Coupling Systems Thinking and Geodesign Processes in Land-use Modelling, Design, and Planning

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Abstract: Integrating systems thinking theories with geodesign processes and land use modelling technologies is a complex undertaking. Existing studies fail to capture the deep rooted connection between the approaches and their potential for helping to understand complex problems. In order to enhance the practicality of systems thinking and the credibility of geodesign, we generate a holistic framework including conceptual framework and procedural infrastructure for use in land-use modelling, design, and planning. We then use a case study in Sangamon County, IL to explain and test its feasibility in practice.

Keywords: Geodesign, systems thinking, simulation, land-use modeling, landscape design

1 Introduction

Interest in geodesign as a design and planning methodology has grown steadily in recent years. The new academic focus has introduced some important contributions for improving multidisciplinary collaboration, advancing the process of sustainable design and promoting participatory planning (CAMPAGNA 2014, EIKELBOOM & JANSSEN 2017, HAYEK, VON WIRTH, NEUENSCHWANDER & GRÊT-REGAMEY 2016). However it still only broadly discusses the general process of collecting, analyzing, and documenting without addressing deeper systemic details and contextual issues (CAMPAGNA 2016). Hence, we propose a comprehensive study of the geodesign framework and methodologies and connecting them to traditional systems thinking approaches.

This study integrates systems thinking (as a theoretical lens) and geodesign (as a procedural guide) into the development of technologies in support of decision-making processes in land-use design and planning. We argue that such integration will not just enhance the usefulness of traditional systems-thinking concepts into application, but also improve the credibility of geodesign. We propose the creation of a holistic framework that includes a conceptual framework, procedural infrastructure and a practical application. We taught a design studio in the Department of Landscape Architecture to test the legitimacy of the holistic framework in three design projects in Sangamon County, IL. We use the development of Land-use Evolution and impact Assessment Model (LEAM) as a basis for this analysis. LEAM's fundamental purpose is to simulate land-use changes and its impacts to help others understand the relationships between human economic/cultural activities and biophysical cycles within a series of complex and dynamic systems.

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2 Conceptual Framework

A systems-thinking conceptual frame helps to generate substantive components of the landscape useful for land-use modelling including:

- Existing regional land-uses
- Regional economics
- Social conditions
- Transportation accessibility
- Social and economic attractors
- Constraining geo-physical conditions

Inspired from work by MEADOWS (2008), the interconnections between system components: stocks, flows, feedback loops, and dynamic equilibrium conditions are diagrammed in a coupled human-environment system (Figure 1). Human and environmental systems represent stocks of accumulated material or information. Their quantities change over time at flow rates determined by system components (such as economic or social conditions) and influenced directly or indirectly by feedback from these systems. The systems-thinking concepts are also utilized in developing the following procedural infrastructure.

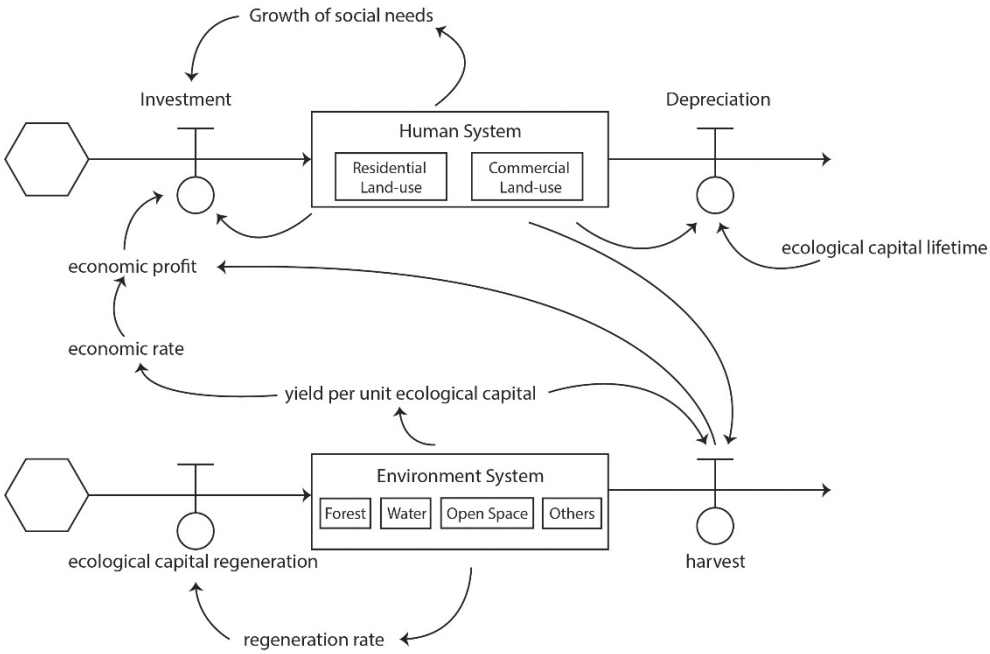

Fig. 1: A stock-and-flow diagram of systems thinking illustrating the relationships between human and environment systems: human systems with its reinforcing growth loop constrained by environment systems

3 Procedural Infrastructure

A procedural infrastructure is developed by merging a geodesign process framework (STEINITZ 2012) with land-use modelling process for which we developed Land-use Evolution and impact Assessment Model (LEAM). Similarities have been found in these two processes: i) they are both targeting the need to systemically tackle and assess the world's complexity; ii) they both sit in data-rich environments where big data is crucial to achieve landscape-scaled sustainability; iii) they both focus on multi-scale analysis, simulation, evaluation and decision making. Given these similarities, it seems feasible and mutually beneficial to merge them. Furthermore, we value the procedural significance of geodesign framework given its systemic basis, decision-driven nature and iterative processes to cope with the complexity and dynamics of regional landscape decisions.

LEAM is a model of Planning Support System (PSS) developed by the University of Illinois with funding from the National Science Foundation to simulate land-use change scenarios, assess change impacts, and make decisions for sustainable design and planning (DEAL, PAN, TIMM & PALLATHUCHERIL 2017). We do not replicate the detailed explanations of the LEAM model in other articles. Instead, we elaborate on the process of LEAM and integrate with geodesign framework to contemplate land-use modelling, design and planning. The LEAM system is available at http://leam.illinois.edu/.

We build the procedural infrastructure based on the vision of change. As SIMON (1969) claims, "everyone designs who devises courses of action aimed at changing existing situations into preferred ones." Design is a process to accomplish feasible changes. We propose six steps to integrate both geodesign and LEAM for a comprehensive process for land-use modelling, design, and planning (Figure 2). Although the steps seem sequential, the design process in practice is much more complicated in non-linear process.

1) Before Change: We start with understanding the existing site condition before change. Similar to the first model of the geodesign framework − *representation model*, it is to identify the significant systems/elements that the study area includes (STEINITZ 2012). Using systems thinking, we address the importance of identifying the systems in different conceptual tiers. Generally speaking, most study areas encompass human and environment systems, which can be considered as the highest-tier variables. The highest-tier variables should be unpacked into multiple conceptual tiers for analysis in much more detail (OSTROM 2009). For example, the environment system can be unpacked into biological creatures, natural features, manmade facilities, etc. To decide how far up or down a conceptual hierarchy should be, researchers need to base on specific case contexts and clients' design/planning objectives.

2) Processes of Change: *Process models* in the geodesign framework is to analyze the design process in order to foresee the impacts of possible changes (STEINITZ 2012). To assess the possible impacts, it is required to understand the processes of possible changes. In systems thinking, analyzing interconnections between systems can fulfill this requirement. One way to explore the interconnections is to combine several variables at the same or multiple tiers for analysis, which leads to different outcomes (OSTROM 2007). It helps people understand how landscape elements operate in different levels and scales.

3) Probabilities of Change: *Evaluation models* of geodesign refers to testing conditions of the study area based on the perceptions of people from the place (STEINITZ 2012). In land-use modelling, proposing probability of changes is to evaluate site conditions from a chang-

ing perspective. In LEAM models, we propose probabilities based on local interconnections (e. g. the accessibility or distance of a specific area to a business center), global interconnections (e. g. how the regional economy influences local economy), and other causal mechanisms (e. g. political forces) (DEAL & PAN 2016). The deliverable of this phase is a spatial distribution map of probabilities for specific land-use types.

4) Scenarios of Change: This step is in line with the *change models* of geodesign indicating the identification of possible changes for a better future of the study area (STEINITZ 2012). In LEAM models, we collect significant factors and requirements from clients as the constraints of the rule set to be used to generate multiple scenarios of possible land-use changes. Using systems thinking, we explore new possible systems and interconnections for the landscape to reveal and challenge design boundaries based on clients' interests.

5) Impacts of Change: This step is corresponded with the *impact models* of geodesign, which is to assess impacts of the comparative scenarios (STEINITZ 2012). Using systems thinking, we assess the impacts of a certain scenario by understanding the feedback loops between the landscape systems that have been proposed to be changed. Feedback loops are "the secondary effects of a direct effect of one variable on another, they cause a change in the magnitude of that effect. A positive feedback enhances the effect; a negative feedback dampens it" (WALKER & SALT 2012). This phase is to find out what secondary effects of the design changes may be generated. LEAM provides a set of comprehensive algorithms to simulate possible impacts by integrating transportation models (DEAL, KIM, HEWINGS & KIM 2013), ecosystem models (MÖRTBERG et al. 2013), hydrologic models (WANG, CHOI & DEAL 2005), etc.

6) Communications for Change: *Decision models* of geodesign means decision making groups communicate decisions, refine the scope of geodesign application, and make final decisions. In LEAM models, we provide an interactive platform for users to communicate all the information and results from previous steps through a use-driven implementation process. We also suggest a greater extent of sentience in land-use modelling development, which facilitate user needs, promote iterative learning, and understand spatial-temporal reasoning behind results (DEAL, PALLATHUCHERIL, KIM & PAN 2015, DEAL, PAN, PALLATHUCHERIL & FULTON 2017).

4 Practical Application

From August to December 2017, we taught a design studio using LEAM as a tool to test the feasibility of the above conceptual framework and procedural infrastructure through a practical application in the Sangamon County, IL. The goal of the class is to prepare students to understand clients' requirements and being adaptable to address future needs through the procedural infrastructure. Three landscape design proposals were delivered to Springfield-Sangamon County Regional Planning Commission (RPC). In this section, we explain one proposal of Springfield (Figure 3) in detail through the six steps of procedural infrastructure.

4.1 Study Context

Sangamon County is an urban/rural region in central Illinois. The study area includes the Springfield Metropolitan Statistical Area (2,270 km^2). This area is compelling because of its

numerous and complex ecological, social and economic considerations. We use this case as a research context for examining the ways that the hypothetical conceptual and procedural infrastructure can enhance technological approach, facilitate collaborative processes, build knowledge of human and environment systems at the landscape scale, and promote iterative and adaptive processes of design and planning. Collaborating with Springfield-Sangamon County Regional Planning Commission, we utilized LEAM for collecting data, modelling land-use changes, building land-use scenarios, analysing impacts, visualizing information, and supporting communication.

4.2 Practical Process Using Procedural Infrastructure

1) Before Change: We used local data to establish baseline information: land-use maps, no-growth zones, public areas, zoning maps, etc. Not only did we collect and calculate land-use change based on each individual data separately, but we also organized data into a systemic hierarchy and explored the interconnections between them. Through this systemic data management process, we enriched the first representation model of geodesign to understand what hierarchical systems are significant for Sangamon County.

For a regional scale of Sangamon County, we focused on three main first-tier variables: human, nature and transportation systems. Under the human system, we identified following second-tier variables: residential land-use, commercial land-use, population centers, employment centers, social-cultural centers, etc. Under the nature system, following second-tier variables are found significant: slopes (DEM models), green areas, water bodies, etc. (Fig. 2). The transportation system was unpacked into: road maps, highway access points, etc. Besides the broad variables in first and second tiers, we also identified more variables in deeper levels. Figure 4 shows three first-tier systems and their second-tier variables. The data is uploaded by users and our team members, and can be downloaded in a tiff format which can be used in ArcGIS for further analysis. The maps are created from a fine-scaled resolution of cells-based models (each cell is 30m x 30m).

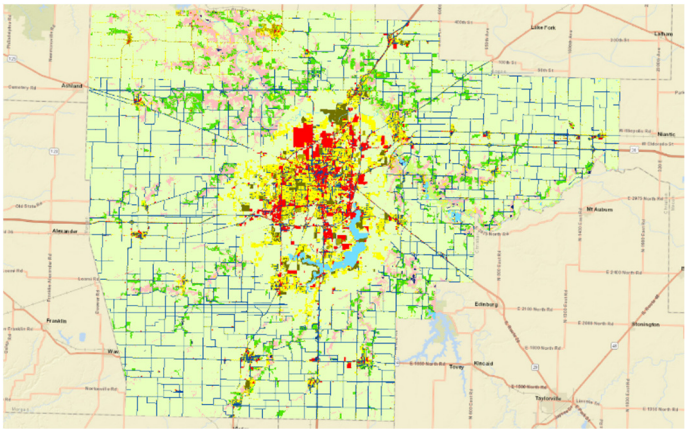

Fig. 2: An exemplar nature system (land use map for water bodies, forests, green spaces, etc.)

2) Processes of Change: To explore the underlying processes between these variables, we combined and explored more detail of some systems to analyze the county's land-uses and related drivers/variables in detail. We created *cost* and *attraction* maps to represent the inter-

connections between the three major systems. The variables identified in the first step were analyzed and given values for each cell based on their interrelations with land-use changes (Figure 3). Cost maps could be considered as a subtraction, while attraction maps as an addition. For example, population cost map represents the cost from the travel time from a cell to its nearest population center, which depends on the distance between and travel speeds. For travel speeds, people travel faster on highway than in farmland. Population attraction map indicates the attraction of the nearest population center to this cell's potentials of its commercial/residential development. All the variables were calibrated, plotted spatially and displayed onto the online LEAM website.

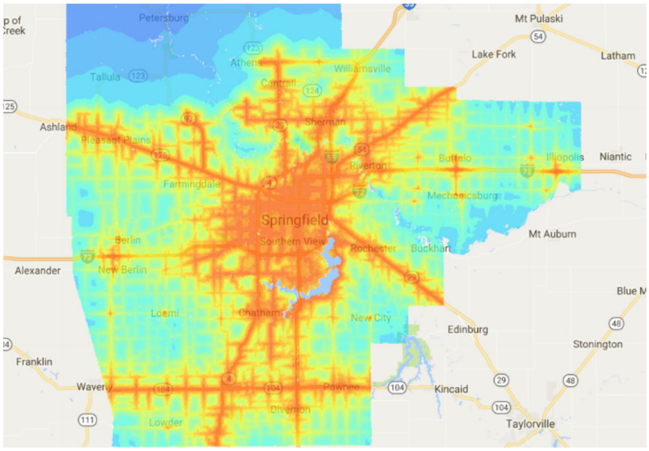

Fig. 3:
An exemplar transportation attraction map. Red to blue represents low to high attraction.

3) Probabilities of Change: By adding up attractive scores of the attraction maps and subtracting cost scores of the cost maps, we generated probability maps for residential and commercial land-uses. The value of each cell indicates the cell's probability to be developed into residential or commercial areas. Probability maps are distributed spatially and displayed in map form on the LEAM platform (Figure 4).

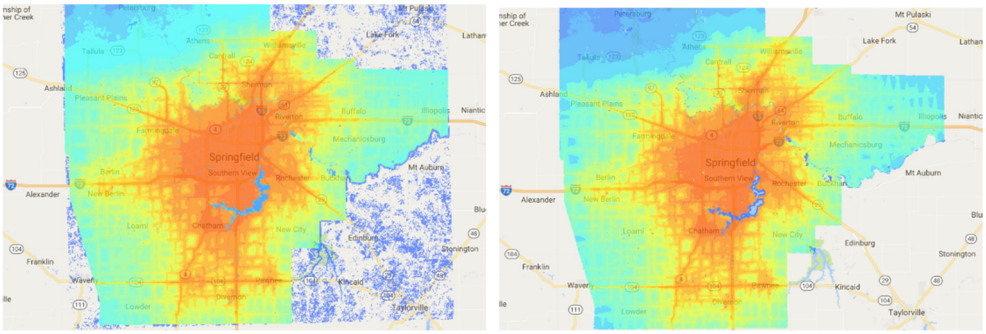

Fig. 4: LEAM Sangamon County Development Probability Map (left: probability of residential land use; right: probability of commercial land use)

4) Scenarios of Change: We created some land-use change scenarios based on different configurations of variables. Almost 20 scenarios are created for Sangamon County by the County's RPC. Scenarios are compared by a cell-by-cell comparison process. Two types of scenarios are always valuable to create: 1) the estimated land-use change: the projected commercial growth and residential growth allocation by the end of estimation year; 2) yearly land use change: projected urban area growth each year. Figure 7 shows both scenarios of Sangamon County.

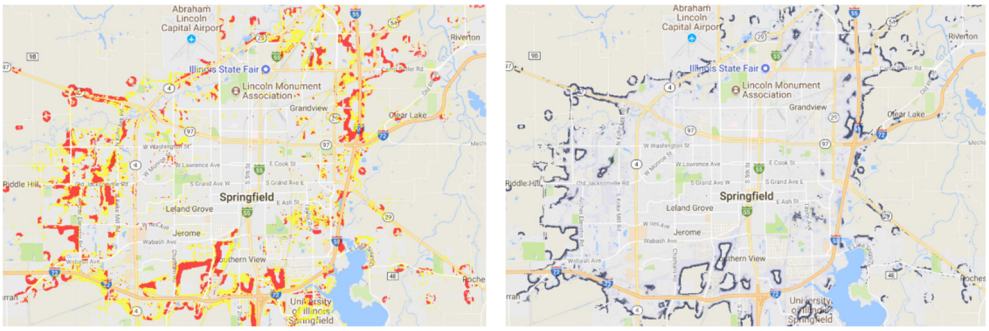

Fig. 5: LEAM Sangamon County Land-Use Change Scenarios. Left: the estimated land-use change (yellow: new residential; red: new commercial); right: yearly land-use change (the most recent growth is represented by the deepest purple color).

5) Impacts of Change: After simulating future land-use, we evaluated following impacts of these changes: 1) the pressure of new residential development on housing cost; 2) the pressure of new residential development on cost burden; 3) new development pressure on transportation infrastructure; 4) new development pressure on ecosystem service; 5) the pressure of residential development on green infrastructure; 6) the pressure of commercial development on green infrastructure. As an example, Figure 8 shows the impact assessment map of residential development regarding its pressure on green infrastructure. Thus the impact assessments provide insights on the interrelations between land-use system with other systems (housing, transportation, ecosystem, and green infrastructure).

6) Decisions for Change: This phase emphasizes the communication between design teams, local planners, stakeholders, policy makers, etc. This step provides feedback from the local salience and value of any given simulation. Although we make it as the sixth step, the feedback is gathered regularly throughout the whole process. In practice, the procedural framework is nonlinear and iterative although they are presented in sequence. More unforeseen issues but also opportunities will come out during the whole process (STEINITZ 2012). However, the six steps provide a thorough guide which should be all passed through for a systemic and comprehensive purpose.

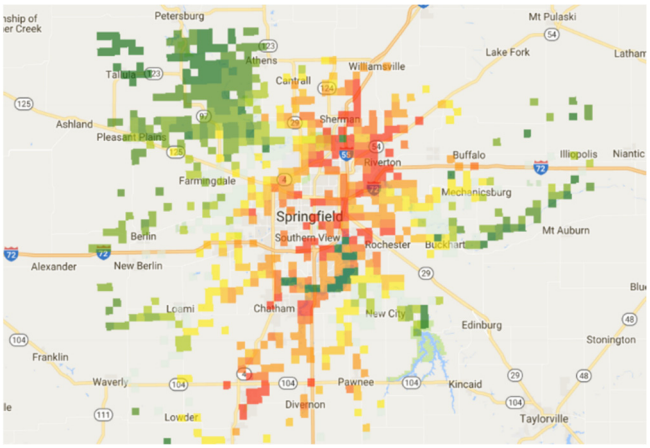

Fig. 6:
LEAM Sangamon County impact assessment of residential development pressure on green infrastructure. Green to red represents low to high pressure of residential development on green infrastrucutre.

5 Discussion and Conclusion

Geodesign may provide a creative approach and a comprehensive process to land-use modelling, design, and planning. Despite the general and broad acknowledgement of the systemic character of the geodesign process however, a thorough study of geodesign framework by integrating systems thinking is still lacking. Hence the holistic framework (conceptual framework, procedural infrastructure, and practical application) is proposed here to provide more substantive, instrumental, and contextual approaches to land-use modelling. Our framework provides systems-thinking concepts for developing deeper substantive understanding of geodesign. It is deployed into procedural details of geodesign process to address instrumental approaches for land-use changes by integrating it with LEAM modelling processes. We use a case study application in Sangamon County, IL, USA to test the feasibility and guide the implementation of the holistic framework.

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