Resilience Thinking Meets Social-Ecological Systems (SESs): A General Framework for Resilient Planning Support Systems (PSSs)

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Abstract: Resilience thinking and social-ecological systems provide advantages to urban planning and design, especially in the development of Planning Support Systems. Using the promising aspects of resilience and SESs, we create a general framework for analysing their interactions and guiding the development of resilient PSS technologies. The case study implements the framework and the PSS technologies to investigate flood issues in Stockholm by land-use and water modelling.

Keywords: Social-Ecological Systems, Land-use modeling, water, resilience, Planning Support Systems (PSSs)

1 Introduction

Increasing pressure from climate change has inspired both social-transitional and social-ecological considerations for tackling urban resilience. Rapid urbanization and changing temperature profiles have brought numerous challenges to cities, such as urban heat island effects, extreme weather events, and environmental pollution (CARTER et al. 2015, DEAL, PETRI, PAN & TIMM 2017, STEWART & OKE 2012). These challenges have triggered attempts to use urban planning and design to increase resilience and overall sustainability for cities (COTE & NIGHTINGALE 2012). One outcome of these attempts is the integration of Planning Support Systems (PSSs) and resilience thinking (DEAL, PAN, PALLATHUCHERIL & FULTON 2017, NORBERG & CUMMING 2008). PSSs refer to the technologies in support of practical planning and decision making. Resilience thinking uses a systems approach to understand human-environment interrelations to forecast and model feasible changes (COTE & NIGHTINGALE 2012). However, more profound epistemological issues regarding the relations between resilience, SESs and PSSs remain to be clearly demonstrated. We argue for the need to incorporate social and ecological systems and their linkages with resilience to explore a new generation of resilient PSSs.

In this paper, we argue that design and planning for resilience requires more than the mere presentation of data. There is a need to enable PSSs to meet resilience principles, including the organization of data into a systemic structures, a holistic planning process for the systems' autonomy, and support multidisciplinary collaboration. This paper starts by drawing out the significant aspects and principles of resilience thinking, and how SESs relate to resilience thinking. Second, we generate a general framework that enables scholars to organize analyses of how attributes of (i) a human system, (ii) an environment system, (iii) social-ecological processes, and (iv) spatial-temporal compositions and patterns jointly affect and are affected by interconnections and resulting outcomes to accomplish resilience. Third, we demonstrate how to use resilience thinking, SES concepts, and the framework to develop profound resil-

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ient PSS technologies. Finally, we apply these epistemological attempts into a practical project in Stockholm, SE.

2 A General Framework for Analyzing Resilience of Social-Ecological Systems (SESs)

2.1 Resilience and SESs

In 1973, C. S. Holling introduced the concept of resilience into the ecosystem literature to address outdated models of ecosystem dynamics in ecology research (COTE & NIGHTINGALE 2012). In the 1990s, the Beijer Institute in Stockholm identified potential connections between the ecological concept of resilience and social science, which promoted the investigation into dynamics between social and ecological systems to achieve resilience (ANDERIES, JANSSEN & OSTROM 2004, COTE & NIGHTINGALE 2012, LUDWIG, WALKER & HOLLING 1997, PERRINGS 2006). In 2000, Gunderson redefined resilience as the capability of social-ecological systems (SESs) to tolerate disturbance while retaining stability domains. SESs are being paid more attentions because of massive climate change and complexity of environmental challenges.

Resilience scholars have developed several combining principles of apparent opposites: redundancy and efficiency, strength and flexibility, diversity and interdependence, autonomy and collaboration (BELL 2002, GODSCHALK 2003, K. TIERNEY 2002, R. ZIMMERMAN 2001). Many scholars (COMFORT et al. 1999, FOSTER 1997, GODSCHALK 2003, K. J. TIERNEY 2003, R. ZIMMERMAN 2001) have explained these principles and applied them into practice by studying the response of resilient systems:

- Redundancy: the capacity of redundant system components that are functionally similar, ensuring the whole system does not collapse when one unit fails;
- Efficiency: there should be more energy supplied than energy delivered in a dynamic system;
- Strength: the power to resist outside force;
- Flexibility: the capability to learn from experience and the adaptability to change based on the experience gained;
- Diversity: the capacity of multiple system components that are different from each other, ensuring to resist diverse threats;
- Interdependency: the system components are interconnected to support each other;
- Autonomy: the independent operation ability of the system against outside force;
- Collaboration: the opportunity for participants to cooperate.

To accomplish these principles of resilience thinking, SESs act three significant roles. First, conventional SES studies have long identified the diversity, redundancy, and heterogeneity of organisms as early-warning signals of disturbance stress (ARROW et al. 1995, HOLLING 1973, WALTERS 1986). SECOND, GUNDERSON (2001) introduced a meta-model termed 'panarchy' to embody an idealized SES with adaptive and dynamic capabilities. The idealized SES highlights its strength and flexibility that changes are allowed to adapt to outside force rather than avoided or controlled for achieving resilience (BERKES, COLDING & FOLKE 2008). Third, SESs emphasize the interrelations between human and environment systems. As COTE &

NIGHTINGALE (2012) claims, human and environment systems are closely interconnected by feedback dynamics, which thus cannot be conceived in isolation. Such relations encourage holistic methods where multiple disciplines are interdependent and integrated to promote collaboration. In the following sections we develop these SES concepts and resilience thinking further, and generate a general framework to highlight their epistemological cores and implementations in planning.

2.2 A General Framework for Resilience of SESs

The key to diagnose why some SESs are resilient while others fail is to identify and examine the interrelations between the system components at multiple spatial-temporal scales and levels (BERKES, FOLKE & COLDING 2000, JANSSEN 2002, NORBERG & CUMMING 2008). Therefore, we must learn how to dissect and analyse the relations between the various components rather than isolate each from the whole system (AXELROD, AXELROD & COHEN 2000). We create a general framework for analysing the resilience of SESs. Figure 1 provides an overview of the framework, demonstrating how human(social) systems and environment (ecological) systems interrelate through social-ecological processes and spatiotemporal compositions and patterns. Each variable is composed of multiple second-level variables (e. g. functions for human systems include material production for human's life, neighbourhood enhancement, landscape aesthetics, increasing real estate values, providing environment for social connections, etc.). These second-tier variables are further made up of third-tier variables, and so on.

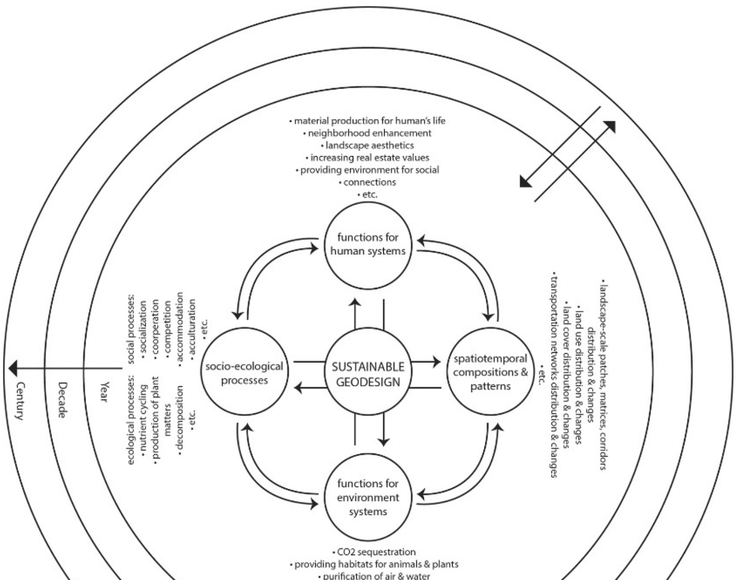

Fig. 1: A conceptual framework of the relationships among social and ecological factors for analysing the resilience of SESs

This framework is useful in identifying relevant variables for studying different system concerns, such as how the land-use system in Chicago affects its green infrastructure system. It also provides a general set of variables to study similar SESs, such as analysing the flood zones in Georgia or the watersheds in Mississippi. Without a framework to identify relevant variables, it is difficult to accumulate the fragmented knowledge and isolated methods in different disciplines or diverse systems in different regions.

2.3 The Framework and Planning Support Systems (PSSs)

To illustrate one use of the framework, we focus on how to develop Planning Support Systems (PSSs) into more advanced technologies to accomplish resilience in support of SESs. PSS is a technology assembled by BRAIL and KLOSTERMAN (2001) for decision making. Recent development of PSSs includes the introduction of use-driven PSS (DEAL, PALLATHUCHERIL, KIM & PAN 2015) web-based methods of information retrieval and delivery, information management (DEAL, PETRI et al. 2017), etc.

In order to accomplish resilience, we provide following proposals to develop PSSs:

- To achieve redundancy, PSSs should enable users to identify alternative SESs' components, describe the components' functions and relations with each other, and organize them into a hierarchical, analysable structure.
- To achieve efficiency, PSSs should visualize the dynamic processes of relevant SESs for users to understand the information flows, energy flows, etc.
- To achieve strength, PSSs should enable users to identify relevant outside force. Specifically, what outside social-ecological processes and spatial-temporal patterns affect the functions of relevant SESs' components.
- To achieve flexibility, PSSs should be capable of learning from experience. The past experience should guide adjustments of future PSSs. It requires PSSs to possess self-awareness about underlying data in different phases, past experience, and user pattern recognition to adapt to future challenges and opportunities (DEAL, PETRI et al. 2017).
- To achieve diversity, PSSs should support multiple media to collect various forms of information including verbal content, pictorial information, video, etc. PSSs should be capable to translate all the information into spatial and analysable data sets for modelling and simulation.
- To achieve interdependency, different system components (such as land-use drivers and future land-use scenarios) should be interactive. The PSS interface should allow users to easily review the model between different variables. For example, the interface should visualize all the relevant variables and modelling outcomes. If one land-use scenario seems infeasible, the interface should enable users to easily click the scenario drivers to check through the model from the beginning.
- To achieve autonomy, PSSs should provide a thorough approach for users to understand the whole planning processes from beginning variables identified to the results (such as future land-use scenarios or impact assessment models).
- To achieve collaboration, PSSs should be an interactive environment for decision making where stakeholders, planners, designers, and citizens can easily communicate and effectively collaborate. It should enable users to submit feedback and respond to user needs (DEAL, PETRI et al. 2017).

3 Applying the Framework in Stockholm

In this section, we apply the framework to demonstrate how to use PSS in land-use and water modelling for the SESs in Stockholm. In this project, we use Land-use Evolution and impact Assessment Modeling (LEAM) (a PSS tool developed by University of Illinois at Urbana-Champaign) and r.sim.water (a hydrological PSS tool developed by the US Army Corps) to investigate potential flood locations, flood depths, and flood extents in the Stockholm region, Sweden (Figure 2).

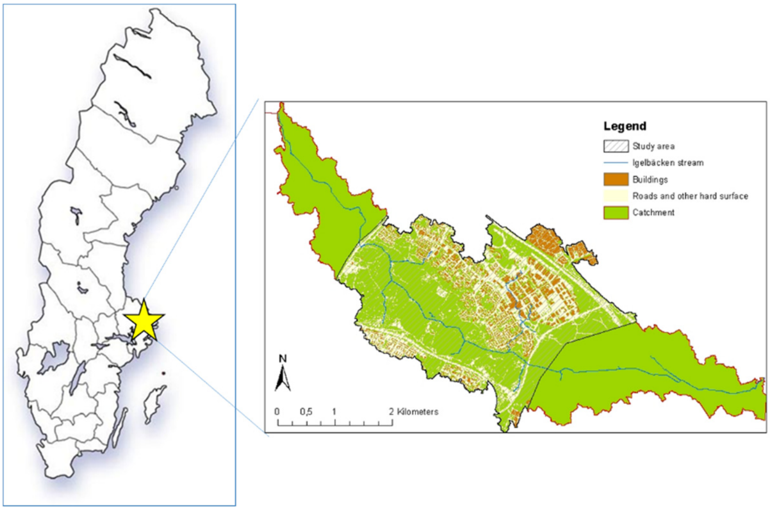

Fig. 2: Location of the study area, Igelbäcken stream catchment, Stockholm region, Sweden

Exploring the SESs in this project requires four assumptions: 1) the social system mainly indicates land uses (including residential land-use, commercial land-use, etc.); 2) the ecological system (referring to water/flood system in this project) is closely related to land uses; 3) the spatial compositions (catchment areas, such as streams, rivers, and ponds) and temporal patterns of these compositions can be identified and are related to land-use changes (DEAL 2018); 4) A sufficient number of social-ecological processes, given the complexity of the systems, are making the long-term impacts on the changes of land-use and flood locations, depths and extents. We also used r.sim.water to calculate flood risks as a feedback to the land-use changes (DEAL 2018) (Figures 2 & 3).

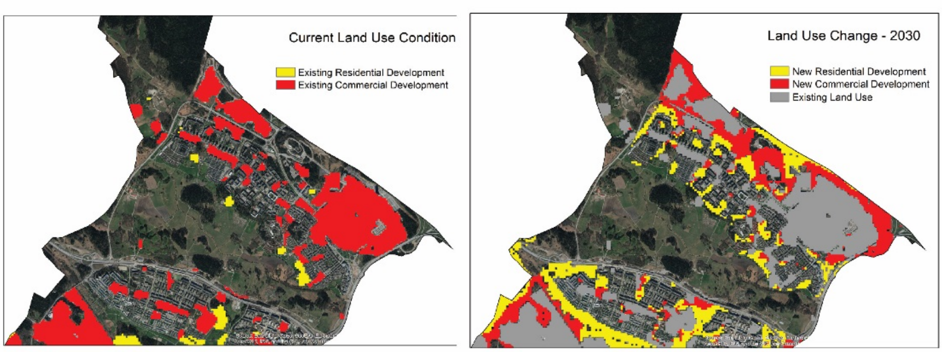

Fig. 3: Flooding extents with water depth above surface for current land use condition and LEAM land-use change scenario for year 2030 displayed together with natural waterways in the landscape, existing roads and buildings

Using the framework to represent the mechanisms of the two PSS models (LEAM and r.sim.water) helps to clarify the robustness and resilience of PSSs. For example, identifying alternative catchment compositions (streams, rivers, and ponds) and land uses (residential, commercial, green space, agricultural areas, etc.) ensures redundancy of the water system and land-use system in the Stockholm region. We also build alternative scenarios to simulate multiple possible models for more resilient future. To promote collaboration, we build an online, cloud-based modeling and visualization platform (http://portal.leam.illinois.edu). To enhance flexibility and self-awareness, we develop mutual learning processes using LEAM for multiple regions (DEAL, PAN et al. 2017, DEAL, PETRI et al. 2017). Participants can use the LEAM online platform to review all the data, calibrate, tune parameters, and learn from the past modeling processes of different regions. Stockholm models are also built and share an online server for this function (DEAL 2018) (Figure 4).

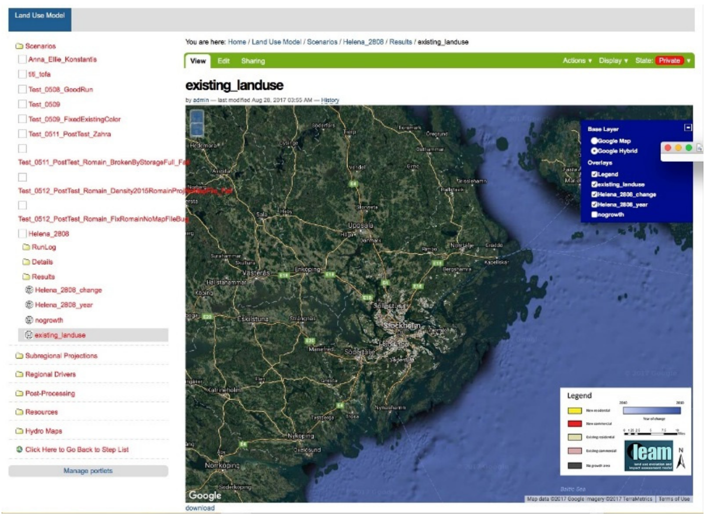

Fig. 4: A screenshot of LEAM Stockholm online platform

4 Discussion and Conclusion

We need a better understanding of resilience thinking and SESs derived from systemic studies that links contemporary gaps between social and ecological science (OSTROM 2009). Furthermore, the aspects of resilience thinking and SES concepts have not been profoundly articulated and implemented in PSS development. Scholars can use the framework presented in this paper to guide the implementation of the theoretical findings in PSS development. However, there is no cure-all framework or method for analysing the resilience of SES. The specific approach depends on the questions of stakeholders, scholars, and residents of the study place. The framework created in this paper will obviously need further development. Hopefully, cumulative use of the framework will introduce more discussions about deeper understanding of how to use resilience thinking and SES concepts in planning technology development.

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