ICT, data collection, and data processing. A sophisticated 'smart' system should be sentient – aware of the context, of the application, and of the user (DEAL et al. 2017). The system should be able to accommodate a wide range of viewpoints, data requirements, and visual representation techniques in order to produce useful and timely information (CARAGLIU et al. 2011, GEERTMAN et al. 2013, DEAL et al. 2017). In this paper we propose that in addition, measuring 'smart' should be based on the system's ability to effect on-the-ground design and landscape scaled decision making.

In this paper, we propose a smart approach to help designers usefully access and utilize big data and information sources. We focus our efforts on ecological resources and their relationship to complex urban systems. Our framework utilizes a planning support system, the Land-use Evolution and impact Assessment Model Planning Support System (LEAM PSS), to connect design decisions to complex urban ecological models in an easily accessible way. The goal of the project is to turn fragmented ecologically based data into easy-to-understand information that landscape designers can use to promote the wise management of ecosystem services in their projects.

2 A Smart Landscapes Framework

2.1 Overall Workflow of the Smart Approach

Based on similar GeoDesign process approaches that typically use a 6 step process (STEINITZ 2012), our modeling framework generally follows 5 steps: 1) identify important ecosystem services and related landscape processes, 2) forecast future development and land-use changes, 3) evaluate how future land-use changes will affect ecosystem services, 4) present spatially explicit visualization data and resources in designer centric forms and language, and 5) revise the model based on design decisions (Figure 1). We expect a feedback loop of land use change, model prediction, and design implications can help the designers and decision-makers to promote sustainable development and optimize benefits from ecosystem services in a constantly changing environment.

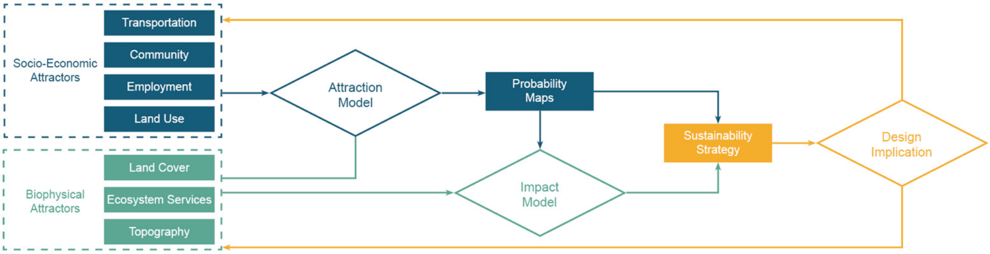


Fig. 1: Framework for a smart approach to landscape design coupling the LEAM PSS and ecosystem service impact models

2.2 LEAM PSS

The LEAM PSS (www.leam.illinois.edu) is a planning support system with the LEAM land use model at its core. The model projects future development based on a wide range of biophysical and socio-economic factors. It also provides an online API from which the users can modify and customize the model to meet their needs (DEAL & PALLATHUCHERIL 2009). Basically, the model works by delineating the current conditions (such as community, employment, or urban green space) as a set of "attractors". An "attraction value", or accessibility to the attractor is then calculated based on the transportation network and travel speed (using travel speed enables different forms of transportation to be assessed, walking, biking, mass transit or automobile). Higher attraction values represent better accessibility to resources such as housing, cultural attractions, or employment. A modular approach enables the stringing of various attractor and cellular automata based decision models (nearest neighbors, the diffusion of resource information, etc.). A final probability surface is used to allocate various cell types (based on economic classification, usually 5-10 different classes of housing and commercial activities).

One advantage of LEAM is that the spatial relationship is represented by time and network, instead of Euclidian distance – used by many existing urban development models. This enables the complexity of the urban fabric to be more accurately reflected in the probability surfaces generated without oversimplification. Moreover, the model is very flexible in terms of input variables, any biophysical or socio-economic factors that may affect future development can be considered as an attractor. As a result, it can be utilized under many different conditions without extensive modification. Figure 2 is an example of LEAM probability surfaces for 3 different economic classifications: community services, industrial areas, and urban commercial development. Altering the input attractor sets enabled an assessment of different types of development.

Fig. 2: LEAM Probability surfaces for 3 different types of development in Sangamon County, IL: community services, industrial areas, and urban commercial. Higher values (yellows) indicate where development is more likely to happen; lower values (blue) are areas where the likelihood of this type of development is very low. Project site discussed in Part 3 is shown as the red polygon.

2.3 Impact Models – Ecosystem Services

The LEAM model helps to conduct ecosystem service impact analysis in two ways. First, natural areas and urban green spaces providing ecosystem services can be considered as attractors and their effects on future urban development can be projected. Second, the final LEAM change map allows an assessment of potential environmental impacts caused by future development so preventive measures can be taken before the actual damage happen.

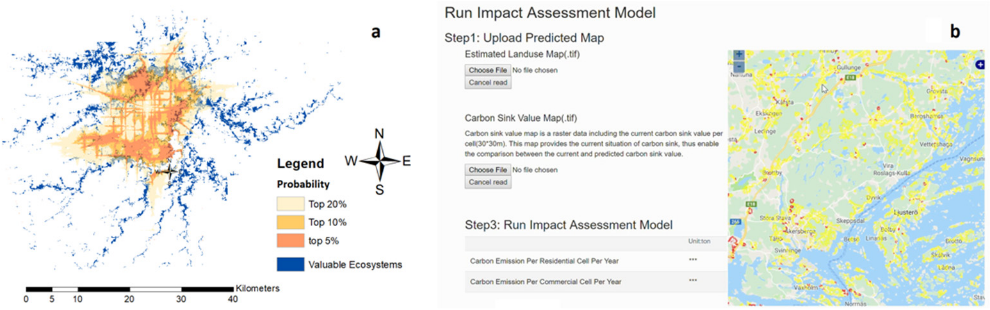
Typically three categories of ecosystem services are considered: 1) provisioning: material values human gain from ecosystems such as wood and fish resources; 2) regulatory: ecosystems act as regulators in these services, such as erosion prevention, water treatment, and storm protection; and 3) cultural: ecosystems used as places of cultural, spiritual and recreational activities. Several approaches are typically applied to estimate the values of each type of ecosystem service. The estimation of provisioning values is usually straightforward, using the market value of the products. The value of regulatory services can be estimated by replacement-cost method. For example, the value of water purification service of a wetland is equal to the construction and maintenance cost of a purification plant with the same capacity. It is difficult to make explicit estimation of the cultural services since they are usually non-market values. But it can still be estimated by people's willingness to pay (Spash 2008). In this study, the National Land Cover Database (NLCD) 2011 land cover map for greater Chicago region is used to determine land cover type for ecosystem service analysis purposes. The value of each type of ecosystem was based on literature review using a searchable database by (Van der Ploeg et al. 2010). Because of the complexity of ecosystems, one type of land cover usually provides many different kinds of ecosystem services. For example, forests have provisioning values by providing fruits and firewood, regulatory values by providing wind protection and cooling, and cultural values by providing recreational spaces. Research projects of ecosystem service values, on the other hand, usually focus on one or a few types of series. Therefore, in this study we have went through different publications to find estimations of different types of ecosystem services values, which were added up to get a total value of the certain land cover. Newer publications with a setting in Midwestern United States were preferred. If a location-specific estimation was unavailable, a more general estimation under a similar climate zone would be accepted for calculation.

Stress Analysis. LEAM probability maps provide information of when and where development might occur. This helps identify areas that may be stressed by the changes – in this case areas of high ecological importance. It also allows an analysis of the potential loss of various ecosystem services. Once impacts are established, mitigation or compensation design interventions can be developed.

We use LEAM probability surfaces to quantify the stresses that potential development has on ecological resource areas. LEAM estimates the probability of development in each succeeding year for every 30 m × 30 m cell in the area of study. We use cell probabilities to derive a probability distribution within a specific geographic area. We use this distribution to statistically analyze how it impacts the resource of study – in this case, ecosystem services.

We use the 80th, 90th, or 95th percentile (i. e. the top 5 %, 10 %, and 20 % of the study areas with the highest probabilities of change). These are classified as 'stressed'. Figure 3a overlays developmental probability surface with high performing ecosystem service areas to exhibit how these ecologically important areas might be affected. Design interventions, such as setting up no-growth zones or buffers that help to preserve important ecological resources can be tested and verified simply using this modeling framework.

The framework makes ecosystem service calculations available for design decisions using a 'what-if' design intervention-based scenario approach. Deign scenarios can be tested using the decision framework (Pan et al. 2019) through a prototype API driven interface. Figure 3b shows the interface describing how future developments may affect carbon sinks in the Stockholm, Sweden region (http://www.leam.illinois.edu/stockholm2017/impact_assessment/impact_assess.html).



Run Impact Assessment Model

Step1: Upload Predicted Map

Estimated Landuse Map(.tif)

Choose File No file chosen
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Carbon Sink Value Map(.tif)

Carbon sink value map is a raster data including the current carbon sink value per cell(30*30m). This map provides the current situation of carbon sink, thus enable the comparison between the current and predicted carbon sink value.

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Step3: Run Impact Assessment Model

	Unit:ton
Carbon Emission Per Residential Cell Per Year	***
Carbon Emission Per Commercial Cell Per Year	***

Fig. 3: Examples of LEAM-based impact analysis. a) a stress test of Sangamon County illustrating how ecologically important areas (forests, wetlands, and riparian areas) may be affected by potential development; b) Stockholm impact assessment model API, currently it can estimate the loss of carbon sinks

3 An Application to Sangamon County, IL

The framework was tested in Sangamon County, Illinois. Sangamon County is a complicated mosaic of land-use types over 877 square miles in central Illinois. The senescence and growth of urban, residential, commercial, industrial, and agriculture land uses are occurring simultaneously in varying parts of the county. The area also hosts valuable natural areas including forests, wetlands, and riparian zones. Many of the natural areas and urban open spaces are interlaced with rural developments. While providing important ecosystem services, the natural areas in the county are vulnerable to a range of disturbances. With the help of the LEAM PSS we forecast changes in the noted land uses over time (to 2050). The forecast is used to identify the timing and location of potential changes in land uses. They are also used to establish the potential developmental stresses likely to be placed on regional ecological assets and the possible impacts on ecosystem services (i. e. wildlife habitat, flooding protection, and carbon sequestration).

To demonstrate how this framework can help landscape designers, we tested our impact analysis and stress model on a potential residential development project in the county. Economic models indicated that employment in Sangamon County will grow for the next several decades and additional housing is required to accommodate the new employees and their families. Our site is a 1,630 ac (6.59 km^2) area located to the east of the City of Springfield (Figure 4). The LEAM growth maps had indicated high probability scores of community facilities (such as school, medical facility, and police station), industrial areas, and urban commercial areas at the project site. Therefore, it was expected to be a candidate for future residential growth, with easy access to community services, employment, and commercial areas. Nevertheless, the site was also close to Lake Springfield, with a significant portion of the area covered by ecologically important wetlands and riparian forests. Moreover, more than a half (915 ac) of the area was in medium to high risk of being flooded (see hatched areas in Figure 4). The complexity of the landscape had made residential development a challenging task for designers – multiple factors needed to be taken into consideration, and trade-offs needed to be made.

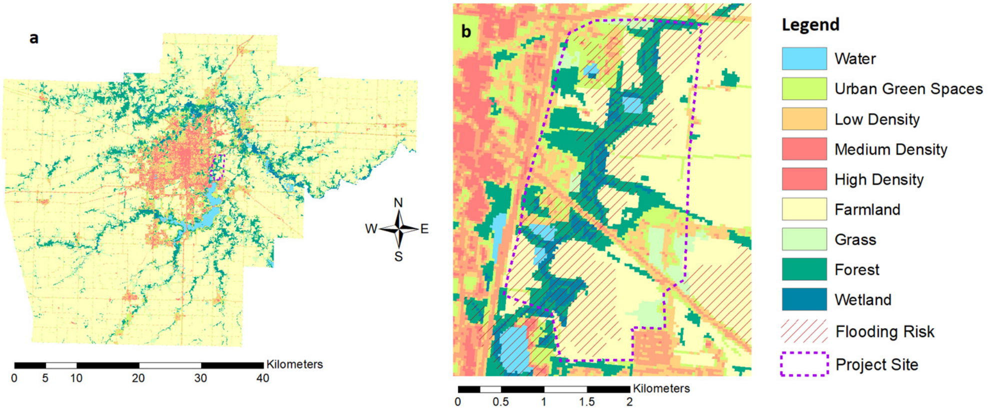

Fig. 4: a) Current land use of Sangamon County, b) current land use of the project site – slated for housing developments. The hatches indicate areas with high flood risk

A successful design of a residential community under such an environmentally sensitive setting will require balancing between housing, conservation of ecosystems, and flood safety. Here we set four goals of the project, while a satisfying design shall meet all of the goals simultaneously: 1) provide at least 3,000 housing units, 2) total ecosystem services value shall be at least 954,048 USD/yr (95 % of current value), 3) total carbon sequestration shall be at least 390,776 kg/yr (95 % of current value), 4) no developments under the risk of flooding.

Using this criteria, we analyzed the current condition (business as usual) and 3 different development scenarios. Total ecosystem service values and carbon sequestration were calculated for each design scenario (see Van der Ploeg & de Groot 2010, Zhu & Reed 2012 for a good description of the analytical process used). Flood risk was represented by percentage of the residential development within areas under medium to high risk of flooding. The results were shown in Figure 5.

Current Condition: The project site was largely undeveloped, with very few scattered residents (Figure 4). The estimated population was 212, with 98 housing units. The area was ecologically valuable, hosting 346 ac of forests and 112 ac of wetlands. The total ecosystem services value was calculated at 1,004,262 USD/yr, with a carbon sequestration value of 411,343 kg/yr. The rest of the site is mainly used as agricultural lands.

Scenario 1: Low Density Development: Under this scenario, 60 % of the site area would be converted into single family houses with a density of 2 housing units per acre – common in suburban areas in the region. Due to the conversion of agricultural land and the abundant green spaces that come with such a low-density development, the total ecosystem services value and carbon sequestration values increased after the development. The low density also meant that only about two-thirds of the desired housing units could be provided. Expanding the development would inevitably damage the forest and wetland areas. Another disadvantage of this scenario was that a significant portion of the development would face severe flood hazards. Low density developments also augment the disadvantages of sprawl and increased emissions from transportation, neutralized any additional carbon sequestration advantages of the additional green areas.

Scenario 2: Mid-High Density Development: Under this scenario, there would be two types of development: medium density single- and two-family houses with an average density of 4 housing units per acre, and high density multi-family houses or townhouses with an average density of 6 housing units per acre. Each of them would take up to 20 % of the total area. This scenario would provide enough housing while the flooding risk would be relatively low, although the environmental impacts to carbon and ecosystem services were significant.

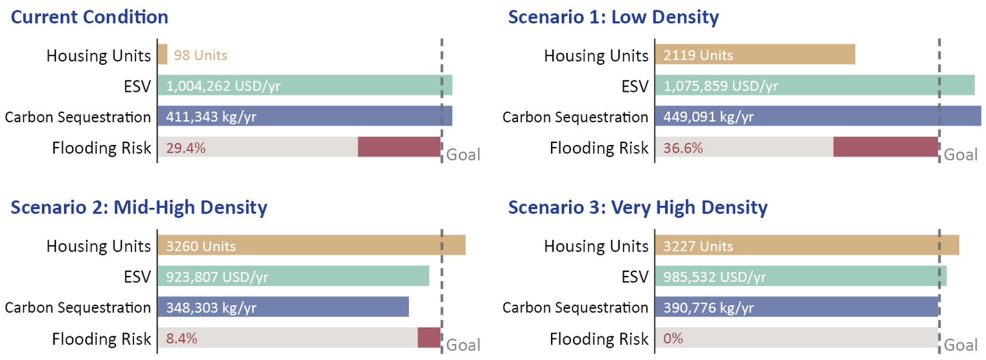

Fig. 5: Comparison of the housing units provided, ecosystem services value (ESV), carbon sequestration, and flooding risk among current condition and 3 different scenarios

Scenario 3: Very High Density Development with Green Roofs: Under this scenario, the development would be multi-story buildings with an average density of 9 housing units per acre, covering 22 % of the site area. In this way we would be able to provide enough housing with no risk of flooding. While high density developments usually did not host a significant amount green spaces, the density mean the development could be restricted in ecologically unimportant areas to minimize environmental impacts. In this case, 27.6 acre of green roof (7.7 % of the impervious area) would be enough to compensate the loss of carbon sequestration. With enough green roofs, this will be the desired scenario that fulfills all of the goals.

4 Conclusion

In this paper we demonstrate a framework for a smart approach to landscape design, combining a dynamic PSS and impact models. We show how it can help landscape designers to make decisions by providing easily accessed information. This framework is based on a similar set of data (such as land cover and digital elevation maps) that are commonly utilized by landscape architects in their site analysis processes. Instead of jumping to design conclusions intuitively however, the framework allows the interpretation of the landscape design using quantitative reasoning. This is an advantage that can only be achieved by smart approaches. Hidden information not revealed explicitly by the data can be revealed by extensive (yet automated) manipulation models. In this case, we were able to provide exactly how much of the ecosystem services and carbon pools might be affected and how many of green roofs could compensate the loss. This not only helps the designers to better understand their project sites, but also introduces better reasoning process, making the design decisions easier to defend when facing clients and stakeholders.

The development of the LEAM PSS and the impact analysis in Sangamon County is still ongoing. We will be presenting the visualized analytical results online in API mapping form or tabular data that is easily accessed (and/or downloaded) by designers. Future work will continue developing the models and related APIs, making the system smarter, more adaptive, and friendlier to landscape architects. Our ultimate expectation of the project is to develop an interactive tool that meets the complex and varying requirements of landscape site analysis.

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