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Building Community Sustainability with Geographic Information Systems

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ABSTRACT

Conceptualization of Green IS must look beyond the limited horizon of profit-driven corporate sustainability to reframe the activities and policies of *communities* to produce adaptable, sustainable, and resilient practices. As web-enabled Geographic Information Systems (GIS) and low cost spatial analytic systems become accessible, communities gain a generative capacity to pursue community sustainability as they face increasing environmental and growth challenges. By expanding the boundaries of Design Science Research, we argue that information systems have a generative capacity, which enables reframing and recasting reality based upon alternative values. This surfaces the opportunity for the design and implementation of GIS to reduce information asymmetry, empower communities, and provide a history of decision-making, thereby enabling monitoring of the components of sustainability. Community members may incorporate local data, present alternative development/conservation scenarios, and gain a voice in the planning process. From this perspective the system design process itself represents an opportunity for situated social action in the formation and implementation of community values. Synthesizing these perspectives, we propose that GIS development and use at a community level is a potentially constructive social process of value formation which can enable communities to envision their own futures.

Keywords

Design Science Research, generative capacity, pragmatic, geographic information systems, community GIS, sustainability, resilience.

INTRODUCTION

As human communities are faced with significant environmental and human-induced changes to their environment, and strain is placed on world resources, the need to design for sustainability is increasing. This research proposes a pragmatic and generative Design Science Research (DSR) perspective which recognizes alternative design paradigms beyond the dominant functionalist perspective. As communities seek to address issues of adaptation to climate change, community sustainability and resilience, and greater empowerment in relevant affairs, researchers are beginning to recognize the need for using information systems to create “new ways of being that did not previously exist and a framework for action that would not previously made sense” (Winograd and Flores 1986). First, DSR can be expanded to incorporate *generative capacity* (Avital and Te'eni 2009) and deemphasize the functionalist emphasis on organizational problem solving, utility, and efficiency. This shifts the design focus to a pragmatic emphasis on the potential for human action (Goldkhul 2004), and a highlighting of emancipation from existing social order and the potentiality of change (Hirschheim and Klein 1989). Generative capacity can be embedded in information systems by providing the ability to identify new configurations and reframe mental models of community sustainability. Second, community Geographic Information Systems (GIS) provides a collaborative environment in which the communities can engage in a generative process of context and issue driven development and planning (Elwood 2006; Sieber 2006). This engagement supports the inclusion of local knowledge and divergent views, as well as community values of historic and environmental conservation, risk mitigation and recovery, and ideographic structural factors. Third, sustainability must be understood as a set of practices and strategies which ultimately contribute to global improvements. We must look beyond the limited horizon of profit-driven corporate sustainability to reframe the activities and policies of communities. Thus sustainability becomes a multidimensional construct at the community level, which requires a theoretical framework which highlights the dependencies of sustainability, resilience, and structural-cognitive factors.

This research presents a conceptual synthesis from selected literatures with the goal of providing a foundation for further research and development. By combining perspectives, we generate a new discourse on DSR, generative capacity, and GIS, as they can be applied to supporting community sustainability. We propose that creating a community GIS is not limited to the design of an artifact but encompasses a broad process that itself is a socio-technical system which can serve as a generative force for emancipatory social activism supporting local definitions of sustainability (Rattray 2006) not simply a tool designed to translate spatially referenced information a representation of patterns and cartographic relationships (Obermeyer 1998).

The Role of Design

The functionalist problem-solving approach which dominates DSR focuses on artifacts evaluated in terms of utility and efficiency as determined by business requirements (Hevner et.al. (2004). Two perspectives enlarge this basic stance. First, a pragmatic perspective on information systems design refocuses attention on systems that provide potential for human concern and action (Winograd and Flores 1986) and that may be tailored to fit changing problem domains, task specifications, and user interests (Germonprez, Hovorka and Callopy 2007; Hovorka and Germonprez 2009). Second, a reduction in the emphasis on problem-solving, and a greater interest in design from a pragmatic perspective (Goldkhul, 2004; Lee and Nickerson 2010) as a generative process (Avital and Te'eni 2009), enables humans to accomplish goals in line with their own values. Thus design can be seen as contributing to knowledge as it can be applied in the service of action (Romme 2003) and then is evaluated based upon value-driven goals measured over time. Design shifts from a predictive mechanism to a generative process incorporating dynamic adaptations, because the design process incorporates information technologies as a component embedded in complex social processes. The IS is not simply an artifact, but is an assembly of things and people whose selection, configuration, implementation, and use is itself a generative process. The perspective of information systems design as a situated social action (Gasson 1999) implies that the processes may be indeterminate and emergent, and the theories and research methods allow the analysis and interpretation of how complex social processes change (Robey and Boudreau 1999).

In the next section we introduce the primary functional characteristics of GIS and explicate the generative role it can play in the collection, analysis, and communication of knowledge from multiple sources. Finally, we discuss the capability it has to provide capacity for generative action through the inclusions of evocative, adaptive and empowering design directives.

COMMUNITY GIS AND GENERATIVE CAPACITY

GIS Basics

GIS stores a spatial representation of real world features in collections of discrete data layers for an area of interest (Figure 1).

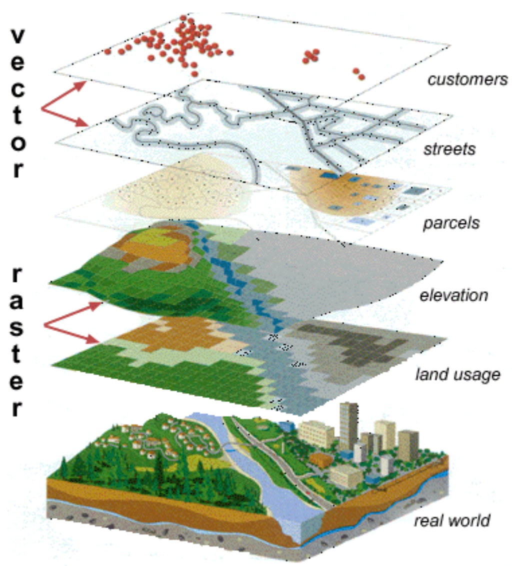

Figure 1. Independent layers of representation in GIS visualization [1]

A GIS analyst investigates relationships among the spatially co-located data, interprets patterns in the data and examines their possible significance. Scenarios illustrating those patterns, usually in a map or 3-D visualization combined with an

[1] From: www.ncddc.noaa.gov/technology/gis

interpretation to facilitate understanding, can be used to communicate the spatial analysis to an audience. GIS is thus used to integrate information from disparate data sources and summarize that information in a manner generally more comprehensible than through examination of its separate parts. Current, alternate, or future frames of reference envisioned through spatial and associated data analysis, such as modeling, focus on a specific issue and area of interest. GIS comprises software and hardware for collecting, storing, transforming, retrieving, and displaying spatial data and associated attributes (Burrough 1986), and although most who encounter GIS typically see only the analytical end-result visualization, GIS provides the mechanism to input, aggregate, derive, and synthesize the totality of information depicted in a spatial analysis.

GIS, however, is not a simple, value-free, analytical tool. A rich discussion of GIS and its use or arguable mis-use in society exists (see Crisman 1987; Pickles 1995; Pickles 2006). Spatial analysis, interpretation, and visualization may all be influenced by values held by the GIS analyst or through external motivations. At the same time, the GIS may evoke possible alternative futures through scenario analysis and the ability to provide visualization and communication of multiple data types. Non-specialists may also provide input and evaluation. It is in this manner that GIS may be used to increase generative capacity.

Generative Capacity

Design of participatory GIS which supports community sustainable value can be informed by the concept of *generative capacity* (Avital and Te'eni 2009). Engaging generative capacity as a design goal shifts the emphasis of DSR from creating a single solution to a known problem, to designing information systems which enable the creation of contextually new possibilities and configurations for as-of-yet unknown problems. This will involve divergent thinking to create multiple models of options that may not have a single optimal solution. Importantly, the design of information systems that enable generative capacity is characterized by their ability to evoke new thinking, and to be adaptable to multiple use patterns and tasks. The original exposition of generative capacity (Avital and Te'eni 2009) has a strong congruence between proposed generative capacity directives and the functions of GIS (Table 1). The evocative features of visualization, simulation, and communication are supported. In addition, GIS supports geo-referencing of multiple data types, thus allowing a wide range of representations (i.e. text, numerical, graphical, imagery, videos) of both quantitative and qualitative data to be included. GIS also supports extensive analytic geo-processing, allowing for generation of new data through logical and numerical manipulation of different data. By changing parameters and time horizons, multiple models and 'what-if' scenarios can be examined.

Generative Design Directives	GIS feature	Illustrative example
Evocative †	Visualization	Interactive map layers, "What if" scenario simulations and 3-D visualizations
	Abstraction	Multiple scales of detail
	Analytic	Analytic tools for geo-processing and the inclusion/exclusion of features and attributes
	Multiple data types	Any spatially associated data type, image, video or text to be integrated
	Communication	Support for a wide variety of output formats (texts, maps, statistics, graphics) as well as links to data archives, counter-texts, and diverse media
Adaptive†	Component-based and tailorable use	Multiple GIS components and publically web-enabled GIS functions can be selected and combined; Outputs can be redefined and tailored to specific needs
	Non-exclusive	User derived add data and local knowledge to create user-defined perspectives Representation of diverse views with presentation of contradictions and disputes
Empowering	Locus of value recognition/creation	GIS as a social and community building tool to identify and promote shared goals Can promote participation and responsibility in community members in development decisions and planning Can preserve and represent history of development and decisions as community context changes of time

† (Avital and Te'eni 2009)

Table 1. GIS example of Generative Design Directives

Two additional characteristics of generative capacity have been identified in community GIS implementations (Hovorka and Auerbach 2010). The GIS is *non-exclusive* in its ability to incorporate local knowledge and user-generated data to be adapted to specific tasks and needs. Furthermore, the ability to incorporate diverse views, contradictions, and disputes democratizes the decision-making process and may potentially lead to increased buy-in of decisions. The rationale underlying alternatives, values, and the decision process can be represented and communicated in the system, thus preserving the history of processes for future reference. This can be a valuable asset as community contexts change and new choices require attention. In addition, the GIS can *empower* users by providing a locus of data, group representation in the planning process, and discourse around which values and goals can be identified. The ability of GIS to include non-official voices and empower community members to participate and take responsibility is controversial but successful instances have been reported in the literature (Sieber 2006).

COMMUNITY SUSTAINABILITY

The design of all information systems is ultimately teleological – systems are designed for a purpose. The focus here is on information systems which will guide decisions regarding values such as sustainability and resilience. Unfortunately, the discourse about *sustainability* is often quite muddled. In some instances *sustainability* is used to describe contradictory goals, such as financial sustainability of housing developments or extraction industries which are ecologically or socially unsustainable. Broadly defined, the concept of *sustainability* is the ability to meet present needs without compromising future generations' ability to meet their needs (Brundtland 1987). For corporations, this is frequently described as the "triple bottom line" where corporations are concerned with social and environmental benefits in addition to the economic benefits enjoyed by shareholders. But the discourse around sustainability assumes that the relationship between financial, societal, and environmental values is based on corporate interests (Winsor 2001). The financially-based model of sustainable value (Cooperrider 2008; Figge and Hahn 2004; Hart and Milstein 2003) has been developed into a corporate strategic logic primarily intended to enhancing shareholder value. This corporate financial perspective implies environmental and social well-being are amenable to the same type of simple utility measures as economic growth.

But interests of corporate investors are often not aligned with community concerns, which may include mitigation of environmental risks, community resilience to recover from catastrophic events, preservation of meaningful areas (e.g. heritage buildings, culturally sensitive sites), maintenance of view sheds and auditory directives, quality of life, desired neighborhood characteristics, ecological diversity, community economics, development/conservation ratios, and environmental services optimization. These concerns are often at odds with corporate goals for development and growth, which *per se* are not sustainable.

Communities are also recognizing that *resilience*, or the ability of a system to recover from internal or external shocks, and to restore and rebuild feedback loops (Meadows 2008; Tobin 1999), is a critical aspect of sustainability. Resilience can be supported by incorporating local knowledge and using structured scenarios to highlight alternatives which provide communities the capacity to learn, to self-manage, and to adapt to socio-economic changes and climate variation.

Climate change awareness has generated the desire to reduce local carbon footprints (Australian Government 2007), and to incorporate building practices designed within a regional climactic context (Department of Public Works 2002). For communities to be equipped for change response, while sustaining or maintaining their unique character and the way of life they value, they need to become *empowered* to understand proposed changes imposed from without (e.g. government regulations, development plans) and their implications for land use by leading from within (e.g. Craig and Elwood 1998). As communities develop awareness of local resources and their inherent value, and understand emergency preparedness, they become empowered regarding the control of utilities, food, or other life necessities and may gain understanding of the science behind policy decisions.

In contrast to corporate shareholders, community members can have a direct and personal effect on community sustainability through alternative energy investment, neighborhood gardens and rain/grey water collection. Therefore *structural-social factors* (Tobin 1999) constrain or enable the available actions necessary for sustainability, resilience, and empowerment. Structural changes (e.g. flood control works; fire-preventative tree thinning) support risk reduction and resilience, and geophysical factors such as local topography, climate, vegetation distribution and land use are contributing factors. But social/cognitive aspects as well as age, culture, education, and socio-economic status, also constrain and enable the actions which can be undertaken to create community sustainability.

Each of these factors, sustainability, resilience, and empowerment has been individually modeled, but the non-linear behavior of built and natural systems over time reduces renders them difficult to predict and control (Folke, Carpenter, Elmqvist, Gunderson, Holling and Walker 2002). Further research on the interaction of these factors can help achieve sustainability, long-term maintenance and monitoring and adjustment--not merely single interventions or short term goals.

GENERATION OF COMMUNITY SUSTAINABILITY WITH GIS

This research focuses on participatory community GIS as socio-technical systems which provide communities capability to identify, reach consensus, and enact activities we identify as leading to community sustainable value. These capabilities include use of structured scenarios to increase cooperation within the community and with governmental agencies, utilization of publicly available geospatial and demographic data to incorporate structural and social factors in community planning (e.g. Elwood 2006; Rattray 2006), and empowerment through reduction in information asymmetry by enabling stakeholders to directly upload and integrate local data.

Although GIS use for community planning has expanded dramatically in the past decade, Carver (2003) notes that technical connectivity and lack of community coordination mechanisms makes it difficult to obtain input from a representative sample of the broad population. Users must overcome the hurdles of obtaining hardware and software, data access, and required technical expertise. The skills, data, technical hardware/software requirements, and complexities of decision-making regarding issues of sustainability and resilience have often limited the involvement of community level stakeholders, leaving the interpretation and planning to government entities (Johnson, Walker, O'Brien and Cottrell 1997).

In a countervailing trend, public access to web-enabled GIS is becoming commonplace (Miller 2006). The popularity of Google Earth and other web-accessible spatial technologies has produced 'citizen cartographers,' whereby spatial data creation by the interested public is proliferating outside of government and privately-produced spatial data infrastructures, without the constraint of metadata and quality control (Parsons 2009). As community-driven data collection and mapping become more prevalent, GIS has the ability to enhance public participation in community planning, and to challenge the status quo (Sieber 2006). Arguments have been put forward that although technical considerations must be addressed, they must remain secondary to the social goals which the technology serves (Crisman 1987). In one case, Google Earth was used to geo-reference data from multiple sources, allowing the New Orleans community to contribute geographically-located community announcements after Hurricane Katrina. Other examples include user-generated maps of invasive pest species sightings, and local catchment environmental health. Web-enabled GIS is one direction for communities to develop sustainable value representations.

Participatory GIS has the potential of enabling community stakeholders to provide decision alternatives that embody their own intangible values over the traditional profit/efficiency measures. The shift has been driven in part by technological changes that have migrated GIS systems from centralized control by large stakeholders, to a distributed and potentially generative environment (Miller 2006). In the centralized case, community participation provides some input into the process, but information and decisions are controlled by entities situated externally to the community. As GIS tools become web-enabled and easier to access, information asymmetry is reduced and the decision-making process becomes less centralized. But a major impetus for the shift has been the desire by communities to have a greater input in the decision-making process, and by an increasing interest in community sustainability and intangible values. This allows for the co-generation of sustainability and resilience strategies within the community and between the community and external entities.

Applications of Community GIS

Despite implementation barriers, literature contains multiple examples of successful community GIS projects (e.g. see McCall 2003; Sawicki and Peterman 2002). The benefits of these projects cover a wide range of issues including:

- Separating *what is* from what *we want to be*. That is, making a clear distinction between the facts and the values held in regard to those facts (what assets are held by the community vs. what we want to do with those assets).
- Visualization and scenario comparison leading to more involved discussion of alternatives. Increased sense of ownership of community decisions.
- Transparency and reduction of information asymmetry between stakeholders, thereby empowering communities to challenge plans.
- Effective tool for spatial understanding of government regulations and proposed economic activity. Sensitivity analysis can show areas that will be highly impacted by a variety of development, conservation, and recreation activities.
- Spatial analysis of community impacts from climate change regarding increased fire hazard, surface and ground water distribution, areas suitable for reclamation with specific plant types, slope and aspects (both land and built environments) suitable for solar power installations, view-shed analysis for sound and visual impacts, identification ecosystem services.
- Participatory GIS can help educate communities and empower them to voice concerns challenging market-driven interests.

One of the most generative mechanisms of participatory GIS is exhibited in planning support. The capacity to visualize proposed changes allows stakeholders to assess alternatives. Some communities influenced the direction of development plans through their input after using GIS-enhanced planning support (Lieske, Lyons, Wall and Wall 2008). Using limited factors to describe a relatively well-understood situation in a predictive model, visualizations demonstrate how outcome is affected by input variation. For example, three possible patterns of future urban growth and land-use were derived using alternative scenario modeling for a coastal township experiencing rapid population growth (Pettit, Pullar and Stimson 2002). One scenario modeled urban growth patterns from a non-intervention approach based on existing socio-economic trends, a second scenario optimized land valuation, and a third visualized a 'sustainably developed' future focused on environmental factors. The scenarios and their underlying models were demonstrated to local government planners, advantages and disadvantages were evaluated, and a strategic plan based upon principles of sustainable development was formulated. Further iterative refinements incorporated trade-offs in areas of conflicting environmental and economically significant areas of concern (Pettit 2007). In these planning support cases, GIS was used to generate understanding or better comprehension of conceptual ideas and models through visualization.

GIS output ranges from maps that portray simple spatial juxtaposition to complex spatial models. Exemplifying community-based participatory GIS, farmers use GIS to reduce petrochemical runoff pollution and input expense, while improving water-use efficiency, crop yields and profits (Tickner 2008). An agricultural region located between World Heritage listed ecosystems demonstrates co-located sustainability values--established agricultural livelihood and ecosystem stewardship responsibility. A GIS stores crop field data layers documenting soil types and nutrient levels, slope and aspect (drainage), salinity, and pest activity, and crop yield is modeled, assisting farmers with location-specific information leading to sustainable practices. Rather than generalized fertilizer, pesticide and water application, variation is based on modeled location need, thereby reducing waste and maximizing yield. Illustrating the empowering directive of generative design (Table 1), farmers use GIS technology to perform precision agriculture, while pollution to ecosystems can be modeled and monitored. Community members are empowered to participate in influential decisions and share responsibility.

DISCUSSION

World events are challenging our assumptions about climate, resource use, and human/environment interactions. Green-IS is a perspective in which we can shift the functional goals of IS from utility and efficiency measures to a different design ontology which will support a broader set of values. By synthesizing concepts from Design Science Research, generative capacity, and GIS, we provide a conceptual foundation for future research. The increasing use of GIS at the community level provides opportunities for further research in how these technologies reframe the way communities view development and recast alternatives in support of community sustainability. The role of GIS in increasing public participation in the planning process and challenging top-down and purely financial-driven development is an open question. Future research can investigate when and how community GIS implementations are used to address social goals such as value generation, diffusion and adoption, and can explore the role of GIS in shaping political, social and economic forces.

First, we put forward the view that information systems support a wide range of values beyond utility and efficiency. Participatory GIS has the potential to support long-term sustainability, resilience, and to empower communities as they strive to meet the twin challenges of climate disruption and energy/resource utilization. By reframing DSR to emphasize generative capacity and the processes which enable human action, we change the discourse of the goals of system design. We view the information system as a part of an ongoing construction of consensus on the community values, which may include different degrees of emphasis on sustainability, resilience, empowerment, development, and economics. GIS enables monitoring of sustainability indicators such as water quality, vegetation, biodiversity, and hazard mitigation to determine the health of the community environment as an ongoing process. Community GIS can address the historic information asymmetry and power relations between government/developers and stakeholders in the community. Significantly, the use of participatory GIS can preserve both the history of the discussions and the differing viewpoints in collaborative activities. Inclusion and representation of divergent viewpoints are important aspects of empowerment, transparency, and consensus-building which contribute to community sustainable value.

Second, as communities seek a greater voice in their own futures, there is the opportunity for community GIS to play a generative role in evoking alternatives. Rather, the long-term goal of community sustainability can be pursued through continued monitoring of economic, sustainability, resilience, and quality of life measures. Monitoring can help a community in determining whether selected actions are having the desired effect on the dynamics of the community, or whether additional interventions are required. The decision process shifts from a one-off event to ongoing evaluation of complex socio-economic-technical systems.

Finally, we propose that the design, implementation, and use of community GIS can itself provide mechanisms by which communities can identify, discuss, and reconfigure values and alternatives. Just as traditional requirements elicitation can help identify key assets, issues, and values, the design and use of the participatory GIS provides a language and a focus for empowerment, involvement and reframing of community sustainability. Thus, even with a minimum of what we might consider to be system outputs (i.e. maps, charts, graphs), the *design process* for participatory GIS increases the generative capacity for a community to envision its own future and pursue sustainability.

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