Title

Spatial Concepts in GIS and Design, Position Papers

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Publication Date

2008-12-01

Specialist Meeting on Spatial Concepts in GIS and Design

Santa Barbara, CA

December 15-16, 2008

The idea for this specialist meeting originates in discussions over the potential of integrating design more fully into GIS, and over the development of curriculum in spatial thinking. The central question might be posed as "To what extent are the fundamental spatial concepts that lie behind GIS relevant in design?" or "To what extent can the fundamental spatial concepts of design be addressed with GIS?" or perhaps "Is it possible to devise a curriculum designed to develop spatial thinking in both GIS and design?" The meeting of about 30 people will be held at the Upham Hotel in downtown Santa Barbara Monday and Tuesday December 15-16, and will include a small number of context-setting presentations and ample time for discussion.

This is one of a long series of specialist meetings organized at the Upham Hotel over the past two decades. It combined a small number of context-setting presentations with ample time for discussion in plenary sessions, small groups, and informal social gatherings.

Meeting Sponsors included the National Center for Geographic Information and Analysis and the Center for Spatial Studies at the University of California, Santa Barbara, and Esri.

Agenda

Monday, December 15, 2008		
8:30	Welcome and introductions. Background to the meeting and introduction to its goals.	Jack Dangermond, ESRI Tom Fisher, University of Minnesota Mike Goodchild, UCSB
10:30	**Plenary presentation on spatial concepts in GIS and design, followed by plenary discussion.**	Helen Couclelis, UCSB Carl Steinitz, Harvard
1:30	**Two breakout sessions:** 1) spatial concepts in GIS and 2) spatial concepts in design.	

3:30	**Plenary presentation of results of breakout discussions** Reactions to the day's discussions.	Paul Longley, University College London Fritz Steiner, University of Texas Austin Sara Fabrikant, University of Zürich
Tuesday, December 16, 2008		
8:30	**Software and implementation issues** Presentations	Bill Miller, ESRI Steve Ervin, Harvard
10:30	**Curriculum development issues** Retrospective and prospective issues. Presentations	Diana Sinton, University of Redlands Karen Kemp, University of Redlands Don Janelle, UCSB
1:30	**Breakout sessions**	
3:30	**Plenary session** Reports from breakout discussions, goals and objectives, mechanisms and next steps	

Position papers from meeting participants are available at http://ncgia.ucsb.edu/projects/scdg/ and at http://escholarship.org/uc/spatial_ucsb_smppr

Position Papers, 2008 Specialist Meeting—Spatial Concepts in GIS and Design

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Spatial Thinking, Exploratory Spatial Data Analysis, and Design

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Not coming from a design background, I approach the interface between design and GIS from the perspective of a tools and methods developer interested in widening the scope of application of spatial analytical software tools in general, and exploratory spatial data analysis tools in particular. This builds upon some recent experience providing analytical support for a forthcoming text by Emily Talen (2009) on *Urban Design Reclaimed*. In this effort, exploratory data analysis, three dimensional design tools and GIS are combined to provide a basis for *spatially informed urban design*. Specifically, the GeoDa software for spatial data exploration is used together with ArcGIS and SketchUp to develop a series of exercises that bring social concerns related to accessibility, concentration, diversity, etc. to the urban design process.

Paralleling this is a motivation to expand the dissemination of *spatial thinking* in the planning and design professions through the introduction of innovative course materials that are organized around user-friendly software tools for geospatial data exploration. Integrating sound data analysis within a design or planning studio environment presents some interesting challenges to both pedagogy and tool development.

In this context, I see spatial thinking as focused on the twin spatial effects of spatial dependence and spatial heterogeneity (Anselin 1988). Geospatial analytical tools provide the user with interactive ways to identify interesting and significant patterns (such as clusters or spatial outliers), visualize them through maps and other graphics, and explain the patterns through spatial correlation and regression analysis. The challenge is to provide added value (data to knowledge) from the exploration of socioeconomic and other data that can inform the design, planning and policy processes, characterized by a normative and interventionist perspective and focused on the built environment. Specific examples of aspects that can inform policy and design development include the identification of clusters and spatial outliers of parcels in terms of demographic and ethnic composition, income, commuting distances and access to public and private infrastructure. Techniques to accomplish this are well established and by now, they are readily used in the social and natural sciences. I see the main impediment to their adoption in the design and planning process primarily from a lack of familiarity, which can be remedied through education, training and dissemination.

The research challenge is to create effective spatial decision support systems that integrate seamlessly with the design and planning process. This requires particular attention to the interface between socio-economic (income, employment, commuting) and natural phenomena (urban ecology) on the one hand and the built environment on the other. The decision support system forms the computing infrastructure on which simulations, visualizations and scenarios can be played out. I view three ongoing research directions as particularly important in this respect:

- the explicit incorporation of space and design aspects into econometric models of the built environment, through so called spatial hedonic models (Anselin and Lozano-Gracia 2009), which provide the basis for quantifying relationships between building characteristics, context, environment and market value, among others
- the explicit treatment of scale in the analysis of relationships between the built environment and socio-economic and natural variables
- the further extension of exploratory spatial data analysis techniques to the analysis of dynamics over time and across scales as well as origin-destination and other flow patterns as they pertain to changes in the urban environment.

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Design as a Growth Process Represented through GIS

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To explore the extent to which the domain of design can connect to, complement, and draw from GIS, we must be clear about our definition of design. A narrow but suitable definition of design as it pertains to geographic systems which I take here to be "cities," is the process of generating physical artefacts which meet "agreed" human (social and economic) goals pertaining to specific points or periods in time and space. Traditionally design has been articulated as an explicit and sometimes formal process of optimization as in engineering or as a process of intuitive discovery, usually grounded in certain conditions or constraints but whose essence cannot be defined. More recently particularly in complex systems, the process of design has shifted from the analogy of "manufacture" or "construction" to one of "evolution" with systems being "grown" according to the kinds of rules that can be distilled from the way biological systems grow and evolve. This argument is appealing because it assumes that design is open-ended in that there is never a finished product; that designs are always subject to the uncertainty of the environment in which they exist, and must therefore respond to such uncertainties so that they might be sustainable.

In a sense, this view of design as a system that evolves or can be grown differentiates the systems to which it can be applied with respect to the environment in which the design exists. Systems that need to be constructed for stable environments tend to be treated much more as products and then the engineering design process is more relevant. Systems at the other extreme that are never finished, imply environments that are continually changing and thus pose a much wider set of constraints that need to be met pertaining to their sustainability. In this note, I will assume that the systems to which this latter focus applies are those that relate more to GIS—geographic information systems and science—with my exemplar being "cities." In fact, cities particularly at the urban design scale—layouts of buildings and streets—tend to be treated as products rather than organic growing systems but there is little doubt that the organic analogy is much preferable even at these scales in that it leads to systems that can be adapted incrementally and grow in sustainable terms through time as many design theorist is from Alexander (1964) onwards have called argued is the appropriate analogy.

There is a theory of design which is quite consistent with growing systems that argues that it is the way the constraints on design are incorporated that generates "good" design. Indeed there is even the argument that design from a blank sheet is simply not possible and it is the way the designer manipulates, interprets and molds the constraints that determines good design. In a way, the search for locations that meet certain constraints which was and is a key method of landscape planning initially through overlay analysis (see Steinitz, Parker, and Jordan, 1976) could be treated as a design problem and it was in this arena that the first rudimentary GIS systems were developed. Indeed line printer mapping in the form of SYMAP was to generate these layers and then combine them into a synthetic layer as a composite constraints diagram that enabled solutions to location problems to simply fall out. Map algebra also came from this kind of problem but in one sense, the use of GIS for this task was really one of bounding the physical solution space. Overlay analysis is like piling on constraints as happens in mathematical programming with the last step—the insertion of some sort of objective function—left to the designer. There were plenty of analogies between this and the design process 30 or 40 years ago (Batty, 1971).

So the obvious feature of GIS that is of direct use to spatial design and planning of this kind is to bound the solution space, thus providing the designer with tools to manipulate the constraints in diverse ways. It could be said that the quality of the design is thus dependent on how the designer configures and orders and weights these constraints layers within the GIS although to call this design in the conventional usage is a stretch. A much more elaborate process of using the constraints is thus needed if design is to be embedded in GIS and just as GIS lacks focus on process, being more concerned with representation, any design activity which in and of itself is a human or decision process must be mapped onto GIS from the outside or the inside. There are various conflict resolution procedures in which the objective function is specified implicitly through conflict being resolved that can be linked to this kind of physical bounding of the solution space, and the author many years ago explored some of these from the technical perspective through to formal decision-making (Batty, 1974; 1984).

These activities are much more focused on the activity of the designer than the processes that drive the system from the bottom up although the group decision approach has elements mirroring or simulating bottom-up action. In this context, a stronger link to GIS would be through embodying the growth and change process in the GI system in question using constraints on the solution in such a way as to bound the space (Batty, 2008). If one were to consider design as an incremental growth or change process operated from the bottom up in the same way that cities grow as some synthesis of multiple quasi-interdependent actions and nest this in a physical solution space which comes from GIS, then the obvious question is "where is the design." Manipulating the constraints is one part of the design is part of the answer of course but also knowing where to intervene in the decision and growth processes is another. In this sense, we have a model of a system which might be a growth or evolutionary process, a representation of the system in physical terms which is contained within a GIS, and a designer or group of designers even who then intervene to produce good designs by manipulating the constraints and identifying leverage points in the process that would lead to good design. The question of what is good is still up for grabs in this characterization but one assumes that this relates to the feasibility of the growth process, and the way this process meets its constraints. In fact, the objective function is often implicit or endemic in these systems and this makes this characterization of design which I would argue is the way we should think of design in cities and complex systems quite different from product design or optimization, which are alternative views of design with respect to some characterization of location problems in cities.

I would like to elaborate these ideas in the seminar and seek reactions from other with different perspectives on design. I am currently merging some of my previous ideas on design processes with the notion of evolving and growing systems from which good design emerges from the bottom up.

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GeoVisualization, GIS, and Design

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By way of a "position paper" I offer some loosely related musings on **Design** and **GIS**. These come from the research "design space" between GIScience, Cartography and Information Visualization that I and colleagues at the **giCentre** have been exploring recently in our **geovisualization** research.

The more we do so, the more I am persuaded that geovisualization and Design are closely related, but perhaps not in the manner postulated in the SCGD 'central question.' The former is highly dependent upon the latter in my experience. More broadly, I would argue that fundamental concepts of Design are very relevant to enquiry-based GIS and are important in supporting spatial thinking, enabling geovisualization and so developing a curriculum that promotes spatial thinking relies upon relationships between Design and GIS.

Concepts such as similarity, quantity, category, hierarchy, proximity and relatedness amongst large numbers of objects of study that vary over space and time can be effectively represented graphically to aid spatial thinking. Geovisualization research develops cognitively plausible combinations of layout, symbolism and interaction according to data, task and user(s) that enable data analysts to mutually assimilate such relationships effectively and understand spatial processes . . . and generates knowledge that supports this process.

As geovisualization is design led I have not been able to resist focusing on design issues here . . .

1. Cartography is Design: But is GIS *Still* Hidebound by the Cartographic Legacy . . .?

Design "implies a conscious effort to create something that is both functional and aesthetically pleasing"[1]. The design process is essential in considering the way in which functionality, aesthetics and constraints are managed in the designed "thing." Cartographers know the importance of design, as stressed by Arthur H. Robinson, and have established principles that guide the map design process. GIS uses some of this knowledge, but Fisher (1998) contended that GI Systems were "hidebound" by the traditional role of the map as data collection and storage device. He argued that GI Systems should be more flexible analytical tools designed to make sense of information and foster insight and that effective visual design was vital:

> GIS must change to support real geographical information as it is recorded by domain scientists, and software tools need to be developed to transform that data into intelligible views and exploratory tools . . . With this change the need for cartographic design skills among GIS users will increase rather than decrease. To ensure that geographic information will be intelligible to the investigator and the user "good" design will be paramount, and is currently noticeable by its absence in system defaults available within GIS. (Fisher, 1998)

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[1] The obligatory Wikipedia entry—'Design: 30/11/08'

The functional nature of early GI Systems may have dominated over aesthetics in design. Liddle (in Moggridge, 2007) indicates that this is typical of technologies as they are increasingly adopted by enthusiasts, then professionals and ultimately a wide base if consumers. But how much have things changed in the last 10 years? To what extent are we designing for *exploration* in GIS? In geovisualization and visualization more generally highly interactive maps and graphics are designed to support this process—to encourage spatial thinking and act as prompts for insight.

2. Layout : A Space-Filling Trends in Visual Design for Exploration

Layout is an important aspect of design in cartography and information visualization—which have different spatial constraints. Methods that use space efficiently to make large quantities of data "intelligible to the investigator" are being developed and deployed in information visualization. There is a notable trend for data dense graphics to fill screen space at the expense of functional interface elements. Spatial information is being used in this way. For example Cui et al. (2008) use edge clustering methods to coherently map migration flows between 1,790 locations in the U.S. with nearly 10,000 edges in a manner that is functional and aesthetically pleasing. The results are stunning: "the patterns are beautifully revealed." GI Scientists are contributing to these efforts. Skupin & Fabrikant (2003) report methods for transforming non-spatial data into designs that "map" information. They apply cartographic principles to these layouts to make them intelligible. We have recently augmented space-filling layouts of trees with spatial information (Wood & Dykes, 2008) and used these in the exploratory analysis of large multifaceted data sets (Slingsby et al., 2008).

These methods have promise, and show trends that address Fisher's concern—but how do we know what is "good" layout or "good" design?

3. Aesthetics: Increasingly are Important (and popular) in Information Visualization

Studies such as that of Cawthon & Vande Moere (2007) may provide some answers. Aesthetics are considered an important factor in making data intelligible in information visualization and research shows that the aesthetic quality of a graphical design can affect their usability (Cawthon & Vande Moere, 2007). The visual emphasis on data rather than functionality reported above may thus have a positive effect on the use of graphics as well as visual quality.

Can we evaluate aesthetics? Kosara (2007) argues for a critical approach to considering aesthetics. He proposes that visualization criticism be adopted by the academic community and suggests a process through which this may be achieved. Doing so may enable us to of evaluate aesthetics in visualization and develop building blocks for a theory of visualization to guide design.

4. Animation: Transitions Have Aesthetic Quality?

Certain aspects of design seem to have a substantial positive aesthetic effect. "Animated transitions" are increasingly popular in information visualization (e.g., Wattenberg, 2005; Rosling et al., 2004). Research also suggests that they can be effective (Heer & Robertson, 2007; Robertson et al., 2008). GI Scientists have considerable experience in modelling and representing temporal phenomena. Their knowledge of and experience in developing animated cartographic designs may provide some pointers for those experimenting with transitions.

Perhaps GI Systems should use space-filling layouts and animated transitions to improve the aesthetic quality of their graphic design and lessen the focus on functionality as they are an increasingly consumed technology?

5. Interaction: A Multitude of Possibilities— with Scope for Spatial Behaviors

In addition to layout, interaction with visual designs is key to the acquisition of ideas and knowledge from them. The way that something behaves requires informed design to ensure that it is functional and aesthetically pleasing. As is the case with layout and symbolism, the effects and qualities of interaction must be fit for purpose and appropriate to context. Moggridge (2007) describes interaction design as being :

> . . . concerned with subjective and qualitative values [and starting] . . . from the needs and desires of the people who use a product or service, and strive[ing] to create designs that . . . give aesthetic pleasure as well as lasting satisfaction and enjoyment. (Moggridge, 2007)

The information visualization literature provides some guidance here. Yi et al. (2007) present a typology of interactions that may help designers navigate through the vast possible solution space. Heer & Agrawala (2006) encode information visualization design knowledge in software design patterns that can be adopted and / or developed. Ongoing work is establishing the extent to which these approaches are applicable to GI Science, but we have recently proposed geographically weighted interactions and presented these to the information visualization community (Dykes & Brunsdon, 2007).

6. Evaluation: It's Difficult to do Geovisualization Evaluation Well!

How do we know what is "good" design in our interactive, animated maps and graphics for geovisualization? Quantitative methods from Human Computer Interaction Design may provide some solutions. But, if our maps are not hidebound by the cartographic legacy then solutions will be uniquely designed for specific users and precise tasks. In this context design evaluation needs to be more qualitative in nature and should involve users throughout the ongoing development process in which requirements are likely to change as needs develop and possibilities are discovered and augmented. There are trends in this direction in information visualization—Shneiderman & Plaisant (2006) propose the MILC approach that uses multi-dimensional in-depth long-term case studies.

Visualization design evaluation is likely to be increasingly ethnographic as a result. Should geographers and social scientists not be particularly good at this . . .?

As visualization design and evaluation are so intertwined a "patchwork prototyping" (Floyd et al., 2007; Jones et al., 2007) approach may be useful. It involves the combination and modification of web services, mashups and existing code, functionality and real data from a variety of sources to rapidly iterate high fidelity prototypes through which design spaces and developing requirements are collaboratively explored. Various evolving spatial technologies exist to support this activity. Our experiences indicate that "real data" are essential in developing and evaluating visualization applications in context and we use a number of flexible and open technologies to produce "data prototypes" as we explore interactive designs.

7. Geovisualization: Solutions are Task/Data Dependent— What are the Possibilities?

We know that cartographic design for geovisualization needs to be informed by tasks and relate to data. Various typologies exist that may help and others would be welcomed. Andrienko & Andrienko (2006) propose a useful task typology for spatio-temporal data that differentiates between tasks with different levels of complexity and different geographies. Dodge et al. (2008) are developing a systematic taxonomy of movement patterns and encourage the community to participate. This is not a comprehensive list—other and ongoing efforts may help inform geovisualization design.

Transforming the masses of data that are now available into intelligible views through which the subtlety, complexity and structure of spatio-temporal information can be explored in the manner that Fisher described is essential if we are to develop geographic knowledge and support spatial thinking. These "musings" describe geovisualization as current trends and efforts that may help us develop, augment and explore design spaces for we try to visualize effectively and understand how this is achieved. They show the close relationships between geovisualization and Design, identify some trends that may be relevant to GIS, demonstrate some progress and highlight some of the difficulties that are to be faced.

Combining knowledge from Cartography, GIScience, Computer Science and Design may enable us to support and advance spatial thinking through "soft," interactive, aesthetically pleasing, informed maps and graphics that are effectively consumed and adequately designed for user, data and task specific geovisualization.

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Spatial Concepts in GIS and Design

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Armed with collected evidence through various systematic empirical evaluations I would like to argue for a theoretical and methodological design framework, grounded in cognitive theory and cartographic design principles, that support the construction of cognitively and perceptually inspired graphic displays for making more efficient and more effective spatial inferences with GISystems.

Geographical Information Systems (GIS) and highly interactive and dynamic visual analytics (VA) tools have become the tools of choice when dealing with complex spatiotemporal problems. Arguably, GIS and VA tools relying on a visuo-spatial paradigm, effectively support spatio-temporal analytical reasoning and decision-making. The popularity and use of such tools rests on the convincing assumption that humans are generally graphically enabled, and that they will better comprehend multidimensional dynamic spatial processes and phenomena that are congruently depicted with multivariate, interactive and dynamic displays. However, to this day, little is known about the effectiveness of interactive GIS displays for exploratory spatial data analysis, spatial problem solving, knowledge exploration and learning (Shah and Miyake, 2005).

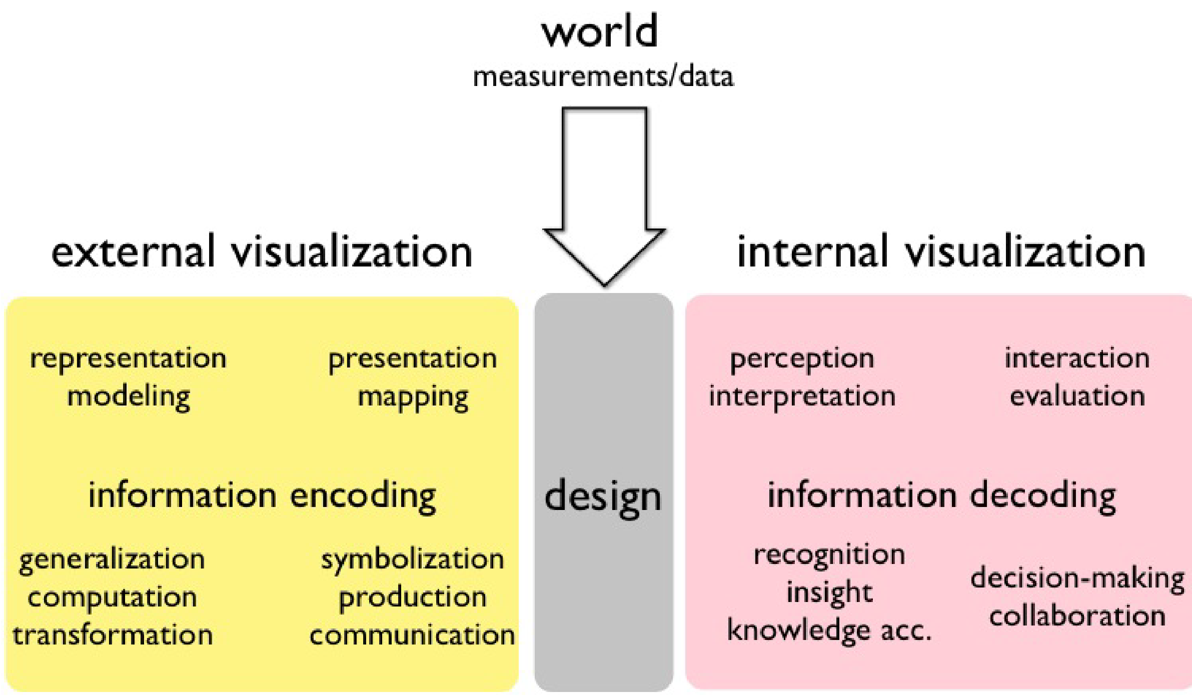
Research in cognitive science has shown that static graphics can facilitate comprehension, learning, memorization, problem solving and communication, including inference of dynamic (spatial) processes (Hegarty, 1992; Hegarty and Sims, 1994). Previous cognitive visualization research has focused mainly on identifying how humans make inferences from graphics, but has not necessarily looked at the possible interplay of human's visual inference making capacities (e.g., visual learning and reasoning) with external, visual displays (Scaife and Rogers, 1996; Zhang and Norman, 1994). This is particularly true for maps or dynamic and interactive GIS displays. On the surface, one might generally argue that based on an already established 5000 year old success story of map existence and map use, humans have been quite successful at making inferences from and with maps.

Hegarty (2004) suggests three possibilities regarding the interplay between internal cognition (e.g., mental representations such as images) and external visualization (e.g., graphics) in an educational/learning context:

1. External visualizations might act as a cognitive prosthetic for people with limited internal visualization capabilities. If this is true, people with low cognitive spatial visualization skills might benefit from well-designed external visualizations (Hegarty, 2004).
2. Use of external and internal visualizations might depend on internal visualization. That is, a base capacity to internally visualize may be needed to take advantage of external visualizations. If this is true, people without internal visualization ability may not be able to take advantage of external visualizations.

3. External visualizations might augment internal visualization for all people, regardless of a person's individual cognitive skill base (Card et al., 1999; Thomas and Cook, 2005).

The question remains as to how these three possibilities transfer into the GIS and design, spatial analysis, learning, and spatial knowledge construction domains. The potential role of design as an interface to and mediator between internal and external visualization (and their design components) is depicted below.



In related work together with colleagues have identified three design areas, based on empirical findings, in which core geographic concepts such as location, distance, region, and scale etc. need to be considered for the construction of spatialized views: (1) the visuo-spatial structure employed to represent the world of information; (2) the representation of meaning encapsulated in the database for knowledge discovery; and (3) the potential experiential effects spatialized views have on information seekers when exploring semantic spaces to satisfy a particular information need (Fabrikant and Buttenfield, 2001). A theoretically sound representational framework of spatialization grounded on ontological and semantic principles can, once established, arguably also be transferred to the explicit geographic domain as a basis to reduce current limitations of how geographic space is represented within GISystems and understood by their users.

Spatial Thinking and Design Thinking—Similarities and Differences

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Spatial thinking underlies both geography and design. Both disciplines deal with the flows and interactions of people, goods, information, and ideas and envision them in two and three-dimensional space. The two fields differ in the uses to which they put this spatial thinking. Geography, like science and social science in general, focuses on what is or what has been. It tracks interactions and flows largely to understand how and why things happen in the present and in the past. Designers in professions like landscape architecture, urban design, and planning draw heavily from geography and the other sciences and social sciences for their knowledge about what is and has been, but they use that information to develop scenarios about what doesn't yet exist, but that might be. Geographers think spatially about the past and present, and designers, about our spatial future.

Geographers and designers also share a preference for visual thinking. Computer-based visualization software such as GIS has become an essential tool in both geography and design, enabling us to see the patterns and relationships that emerge from large amounts of data. This, in turn, enables us to understand complex situations and settings more easily and to perceive changes and trends more readily. The two fields part ways in where that visual thinking leads them. Geographers use visualization tools to accommodate ever-larger amounts of data and to make ever-more-complex connections among phenomena. Designers, in contrast, use these tools more to communicate what could be, reducing complex realities into comprehensible alternatives for us to follow. Geographers use visual thinking to enhance our understanding, designers to prompt our action.

Geography and design also reason in concert. Both fields not only use inductive and deductive reasoning— working from particulars to draw general conclusions and working from general hypotheses to particular evidence—but also a third form of reasoning that the philosopher of science, Charles Sanders Peirce called abduction. As Peirce observed, "Deduction proves that something must be; Induction shows that something actually is operative; Abduction . . . suggests that something may be." Geographers and designers, however, use abductive thinking differently. Geographers use abduction to come up with new ideas that help us explain or deal with new facts and unexpected situations that arise from spatial analysis. Designers, in contrast, use it to "regulate our future conduct," as Peirce observed, creating the settings that reinforce our ideas about how we should live. Both geography and design involve creative responses to human activity in physical environments, but one uses abduction to explain and the other to bring something into existence.

The interaction of geography and design is both overdue and largely unexplored, and yet it has tremendous potential in enabling both disciplines to transcend their current boundaries in order to deal with some of the unprecedented problems we face around the globe. Geography, with tools such as GIS, has excelled in helping us understand the nature and extent of dilemmas such as an exponentially growing human population, using finite resources at an unsustainable rate, damaging the natural environment at ever-rapid pace, and concentrating wealth and power among an increasingly small number of people. But geography, itself, cannot show us what to do about these problems going forward. Design, in turn, has excelled in helping us see possible futures and conceive of alternative scenarios to challenges like overcrowded cities, water conservation, habitat protection, and affordable housing. But designers too often imagine those futures without the data necessary to evaluate or implement their ideas.

An alliance of geography and design holds the promise of developing GIS into a projective tool as well as a superb analytical one. GIS offers a common base on which we can not only understand what is going on, given the complex flows of people and resources across the planets, but also envision what we could do better in the future, based on that knowledge, and how we might convey that to others in visual and spatial ways so that they can comprehend and act on it. The problems we face as a species present too grave a prospect for us to continue along the course we have followed in the past. With more sophisticated analytical and scenario-building tools at our disposal, we can begin to reshape our future in ways that will be more sustainable and more just for all who share this planet.

Spatial Concepts in GIS and Design

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My current part-time position as co-Director of the New York Center for Geographic Learning has brought an unexpected bonus—standing, for a dozen 18-minute blocks of time every week, on a crowded subway, where writing, telephoning, or even reading a book or newspaper is not feasible. Rather than simply stare at the advertisements, ceiling, or other riders, I got into the habit of taking a couple of densely-worded journal articles on each trip. The selection of articles followed the trails of author citation and keyword searches wherever they led. The result, after several years of "conscientious subterranean inquiry," is a rather sizeable bibliography of thoughtfully digested articles from more than 130 journals in a wide range of related disciplines, including architecture, developmental psychology, linguistics, logic, neurobiology, robot engineering, and vision science, as well as geography and geographic information systems.

The focus of this inquiry is the burgeoning volume of research on human spatial cognition, a field that has expanded even more rapidly since the development of reliable brain-scanning technologies such as fMRI, PET, and TCMS. I think is reasonable to say that these technologies, and the inferences made from them, will prove to be as important in psychology as the theory of Plate Tectonics was in geology. For us in geography and related disciplines, the primary message is that we can no longer accept the simple but in their own way revolutionary ideas of the late 20th century (as encapsulated in Howard Gardner's justly famous book, Frames of Mind: The Theory of Multiple Intelligences). Where he posited "a" spatial intelligence, we must now acknowledge that the human brain appears to have several, perhaps as many as a dozen, at least partially independent structures that seem to be dedicated to doing analytically distinct forms of spatial thinking—e.g., comparing numerosities in different places and the sizes of different areas, preserving memories in spatial sequence, viewing areas or landmarks as part of spatial hierarchies, drawing analogies involving places that are spatially similar in some way, recognizing and describing spatial patterns, and so forth.

The astounding (but, in retrospect, quite predictable) fact is that scores of studies in dozens of journals have independently verified a rather simple statement: different individuals may preferentially employ different modes of spatial thinking to examine the same landscape, map, or other geographic representation, with measurably different degrees of proficiency according to different kinds of assessment. Teasing out any kind of explanatory theory at this time is undoubtedly premature; my own recent effort has been to ignore the nuances and potential conflicts and simply to focus on designing educational materials that might trigger (or at least provide practice in) specific modes of spatial thinking. In the grand scheme of things, these materials and teacher instructions are best viewed as hypothesis generators, not hypothesis provers, although in revised form they could serve as raw materials for controlled studies at some future date (a task that they might serve far better than the imaginary and often patently unrealistic maps that are the focus of a deplorably large number of published studies).

In any case, our maps and supporting materials have been used in a number of New York City public schools that have produced dramatic increases in standardized-test scores in very challenging demographic and socio-economic environments. Scientific integrity precludes any claim of a strong causal relationship between our materials and these test scores—the sample size is far too small and the "experiment" has no controls, in the accepted sense of the word. But we can sleep comfortably at night, knowing that we have honored the doctor's Hippocratic Oath—"Above all, do no harm." In short, there is no credible evidence that devoting significant amounts of time to these specific kinds of geography lessons in kindergarten, first grade, third grade, middle school, and high school have had any adverse effect on standardized reading or math scores.

Partly as a result of these pilot studies, we now have some evidence to use in debates with people who think that studying geography will harm students because it will decrease the class time spent on reading and math, and therefore will result in lower scores on the standardized tests that are such an important part of the educational environment in 2008. Our results hint at the exact opposite: They suggest that if you want to improve scores on reading and math tests, you should at least consider teaching more and better geography!

It is from this perspective that I can now return to my initial research interest on the origin and propagation of error in GIS and its applications in resource management. One tentative but potentially disturbing pair of conclusions (both solidly supported by dozens of research studies) is that different people may preferentially perceive different things in a geographic representation, and that modern GIS software does not support all modes of spatial thinking equally well. As a result, the knowledge gained from a geospatial analysis may not be equally approachable by all the stakeholders who may have an interest in its application.

And that is probably a topic for another decade of research!

Spatial Concepts in GIS and Design

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Recently there has been widespread interest in identifying the fundamental concepts of critical spatial thinking. Several factors seem to be driving this interest. First, the advent of Google Earth and other related sites is raising interest and awareness among the general public of the power of geospatial technologies, the abundance of data, and the relevance of both to everyday activities. This *democratization of GIS*, in the form of sophisticated but at the same time easy-to-use tools, begs the question of what every citizen needs to know to use them effectively, and to avoid making misinterpretations. Yet at the same time, and despite the vast amounts of attention given to number and language skills throughout the K–16 curriculum, almost no systematic attention is given to the development of similar skills in reasoning and inference from *spatial* information. Even geometry, which addresses fundamental spatial properties, appears to be losing ground to algebra across the mathematics curriculum.

Second, the growth of geospatial technologies is dwarfed by the rapid increase in the accessibility of imaging and video, in the form of games and entertainment. The current generation of students is far more attuned to visual methods of communication, which appear to have replaced text as the focus of increasing amounts of attention.

Third, in recent years the group of tools collectively referred to as GIS has become significantly easier to use. Pull-down menus and pointers have replaced the command line of old, allowing the GIS user to focus more on the meaning of data manipulation and less on the mechanics. GIS still has a reputation for being difficult to learn and use, but there is no doubt that the interface has improved dramatically, allowing greater opportunity for critical thinking.

Several lists have been published in an attempt to identify the atomic concepts of critical spatial thinking, and at UCSB we have recently been engaged in an effort to develop a compilation, with cross-references and other aids. Some are rigorously defined, particularly when they are derived from concepts in mathematics, while others are more conceptual. Familiarity with some concepts clearly develops early in childhood, while others are typically encountered only in specialized university courses. Thus one way to organize the set is along a scale of conceptual sophistication. Another is according to metrics of similarity, and hierarchical relationships can also be investigated. In the second phase of our project we intend to develop a number of such organizing methods, to allow the set, which currently numbers 99, to be searched, visualized, and navigated systematically.

One of the motivations for this work lies in its potential to drive a more intuitive, easier interface to GIS. Over the years the number of functions supported by GIS has grown, and today it is possible to assert that GIS software can perform virtually any recognized manipulation on geospatial data. But organizing the user interface has proven to be a difficult challenge. ESRI's

ArcGIS Toolbox had 510 functions in its 9.2 version, and many other functions were accessible through pull-down menus and extensions. Although these are grouped hierarchically, the grouping often makes little sense. A well-organized, logical list of spatial concepts, organized according to well-defined principles, could help enormously to make the tools of GIS easier to learn and use.

The concept lists were almost without exception devised by geographers, and some date from the earliest years of geography's so-called Quantitative Revolution in the 1960s, when there was a widespread effort to identify the fundamentals of a scientific approach to the discipline. That approach was grounded in a positivist philosophy, with the objective of discovering natural principles and laws about the geographic landscape, both social and physical. Ever since the 1960s there have been efforts to apply the knowledge discovered in this way for normative purposes, in other words to design improvements to the geographic landscape. This is very much the position of the subdiscipline known as applied geography; it explains the often tight relationship between geography and planning; it explains the interest that is expressed from time to time in a geographic form of engineering; and it underlies the development of spatial decision-support systems. In all of these cases attention shifts from how the world looks and works, to how it might be given various forms of intervention. Moves of this sort remain contentious in geography, however, as they do across many areas of science, because they appear to divert effort from the central mission of discovery.

Many areas of GIS are already devoted to design, however. The functions of location-allocation, vehicle routing and scheduling, logistics, and spatial decision support are all oriented to computing solutions or designs that optimize well-defined objectives. Yet many areas of design lie well outside the domain of GIS, and it is not uncommon to encounter hostility to information technology in some areas of design. Methods such as location-allocation that are highly formalized clearly adapt themselves readily to GIS, whereas information technology can appear to have little to offer to the more artistic, humanist, subjective areas that defy formalization.

But if a continuum exists between the objective and subjective extremes of design, where exactly should the limits of information technology be placed? As information technology becomes more versatile and easier to use, should the limits be moving to encompass a larger part of the continuum?

These questions can be addressed at various levels, and the participants in this specialist meeting have been chosen with that in mind. At the most basic level, we can ask about GIS technology, and about the functions that would have to be added or enhanced to place greater emphasis on design. These would include tools to support sketch and other kinds of intuitive input; and to support the analysis of such input against various criteria. The sketch/simulate sequence in which a user would first sketch a rough design, and then allow the system to simulate and evaluate its impacts, seems particularly important, and suggests the need for a series of tools for simulating dynamic processes. Spatial decision-support systems have been discussed for many years, but we have yet to develop a set of reusable software components to support decision making in GIS, and fundamental research is still needed to identify those components.

At the conceptual level, one would pose the question very differently: What are the fundamental concepts of design, and how are they related to the spatial concepts identified as fundamental by geographers? For example, if spatial dependence in the form of Tobler's First Law—nearby things are more related than distant things—is a general and fundamental principle of geography, what is its meaning in design? Are there spatial concepts in design that need to be added to the 99 in the UCSB list?

Understanding Purposive Space with GIS

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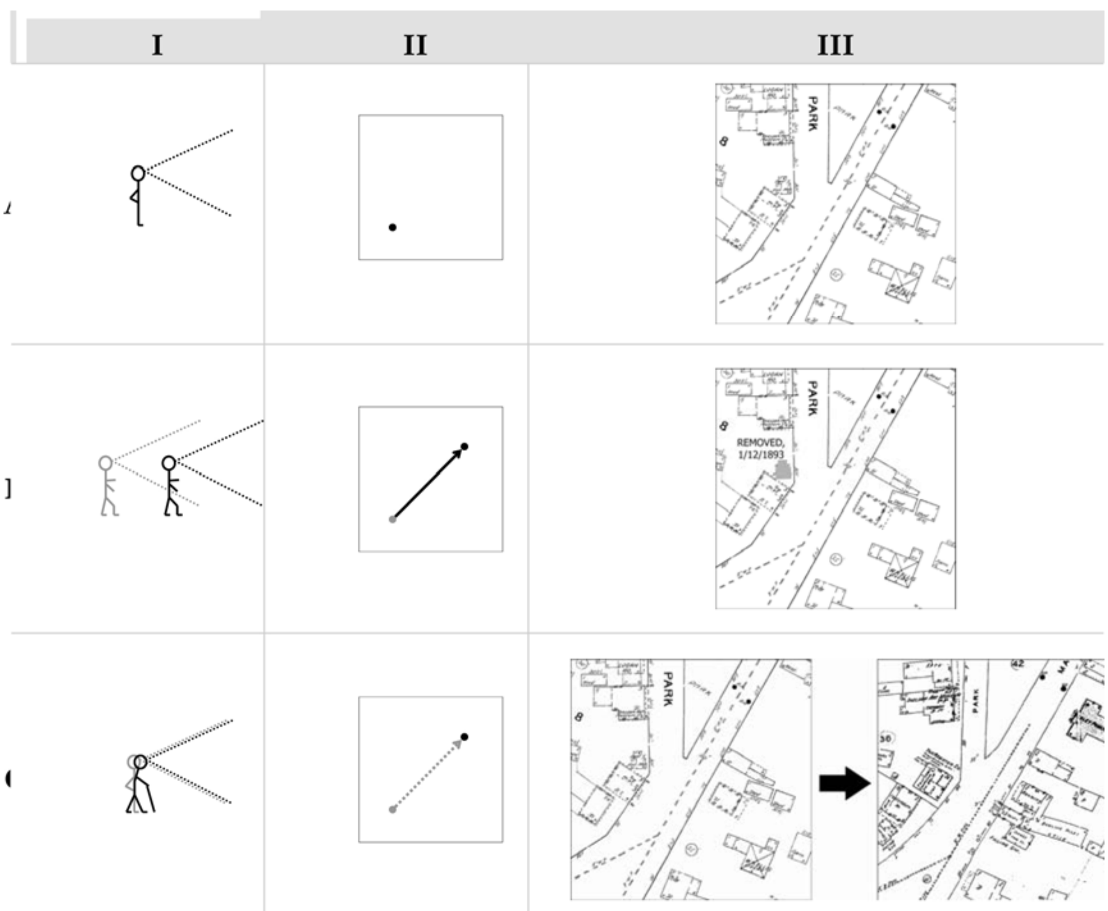
Fundamental spatial concepts of design cannot be divorced from concepts of purpose (what is this for?) and normative logic (how should this be?). In my research, I aim to improve the capacity of spatial databases to handle questions about the purposive and normative qualities of the environment. To this end, my dissertation developed a model that (1) associates human goals to spatial features and (2) associates telic relations between goals, where one goal is a means to another. I showed that this model can bring together information about human activities and spatial configurations in order to support queries about the human environment that traditional spatio-temporal models in GIS cannot support.

The figure below briefly outlines the problem domain for my research. The columns represent three general views of space that are commonly used in planning: (I) the perspective a person gains of the environment when they are in (or above) it, (II) a person's position plotted on a map, and (III) the configuration of the built environment also plotted on a map. The rows show three temporal cases: (A) static, (B) when change in the location or attributes of perspective, person, or built environment is observed, and (C) when such change is not known.



For any of the three views, we might want to ask three general questions: (1) Why do the things in this view look like this? (2) Why did the things in this view change as they did? (3) How might things have changed during gaps in our observations?

My research explores ways to answer these questions by using a model of purposive space that facilitates normative reasoning. This model provides an answer to the first question by measuring the "fit" of the given view for a particular purpose. For the second, it identifies functional reasons for observed spatial changes, such as improvement, deterioration, innovation, and obsolescence. For the third, it leverages knowledge about activities to make inferences about spatial changes, or vice versa.

My ongoing research continues to explore how normative reasoning in GIS can expand the kinds of spatial questions that may be investigated with this tool. This includes methods to (1) anticipate changes in patterns of activity that result from proposed spatial changes to a landscape and (2) evaluate the degree to which the actual use of space matches its intended use.

"Design?"

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Over the last year I have had the opportunity to assist as a teaching associate for four geographic information systems and science courses in the department and have also had the opportunity to conduct my own introduction to geographic information systems course this past summer. My interests in this gathering are driven by the experiences I have had working with students from various departments on campus.

The reach of the Geography Department's Geographic Information Systems and Science upper division undergraduate course series has grown in remarkable ways over the last few years. We are seeing more and more students interested in the series and these students are originating from outside of the geography department. Notably, students from Anthropology, Sociology, Political Science, Communication, and History of Art and Architecture are growing in enrollment—all of which have expressed interest in the built environment. With street center lines, parcels, building footprints and socioeconomic data appearing in arguable every GIS course with structured labs, implementing design as viewed through the lens of urban planning seems ripe with opportunity. From what angle do we approach this? Student driven projects this past year have addressed elements of landscape architecture, emergency response routing based on campus long range development plans, building interior use case assessments and 3D modeling along with a host of other analyses that touch upon design elements.

When assisting students with various site suitability analyses, I often wonder what the unintended consequences are for our exercise driven decisions to site a business at a particular location, a park in an urban expanse, or even a labyrinth on campus. While we take into account networks, view-sheds, and target demographics, the GIS has no built in knowledge of design elements. At no time will you receive any decision support related error messages alerting you to key design concept that have been violated. The software performs exactly as directed, which may be something that we want to maintain; leaving the intersection of design and spatial thinking to instruction in the classroom.

In my experiences with students in the classroom, reoccurring themes driven by real world examples to demonstrate concepts help to solidify understanding. With limited time to convey a host of conceptual foundations, where does design fit? I would hope to approach design in a way that would allow it to be intricately woven into the spatial concepts and foundations that are already at the core of instruction, as opposed to setting it aside as a standalone lecture.

Spatial Concepts in GIS and Design

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To what extent are the fundamental spatial concepts that lie behind GIS relevant in design?

This is a tricky question, and one that I feel ill-equipped to answer despite working for seven years in a planning school. Pushed for a response, I would probably take refuge in the work that I did with Mike Batty back in the 1990s, a high point of which was the "Fractal Cities" monograph. Much of this book sets out the superficially different ways in which planned, organic or hybrid cities fill space, and many of my interests at the time focused upon the use of fractals to provide measures of space filling norms that characterise urban development across a range of spatial scales. Statistics pertaining to space filling are now much more widely available than they were, both within and outside of GIS.

Related to this is my interest in evaluation of urban models. Fractal geometry crystallised my interest in the notion (popularised by Mandelbrot) that a fundamental test of any model should draw upon the qualitative notion that it "looks right," and that such evaluation was more important than mere numerical comparisons. These considerations are frequently neglected in geographical models, but are nevertheless important at scales ranging from the architectural to the global.

Largely unrelated to this, I also think that the conception and measurement of diversity is pertinent to issues of design—see below.

To what extent can the fundamental spatial concepts of design be addressed with GIS?

I would probably again take refuge in the ability of GIS to provide measures of size, scale, shape, dimension and space-filling, to artificial as well as natural structures. Additionally, design is often about planning for diversity, as with issues of homogeneity and heterogeneity of neighbourhood communities. It is an interesting conjecture as to whether communities should be, or can be "designed," but it is clear that GIS provides a valuable tool for measuring and monitoring diversity of built structures and residential (and also daily activity pattern) characteristics.

Is it possible to devise a curriculum designed to develop spatial thinking in both GIS and design?

My own current interests in this area focus upon ways in which the diversity of communities is conceived, represented and analysed. This introduces a number of GIS related tasks, including: (a) the creation of new information resources in order to measure diversity; (b) the harnessing of consultative practices to the classification of neighbourhoods; (c) the effective use of GIS to accommodate issues of disclosure control in effective representation; and (d) the use of geoweb 2.0 architectures to build and disseminate neighbourhood classifications. We are in the process of designing teaching and professional development packages to articulate these, as part of the "Spatial Literacy in Teaching" Centre of Excellence in Teaching and Learning at UCL.

Spatial Concepts in GIS and Design

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My interest in the intersection between design and GIS stems from: (1) an understanding of the basic function of all organizations, (2) the definition, scope and purpose of design, (3) what we mean by "geo-scape," as opposed to "landscape," and 4) the potential role GIS might play as a "geo-design" tool.

1. The Basic Function of All Organizations

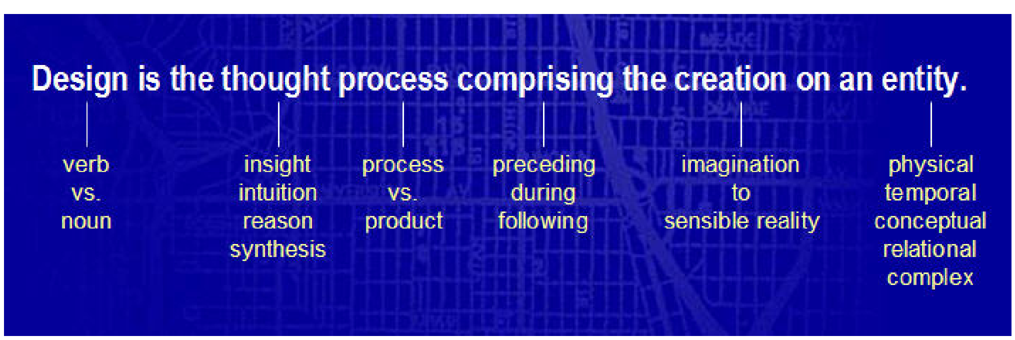
All organizations, be they large or small, public or private, do three things: they get and manage information (*data*), they analyze, evaluate, or otherwise assess that information for some purpose (*analysis*), and then, based on that analysis, they create or re-create some form of good and/or service (*design*). This design activity produces the substance (the goods and/or services) that give the organization its reason for being and forms the basis for its economic vitality.

GIS technology has served, and continues to serve, the first two of these three activities quite well. GIS has not, however, served the creation-based (design) needs of organizations.

2. The Definition, Scope and Purpose of Design

While design, defined as the creation or recreation of goods and/or services, provides a contextual understanding of the role design plays in organizations, it does not provide us with a clear functional definition of design. That is, it does not tell what design really is, or how to do it.

The following definition of design is "designed" to give us a better functional understanding of design and how we might go about the business of geo-spatial design, that is, the business of creating or recreating goods and/or services in geographic space.



An entity can be anything, an object in space, an event in time, a concept (like the theory of relativity), or a relationship. Most entities are complex entities, that is, they are composed of one more of these four entity types. This is surely the case when one thinks of geo-spatial entities, such as a forest management plan, a disaster response plan, or the design of an urban center. They are not only complex with respect to containing different types of entities (objects, events, concepts and relationships) they also geo-spatially complex. That is, they reside in a complex geo-spatially dependent environment.

An interesting thing to note is that this definition does not contain or express value. That is, it does not contain any statement as to what constitutes good design. The notion of goodness does not come from the definition of design but rather from its corollary, its purpose ... which, I believe, is always the same.

Simply put, if an entity facilitates life it is good, if it inhabits life it is bad, and if it does neither it is neutral. I think one can easily see how this statement of purpose, this ethic (if you will), can be applied to the creation of entities in geo-space . . . what one might call our *geo-scape* (as opposed to *landscape*).

3. Our Geo-Scape: The Planet's Life Zone

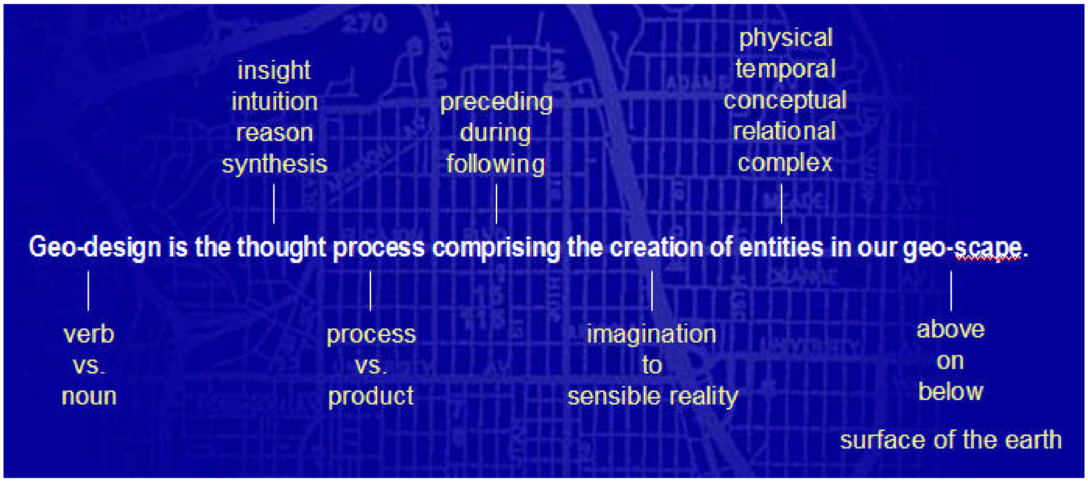
Landscape, as defined by most landscape architects, typically refers to what I call "the green in between," that is, the open space (parks, promenades, gardens, etc.) in between our buildings and civil infrastructure. The definition is also most often limited to what occurs on the surface of the earth . . . the "land."

Geo-scape goes beyond "the green in between" to include everything on, above, and below the surface of the earth that supports life. It is not "land" dependent, but rather refers to all aspects of the planet's life support system: including the physical, biological, social, cultural, economic, and spiritual aspects.

4. Geo-Design: GIS in Design

Technically, we could say that *geo-design* is the thought process comprising the creation of entities in geographic space, that is, the creation of entities that are geo-referenced to the surface of the earth. This, however, would have a tendency to limit our thoughts to what we can show on a map and would thus quickly become just another techno-term for cartography.

Thinking more holistically . . .



This is a bold concept, as it gives us the conceptual power to create (design) complex entities (of all types) in 3D geographic space (our geo-scape) to enhance (facilitate) the quality of life on the planet.

Up until recently, the core of ESRI's software, with the possible exception of ArcSketch™ (a set of 2D geo-sketching tools), has provided little or no support for doing geo-design. This is about to change.

ESRI is in the process of extending the capabilities of its software to fully support the geo-design process. These extended capabilities will be designed to meet the geo-design needs of all sectors of its user community, including those working in 3D space. These capabilities will include the functional tools for doing geo-design (creating, editing, visualizing, etc.) as well as those tools required for managing the application framework (semantic structure, digital workspace, user workflows, etc.) in which that process takes place.

This is a major challenge and will be a lengthy undertaking. The results, however, will be a suite of tools and supporting frameworks that support the geo-design process . . . the process of creating goods and services in our geo-scape.

Information for Design: Interacting Environmental Systems in Space and Time

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Thesis

Effective planning for environmental resource protection and sustainability happens best when all stakeholders understand the impacts of changes in one system on another, and can be shown and understand the implications of those changes over a variety of short- and long-term time scales. Good decision-making relies as much on accurate understanding of those system interactions as it does on the emerging results of the analysis.

As an educator in landscape design and planning, that is where I must focus, on developing understanding of the system interactions and change through time, because it is critical that beginning designers be clear about the ways that their design decisions shape those interactions. I also believe that that holds for most decision-makers and citizens turning to GIS to tell them how close and how bad things are going to be, and how soon they need to act to avert disaster or flee.

I want to raise four issues here:

1. We have done a great job of developing tools that allow us to access vast amounts of data, manipulate it smoothly, and create beautiful and compelling images of the resulting analysis. Where we are weaker is in having nimble and smart tools to inform scenario development—the GIS/modeling equivalent of the back-of-the-envelope or cocktail napkin sketch.
2. Cultural and social issues are often critical constraints on development in the minds of citizens—and they may dominate thinking regardless of the sophistication and completeness of a technical planning solution. We don't have good ways to use qualitative information in the context of technical planning, so it may be valued too much or too little, or simply go un-addressed.
3. Time is critical in planning, but we don't yet know how to explore time. The concept of discounting, establishing the present value of a future resource, embodies the idea of time as a linear progression, but for natural or cultural resources the time-frames are much larger and the perceived "shape" and implications of time may be quite different.
4. GIS analyses are increasingly shared as visual presentations, often highly detailed 3-d representations. However, there has been depressingly little study done of the effectiveness of, say, photo-realistic renderings vs. diagrammatic images in supporting rational decision-making.

Direction

Scenario-development: We need rapidly-configured and intuitive "what-if" tools that I can use to test an hypothesis and learn about the underlying dynamics of a system—which are the important and which the less-important variables, does the system move along steadily or spiral out of control? Ironically, it is the dynamism and complexity of environmental change that excites us intellectually but then makes it so challenging to project outcomes and make sound decisions that will get us there.

We have vast information about environmental change that is inaccessible for day-to-day decision making because it is distributed over many disciplines, each with its own way of using and representing data. Potential connections between independent systems have been acknowledged and implemented in sketch planning systems such as CommunityViz. But while CommunityViz makes complex combinations of issues palatable, and the underlying spatial dynamics derived from agent-based modeling may be readily grasped, the overall system remains a magical black box if there is no ability to decompose the analytical processes so that each is clearly understood. The complexity of most land-use questions will take decision-makers into new disciplinary territory where, no matter where their individual expertise lies, they will not be familiar with the basic underlying systems.

I believe that we need to re-focus energies on creating system understanding among planners and citizens using simpler, exploratory, "front-ends" to GIS. The beauty of an envelope or napkin is that it responds in the moment of an intuition, immediately provides a medium for further exploration, and is quickly discarded when the "what-if" is rejected as inadequate. Interactions between resources and agents must be explored and the salient relationships understood before they become embedded in bigger design and planning systems—substantively changing the way we understand the implications of our plans vs. just doing them faster with better graphics.

Cultural and social issues: Decision-making in the public policy arena is constrained by the challenge of reconciling multiple perspectives on complex environmental issues and has clear implications for areas such as environmental adaptation, stewardship via incentives programs, multi-scale and grounded management, and shared responsibility and governance. Often the issues are framed in subjective, qualitative terms rather than the quantitative descriptions we expect for natural systems and populations.

The challenge with qualitative data is to identify metrics by which those and quantitative data may "talk" to one another. Some qualitative methods such as Q-methodology provide measures, such as the subjective relationships between the values of people involved in evaluating a scenario, but oral histories, historic photos and the like may not possess suitable attributes. A heterogeneous data approach might include some resources represented by numerical models or stored data tables, others by Q-sort evaluations of scenes within a geographic area, while others may be, say, events listed in tables of cause and effect relationships derived from focus groups of domain experts. In operation, information such as records from oral histories could be indexed by key words that are triggered when particular data conditions arise in running a projection or other scenario. The goal would be to deliver to the decision-maker the widest range of data germane to making the evaluation at hand. However, within this range of possibilities there is no emerging accepted or generalizable approach.

Dealing with time: We are all challenged when asked to evaluate alternate responses to anticipated large time-scale environmental impacts, whether the result of direct human agency such as policy change, or more indirectly through climate change or natural disaster. Interactions within environmental systems are extensive and complex, but our ability to comprehend the urgency of action to address change is limited.

While we are very good at evaluating current environmental conditions we are less good at projecting those conditions into the future. Models tend to report singular outcome conditions but even with robust projections, complex systems acting over significant time horizons accumulate significant "error" that could result in numerous plausible outcomes. Urgency is based on our perceptions of risk, the severity of the event, and how soon action must take place. If we have no firm understanding of future conditions it will be a huge challenge to discount impacts back to the present to enable us to mobilize the appropriate immediate responses. We act now to divert impacts that may not occur for tens or hundreds of years.

Time plays a central role in the development of environmental problems, and in their solution, but there is no substantial literature that examines how time is represented or interpreted. While the concept of discounting is critical to business and investment modeling, there is no equivalent focus on how decision-makers perceive future impacts, develop attitudes towards them and then behave when making resource management choices.

Visualization: Visual imagery is a key means to making information accessible to all disciplines. An entomological model describes the spread of insect damage but a visual image illustrates the implications of that spread to non-specialists. Similarly, other germane environmental factors can be projected via the same visual interface, providing a platform for sharing disciplinary perspectives of a complex problem.

However, there is a serious gap in the development of scientific and environmental visualization to date. While we can create sophisticated images of hitherto poorly explained phenomena, there has been relatively little study of the effects of the visual tools being employed. While the choice of visual signals to represent the advance of a cold front across a weather map may be inconsequential, the representation of change at a real location as a result of environmental factors must inform policy choices but not manipulate them by use of, say, an exaggerated image. The validity and reliability of visualizations illustrating environmental change is a topic begging for some concerted scientific study.

Closing the loop on these comments, we have to shift focus away from the product to the system driving the product; to factor in not just the scientific but the attendant cultural issues; to learn how to understand change over long time scales; and to avoid fooling ourselves with the brilliance of our wizardry.

Toward a "Leonardo da Vinci approach" of GIS for Spatial Design

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Foreword

At the very beginning of the 1990s, a student happened to use a pen in a pen plotter that was smaller than the required size to fit the holder, which produced squiggle line drawings very similar to hand-generated plots. Taking advantage of this "accidental" discovery, and so as to establish the impact of this "technique," Van Bakergem and Obata decided to voluntarily use this particular process to produce various plots, and to show them to architects and architecture students in order to test their respective reactions. Two sets of pen plotted perspective drawings were presented. The first set was printed with precise lines, and the second one revealed the results of the "new technique" simulating hand-sketching. The first set was judged as a final closed image that dampens creative ideas; whereas the second one was considered as interesting and stimulating. This experiment gave birth to a new technique for producing non-photorealistic images from photorealistic images.

(Van Bakergem and Obata 1991, cités par Brown 2003)

Realistic and non-photorealistic pictures (Litwinowicz, 1997 in Ostromoukhov, 2002)

Spatial representations in GIS and Spatial Design

Spatial representations, whether physical (maps, pictures, models . . .) or mental (cognitive models, mental maps . . .), constitute the main components of spatial design processes. Such representations can be seen as the products (intermediary and most of the time final) of those processes. But, like boundary objects (Latour, 1995) or intermediary objects (Vinck, 1999) they can also be considered as the "fuel" to carry out these processes, taking various forms depending on the phase of the processes and on the nature of the processes themselves.

Based on this assumption, my position paper will try to explore the intersections between GIS and spatial design through their respective relationships with spatial representations. The first section provides a brief overview of the spatial commonalities between GIS and spatial design from the perspective of creating and manipulating spatial representations. Secondly, I will give some facts to explain to what extent current GIS are not built for spatial design and, more specifically, why spatial designers do not see themselves reflected in GIS spatial representations. Last but not least, the third section raises some questions based on current research projects running at the Centre for Research in Geomatics, Laval University (two potential demos for the specialist meeting).

1. GIS and Spatial Design seem to have many spatial commonalities

With respect to the basic spatial concepts embedded in GIS, and regarding the production, management and use of physical GI spatial representations, it clearly appears that GIS and spatial design have many spatial commonalities. The following concepts are especially available in GIS as spatial analysis operators or tools, and all these concepts refer to basic spatial skills for GIS users:

- spatial references (coordinate, linear, punctual . . .),
- multiple scales (zooming),
- multiple views (place, time),
- multiple sources (interoperability),
- spatial move (panning),
- multiple granularity (generalization),
- etc.

Wikipedia defines Spatial Design as a "*relatively new discipline that crosses the boundaries of traditional design disciplines such as architecture, interior design, landscape architecture and landscape design as well as public art within the Public Realm. The emphasis of the discipline is upon working with people and space, particularly looking at the notion of place, also place identity and genius loci (the spirit of a place). As such the discipline covers a variety of scales, from detailed design of interior spaces to large regional strategies.*" Even if this definition is disputable and lacks some notions, especially the connection to Urban Design, it shows that the GI spatial concepts mentioned above are explicitly or implicitly included in spatial design: scale, place, time, multiple representations . .

Forester (1999) mentions that urban design process is four-fold: making a diagnosis, analyzing possible areas of intervention, planning local solutions, combining the local solutions together to generate a global solution. GI literature has widely demonstrated to what extent GIS could provide efficient and relevant solutions for each of those four steps (Roche and Hodel, 2004). Consequently, GIS should theoretically fulfil spatial design requirements. Yet, in practice, the situation seems to be quite different and more complex. A recent research achieved by one of my graduated students (Ciobanu, 2006) in collaboration with the school of planning (faculty of visual arts, architecture and planning) has revealed that spatial designers do not see themselves reflected in GIS, and especially in GI spatial representations. The main reason given by designers is that GIS are not built at all to meet spatial design needs and requirements. More fundamentally, exploring the way spatial representations are produced and used by designers, as well as the nature of such spatial representations helps to better understand this situation. The example of the Preamble is a good starting point to do so.

2. Some facts: GIS versus Spatial Design

Forester (1999) specifies that the main interest of urban spatial design is the flexibility of the process, its adequacy to creativity, its ability to integrate non- (or little-) formalized aspects. Indeed, spatial design is based on a complex creative process (mixing artistic, scientific, technical, legal, economic aspects . . .). Spatial design, and more particularly urban design, is also based on a deliberative approach; that is to say designers find solutions through talking. A detailed analysis of this type of process emphasizes the following elements:

These "deliberative rituals" (Forester, 1999; Innes, 1996) place emotions at the very core of the motivations of the design process. From a spatial point of view, these emotions translate into "verbal spatial representations" at every stage of the process. When they translate into some physical form, they appear as spatial representations with open and unstable features, both regarding the shape of the represented objects and phenomena, and their localization (Brown, 2003). On the contrary, GIS are characterized by stable and closed representations (Lardon et al., 2001).

The creative side of spatial design processes originates from the ambiguity (as March defined it, 1978), which increases at each stage. However, most of the works dedicated to developing GIS as spatial decision-making tools are based on the principle that any spatially informed decision should be built upon simple representations (and not simplistic). According to Lemoigne (1999), simplifying representations directly or indirectly exerts a reducing effect on the "clear and sharp" features. He also emphasizes the fact that Leonardo da Vinci's "light and shade" technique remains the most efficient one to report effectively on any complex phenomenon (this is precisely what the example presented in the foreword revealed). It is specifically on the richness of this ambiguity of human perception that spatial designers develop their ideas. In the field of spatial design, ambiguity and "light and shade" effects in spatial representations stir up creative inspiration, whereas GIS are specifically developed to reduce this ambiguity to produce "clear and sharp" spatial representations, considered as being synonymous with quality.

A closer examination demonstrates that the debates between designers deal with spaces

(Places) being studied that are progressively defined in the course of their discussions. Designers first develop a temporary local solution (realized in a verbal or physical spatial representation), and then they pursue with another space for which they propose another temporary solution (realized in another representation). Finally, they make the necessary adjustments to the first solution so that both solutions could work together (Figure 1). The steps are repeated until the end of the project. This type of dynamics makes analytical perspectives change at a rapid pace. Designers use this particular process to gather the local solutions all together (which in fact correspond to local perceptions) into one global solution or representation. These spatial, temporal and semantic perspective changes were highlighted for example by Tversky et al. (1999). These changes are followed, with respect to spatial representation, by a constant evolution of the shapes of the spaces being studied during the design process (Figure 1).

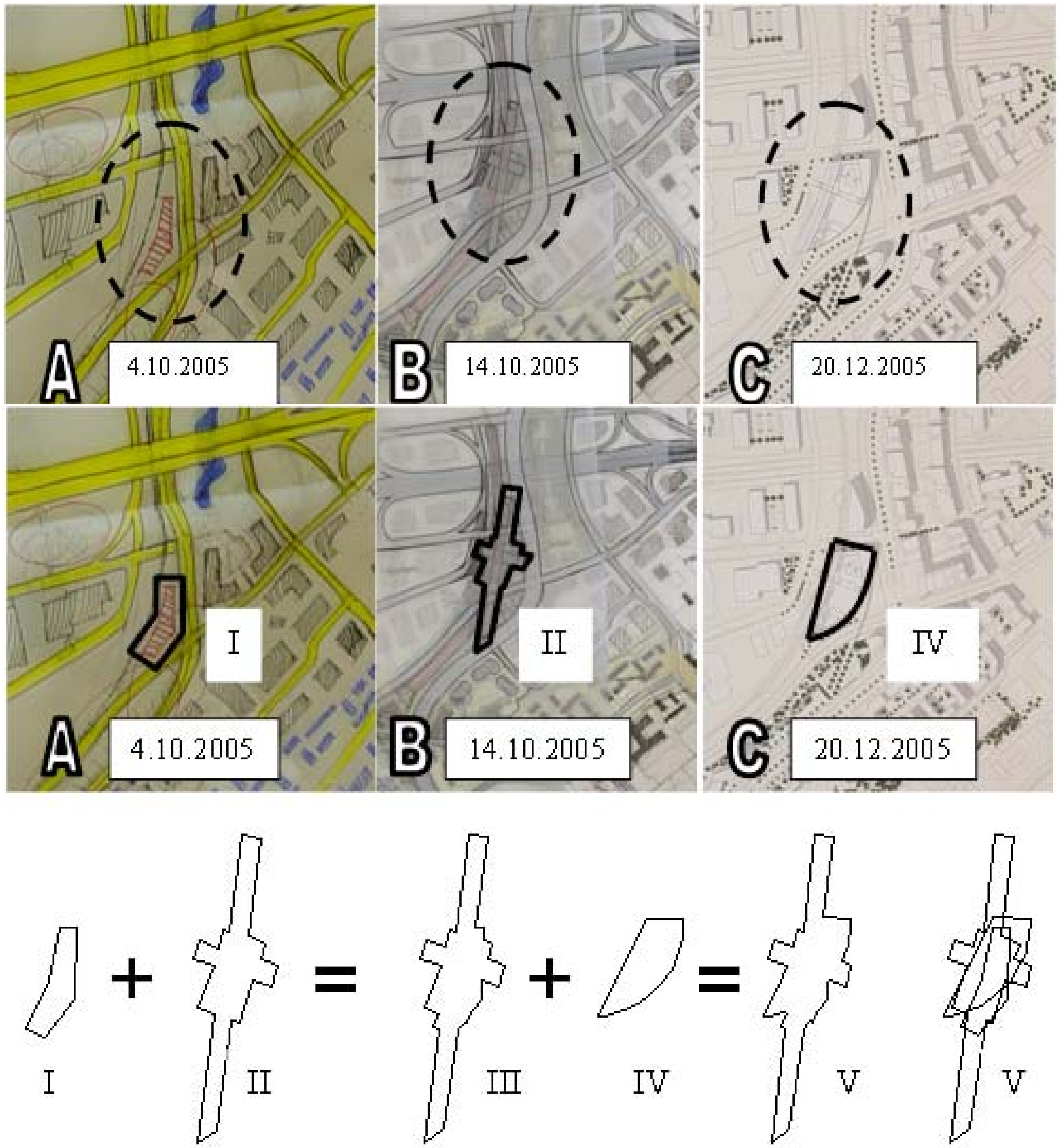

Figure 1: *Dynamic evolution of the shape of the spaces being studied.*
Source : Urban design workshop, School of Architecture and Visual Arts, Laval University, fall 2005.

The constant evolution of the shape of the spaces being studied is usually formalized through sketches that designers substantiate with photos or paper maps. However, as far as designers are concerned, this modus operandi is limited, and neither GIS nor CAD provide them with the flexibility they need. For instance, Goel (1995) asserts that the non-discursive expression of thoughts using the symbolic dimension of sketching must remain hand-generated, since current computer-based representations are not rich enough to produce the same effect.

Finally, spatial representations produced and used for spatial design are most of the time based on qualitative spatial reference frameworks (as defined by Edwards and Ligozat (2004)). That is to say, designers usually provide spatial reference to their thoughts and representations not through using formal rectangular coordinates systems, X-coordinates curvilinear system, or Metric-point linear systems, but through using salient objects and relative positions. This type of spatial reference is not easy to formalize into a GIS, since it is based on a Euclidian view of space (quantitative spatial reference framework). Therefore, in order to adapt GIS to spatial design, it is necessary to move from a surveyor's conception of space to a designer's conception of place . . .

3. Some perspectives: A Leonardo da Vinci approach of GIS

The above observations raise a number of questions. It appears clearly to me that if we want GIS to be really useful to spatial designers, some crucial issues have to be addressed:

- How to make GIS produce spatial representations that would be more open and flexible so as to free the creative process of spatial design?
- Is there any solution to use GIS to formalize verbal spatial representations (with the purpose to support the deliberative process)?
- In keeping with this idea, how could we improve GIS capabilities to ensure the spatial and semantic traceability of the spatial deliberative design process (rapid and constant perspective changes)?
- How to constantly and actively support such perspective changes?
- How to introduce and feed (with GIS) the minimal level of ambiguity required in spatial design? In other words—and focusing on spatial representations—how to move from a "clear and sharp" GI approach towards a "light and shade" approach of GI?
- How to build GIS spatial representations based on non-Euclidian spatial reference systems?
- Considering Public Participation GIS- PPGIS and their new bottom-up evolutions, Volunteered Geographic Information (VGI), how could we feed the spatial design process (which is most of the time local-based) with more efficient and exhaustive local knowledge?

Two demos . . .

1. A dynamic mapping tool built to support and ensure the traceability of urban design deliberative process,

2. Spatially referenced and scalable sketch mapping— Geosketch: a sketch tool for designers, running on Tablet Pc and PDA.

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Spatial Concepts in GIS and Design

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Exploring the connections between spatial thinking and "design" is of particular interest at the University of Redlands as we are actively engaged in curricular activities in both areas. *LEarNing Spatially (LENS)* is our campus-wide initiative that promotes spatial literacy as a foundational component within an undergraduate liberal arts setting. This is the outcome of 10+ years of Redlands' dedication to spatially-related curriculum, research, and programs. *LENS* connects the integrative power of geography with a range of geospatial technologies to visualize knowledge, solve problems, and understand relationships through a spatial lens.

This year we have been challenging ourselves to treat spatial thinking as a subject of its own. The National Research Council's *Learning to Think Spatially* report repeatedly states that all spatial thinking must be "domain specific," that it cannot be taught out of context. Yet it should be noted that such suppositions come from scientists who have never attempted to do so and lack any particular motivation to try, or they are referring to the challenges of transferring one type of spatial skill (mental rotation) between domains. In fact, having spatial thinking be the explicit focus of a course creates opportunities for numerous contexts, in so far as thinking ***in***, ***with***, and ***about*** space are part of our everyday lives. Moreover, while the value of spatial thinking is explicitly recognized within several disciplines (engineering, architecture, mathematics, physics, geology, others), the subject within which spatial thinking is most closely aligned—geography—has paid relatively little attention to this cognitive mode or approach.

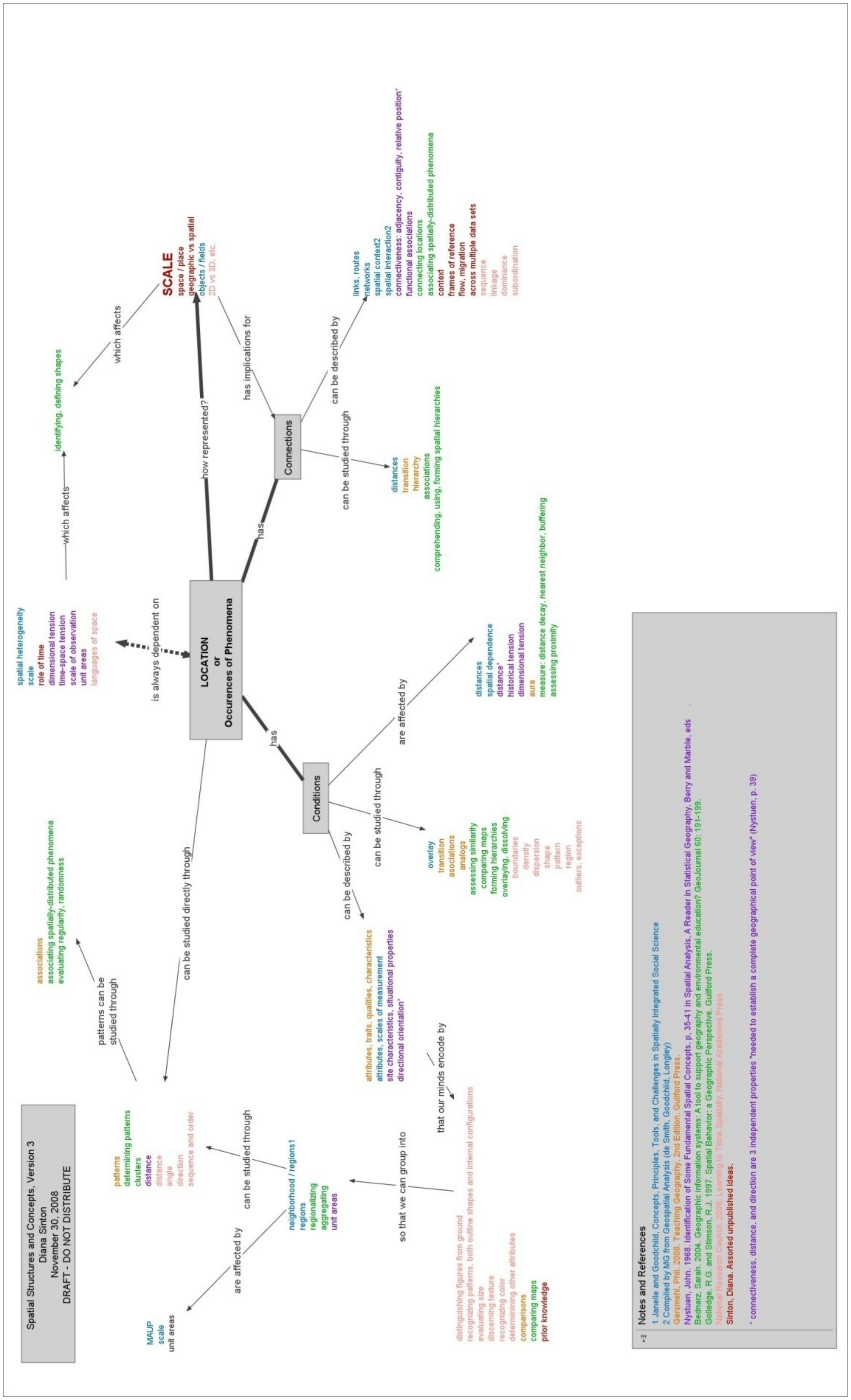
This semester (Fall 2008), I offered an introductory "spatial thinking" class as a First Year Seminar (FYS). Ideas for this emerged from a Summer 2008 Symposium—held at the University of Redlands and co-organized with colleagues from UCSB—during which we brought together academics interested in this notion of an explicit curriculum for spatial thinking. The group recognized important challenges: that no consensus exists about core spatial concepts, despite several enumerations having been suggested, and that the vocabulary itself is problematic. With few exceptions these core concepts are simple English words (location, distance, pattern, etc.), yet each is so loaded with disciplinary connotations that in practice one must carefully unpack the terms to reach a place of common ground.

The notion of common ground among researchers and educators is represented in a sketch that I created for the class (Figure 1). This diagram has multiple uses, but its initial objective was singular: to help students navigate the domain of "spatial thinking" concepts. As a teaching tool, the diagram allowed us to focus on spatial principles exclusively and explicitly. This could be considered "out of context" teaching, and I found that once students were comfortable with the concepts in an extra-contextual sense, they launched themselves back into multiple contexts. We discussed the distances (both geographic and idealistic) that affected the candidates for the presidential election, the patterns of water usage in the West, the experience of proxemics in a newly-shared dorm room, and the spatial strategies that a successful soccer player undertakes. We categorized spatial games, made note of spatially-influenced language, and generated multiple, differently-mapped representations of locations.

For a first-time FYS with a primary goal to "Expand your awareness about the role of spatial thinking in your life and the world around you," we can claim success, but many questions remain and others have surfaced. What kind of differences does a single class make? Should we track these 17 students throughout their college careers to see if any of this knowledge is transferred to their majors, or to their post-college life in other ways? How would we begin to know? If any of these students were now to study GIS or GIScience in depth, would they answer questions or solve problems differently? Because they studied the spatial concepts of distance decay and diffusion, would it occur to them to try to measure the effects somehow? Might they seek out a tool that buffers? Furthermore, in what other ways can we have students exposed to the ideas from this class? Should there be a role for this in our general education curricula and what would it look like?

In addition to the spatially-based curriculum that we are providing at Redlands, we are starting to explore how concepts of "design" could play a different but related role in a liberal arts and sciences curriculum. We know we do not have the type of academic infrastructure that one might typically associate with "Design"—architecture, engineering, planning—nor do we have intentions of beginning those programs as they are traditionally understood. Instead we are focusing on a broader interpretation of "design," connecting it with liberal arts foundations of psychology, philosophy, art, and perhaps geography. If the best schools focusing on design are graduate ones, what would make the best type of undergraduate preparation? Liberal arts students are expected to **read critically**, **write critically**, and **think critically**. The graphicacy component of our *LENS* curricula adds **view critically**. Now, if "Design is the thought process comprising the creation of an entity" (Bill Miller, 2004), could we design a curriculum that leads students to **create responsibly**? For example, how can we best prepare our students to create sustainable communities? Would it involve exposure to spatial thinking and spatial concepts? What role can we count on GIS to play?

Figure 1. Sketch of Spatial Concepts.



On Scale and Complexity and the Needs for Spatial Analysis

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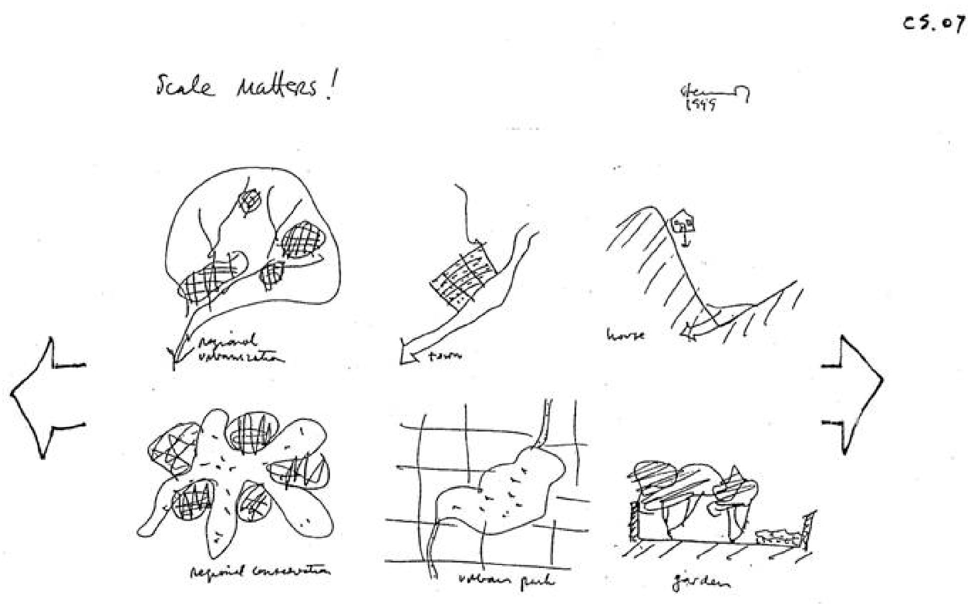
First, I thank the organizers of this very special conference on design and GIS for inviting me. The best definition of "design" is that of Herbert Simon.

> **"Everyone designs who devises courses of action aimed at changing existing situations into preferred ones"**
>
> **Herbert Simon**
> **The Sciences of the Artificial**
> **1968**

I come from a professional culture in which I began as an architecture student in a School of Architecture, I then studied city and regional planning and urban design, and I have taught in a landscape architecture department and organized landscape planning studies for more than forty years. Working at a territorial scale—in which algorithmic thinking and spatial analysis are essential—is, in my opinion and in my experience, very different from what is taught to and practiced by most designers. I want to discuss the implications of scale and complexity, two themes that differentiate design activities and their needs for spatial analysis methods. In doing so, I will purposely sharpen contrasts that are really more subtle and frequently mixed.

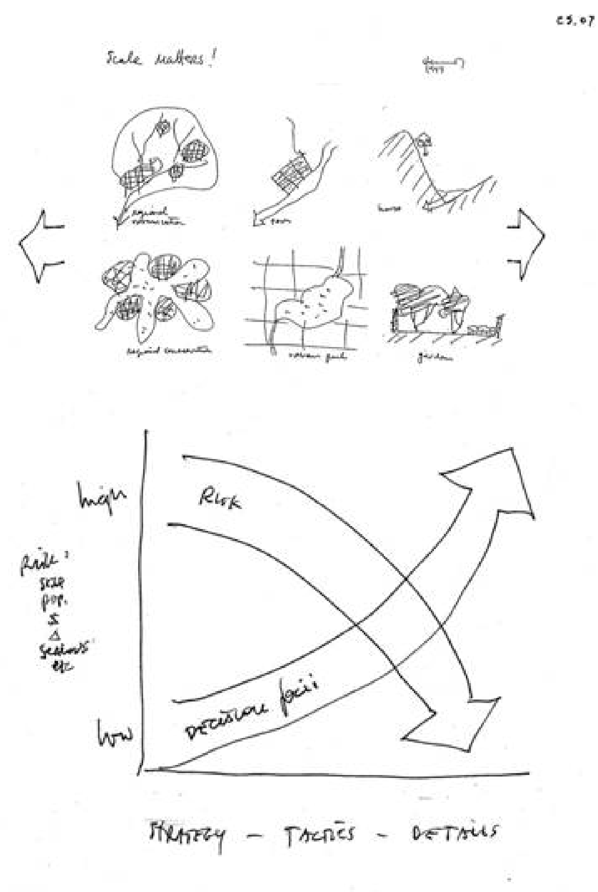


"Many devices which work on a small scale do not work on a large scale."

Galileo

Scale matters, and Galileo was right. Many methods, many processes, many ideas that work at one scale, don't work at another scale. My school has architects, landscape architects urban planners and designers. We have a studio-dominant culture, and there are different scales of "problem." Most students' studio sequence starts small and gets larger and more complex but does not include the full range of scales. Problems dealing with the landscape include placing a building on a difficult site, designing a garden, and then designing an urban complex in a difficult ecology, or a large urban park. Most students who think about the landscape stop at what can still be considered "project scale." They stop at the scale where the assumption is that you have a client, a site and a program and eventually something will be built. Relatively few students, the ones who work with me at the end of their studio sequence, think about regional scale urbanization and regional conservation.

There are many people in the world who think in the other direction, from large to small. Geographers, cultural historians, hydrologists, geologists, ecologists, political scientists, and even lawyers and bankers, tend to see things and work from large to small and they almost never get to the details so important to architects and landscape architects . The question is: what is the lens through which we should look at the problem. I'm interested in the larger scales. I have spent a long time working at the territorial scale, and sometimes I get to the project scale but I stop before the details. I tend to think from larger to smaller.

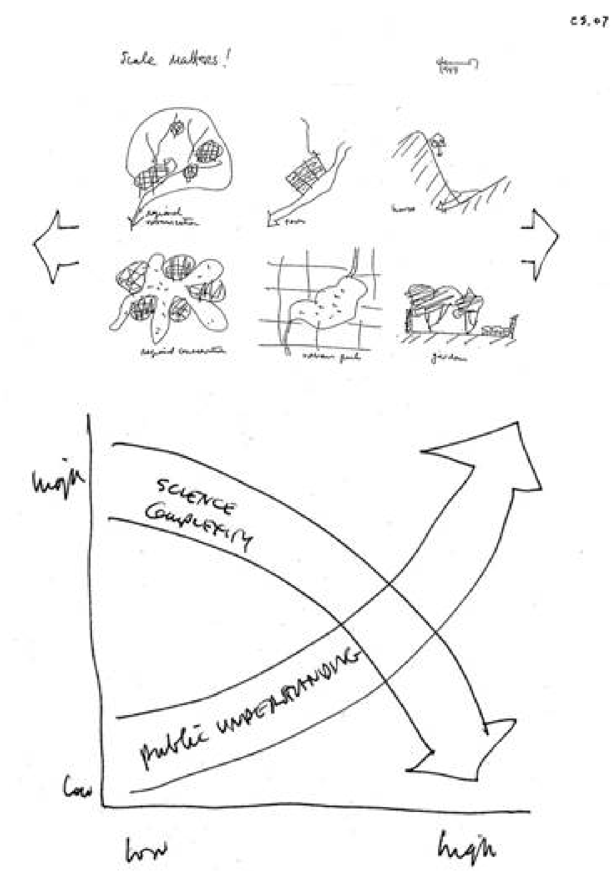


The focus of design decision changes with scale. At large scale, you are dealing with strategy, at middle scale you are dealing with tactics and at small scale, you are really dealing with details, and here the details do matter.

The wise school mixes scale-direction, but must recognize that there are real differences at the extremes of these two scales. At the large scale, if you make a mistake or decide something badly, you have a very high risk of harmful impact. The concept of risk dominates working at this scale. You want to minimize it. Why? Because the landscape is big, it has lots of people, lots of money, lots of change, and the larger decisions are very important. The benefits can be great, but the risks are serious.

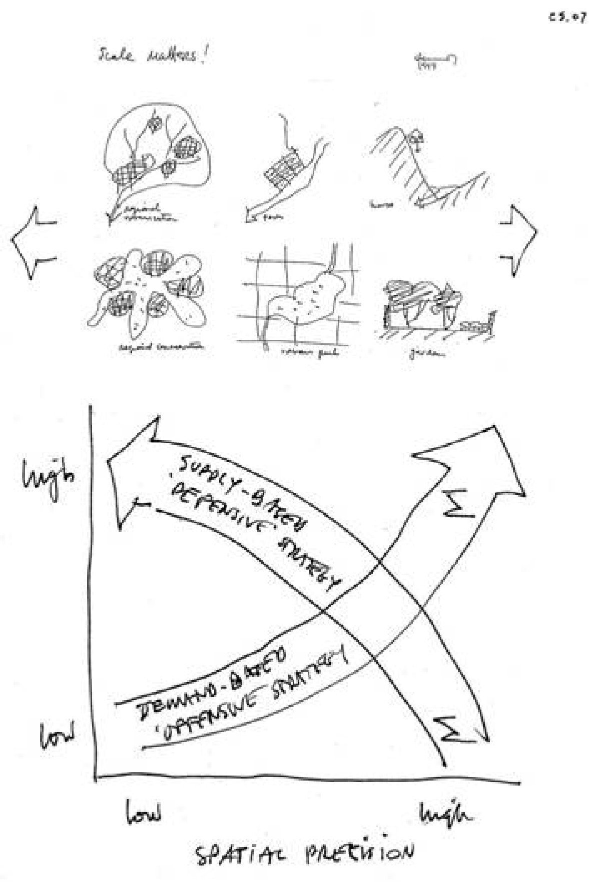
As you go to a smaller scale, the risk goes down: I don't care so much if my neighbor has a modern house or a baroque garden. What's the risk to me? However, I do care greatly if I don't have drinking water. That's a very important risk. The greater the risk, the greater the need for serious analysis, and this is much more a need as scale-related risks gets larger.

Minimizing social risk, economic risk, ecological risk, etc. makes a landscape plan essentially defensive. Here, the design processes emphasize "allocation," deciding what goes where or where not. At a municipal or large project scale, it is more decentralized, with different professions, different neighborhoods, and different clients all coming together. At large project scale the design emphasis is on "organization," how different elements relate to each other. At small project scale, the emphasis is more on "expression," what does it look like, what does it feel like. These are very different.

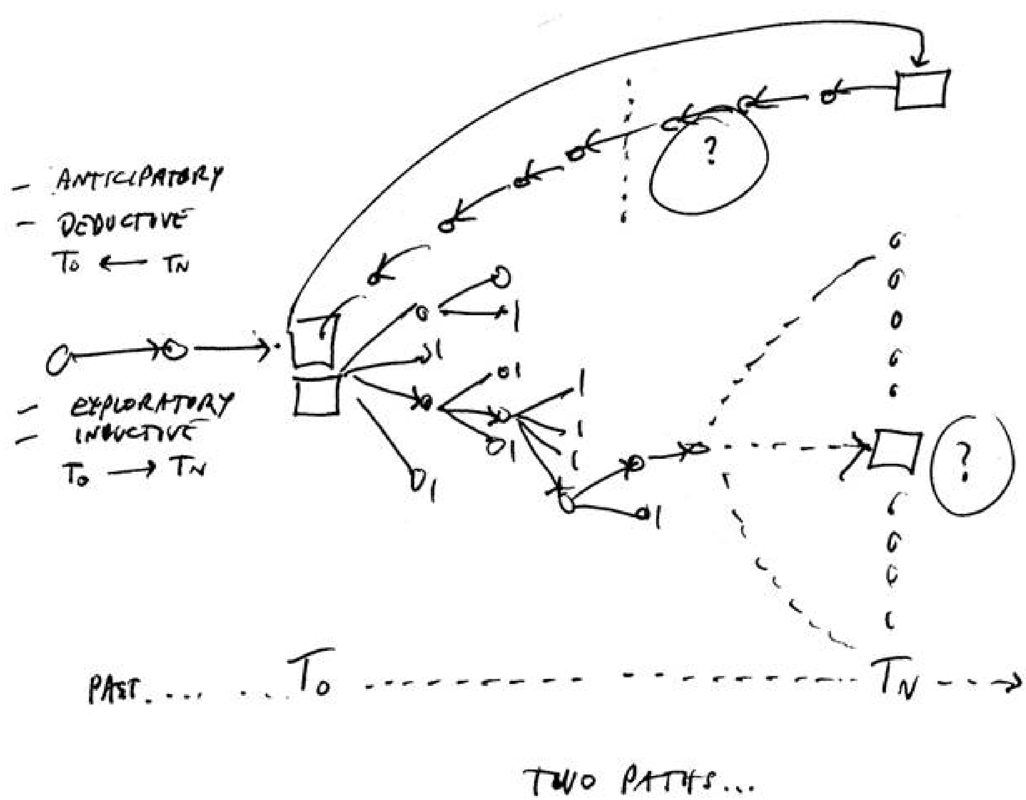


At large scale, you must have a high reliance on science; and you must have a much more complicated formal strategy. At the larger scale, the idea that you can make a simple "design concept" diagram and really see it on the ground is foolish; it doesn't work. At this scale, however, you must have much more public understanding, and this is not easy. At large scale there is no single well informed "client." At small scale there usually is. People normally understand their own house, they may understand their neighborhood; they usually don't understand their city and they surely don't understand their regional problems. In a democracy, informing the public requires clarity and transparency in both assessment and presentation. There is necessarily a difference in roles between experts and the popular will in decision-making.

As a result, at large scale, landscape decisions are made by experts and elected people and unelected people. Elected people are the people who you vote for, your government. Unelected people are the heads of banks and development companies who make planning decisions. These larger decisions are not normally made by popular vote. However, at small scale, everybody makes decisions.



As the spatial scale gets smaller, you have more of a demand-based strategy. What I mean by that is that a client says, "I want something!" You happen to agree and you do it. It is based on demand; it is based on the push of the market. At large scale, it is more supply-based and defensive: you have to understand the landscape, you have to understand the cultural values, you have to establish priorities, and then you do have to defend them.

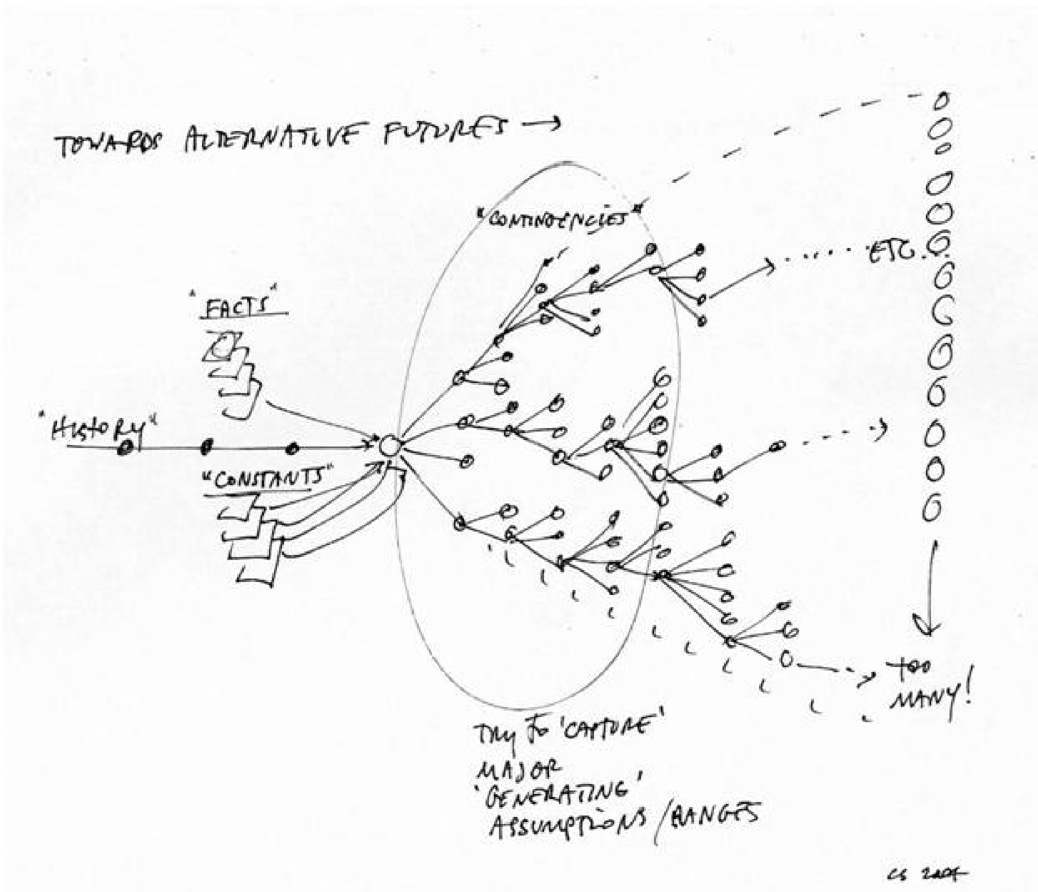


There is another important complication related to scale. There are two fundamentally different ways to make a design. (I am purposely making this contrast, fully aware that the two ways are frequently combined). The first way is anticipatory and deductive. You are sitting in the middle of the night, at your table, and you have an idea. And you see the future. You see the future, and then you have to figure out how to get there. Every designer has had this experience, likely many times. You have thought about the problem and you see the solution, and then you have to figure out how you get there, and you almost always fail. It's hard!

The other way is explorative and inductive. You basically put together a set of issues and choices—a "scenario." A scenario is a set of assumptions and policies that guide you to the future. There are basically two ways to navigate this I scenario chain. In the first and typical way for designers, one goes "out" as far as one can, and recycles back when confronted with a design "problem." You decide to do this and this and this . . . .etc. The second way is to simultaneously test several different scenario combinations and systematically compare them before proposing a solution. You realize that you could do this, this or this, let's suppose I do this: I then can do this, this or this; let's suppose I do this, this one, or maybe I should have done this way . . .

And either way, you almost always fail, because a typical large plan might have a sequence of 20 to 50 important decisions. And if you can make 20 correct decisions in a row, you should be a gambler in Las Vegas. That's why you frequently say, I've done enough, I don't care what color the carpet is. It's normal. It is a function of scale, of the lens through which you assess the problem and its solution.

At small scale the deductive method is absolutely appropriate. The history of architecture and the history of landscape architecture are full of examples. The idea—let's make a white garden, let's make a round building—these are appropriate inspirations. But at large scale, the inductive methods are better. Why? Because if you make the wrong decisions in the beginning you, have created the likelihood of a very high risk. Early, high risk choices require the most serious assessment methods.



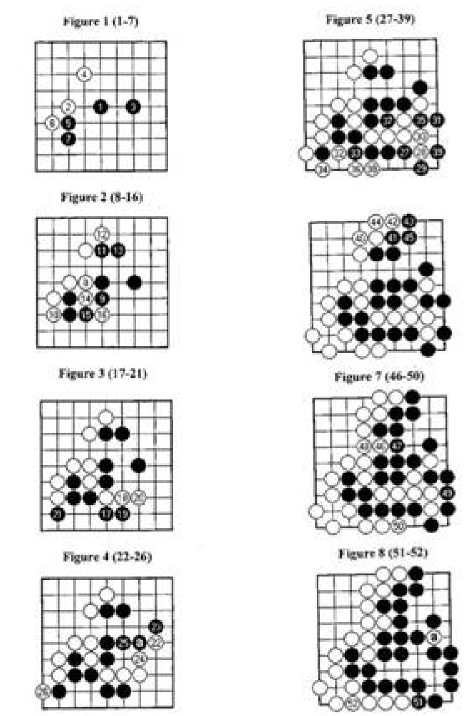
In making a design at large scale, you have four fundamental considerations. One of them is "history." You must know the history of the place, and especially the history of the plans for the place. I have never in my life worked in a place that didn't already have past plans. And the people who made them were not stupid.

The next things are "facts." Facts are things that will not change in the life of your own plan and your own study. I might work towards 20 years or 30 years in the future, and the bedrock geology is not going to change (if is not volcanic).

Then there are "constants," which are the things that are going to happen during the course of your plan. You must find out about them, because if you don't, your plan will never be implemented.

And then there are the "contingencies," the things that could happen, and here it is really important to capture the major generating assumptions and their alternative choices. You have to be able to say: either here, here or here. The beginning assumptions in the scenario "chain" are the most important because if you make the wrong first steps, you will end up wrong. If you make the right first steps you still may end up wrong but you have a better chance.

An example game of Go



The good learning tool (for design AND spatial analysis) is the Japanese game of GO. In GO, the first moves tell you a lot about what the territory will look like at the end, and it is very good training for designers, especially at larger scales.

My second theme, complexity, interacts with scale. It represents the level of complexity that the analytic methods underpinning any design must achieve, especially in its understanding of process models. I think that there are six questions which must be asked in any design problem and at any scale. They are:

How should the state of the landscape be described in content, space, and time? This question is answered by representation models, the data upon which the study relies.

How does the landscape operate? What are the functional and structural relationships among its elements? This question is answered by process models that provide information for the several assessments that are the content for the study.

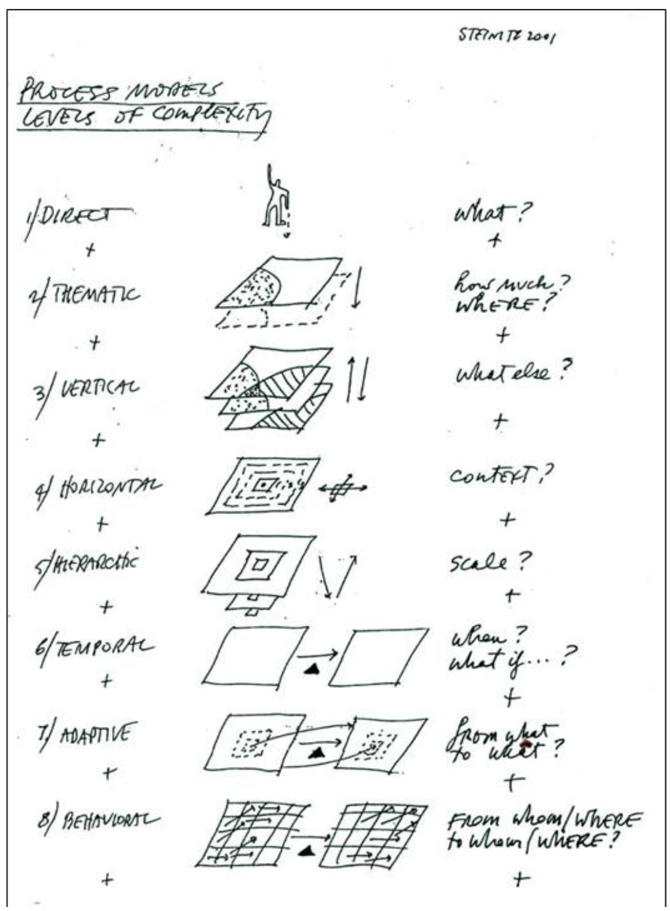
Is the current landscape working well? This question is answered by evaluation models, which are dependent on the cultural knowledge of the decision-making stakeholders.

How might the landscape be altered, by what policies and actions, where and when? This question is answered by the change models that will be tested in the research. They are also data, as assumed for the future.

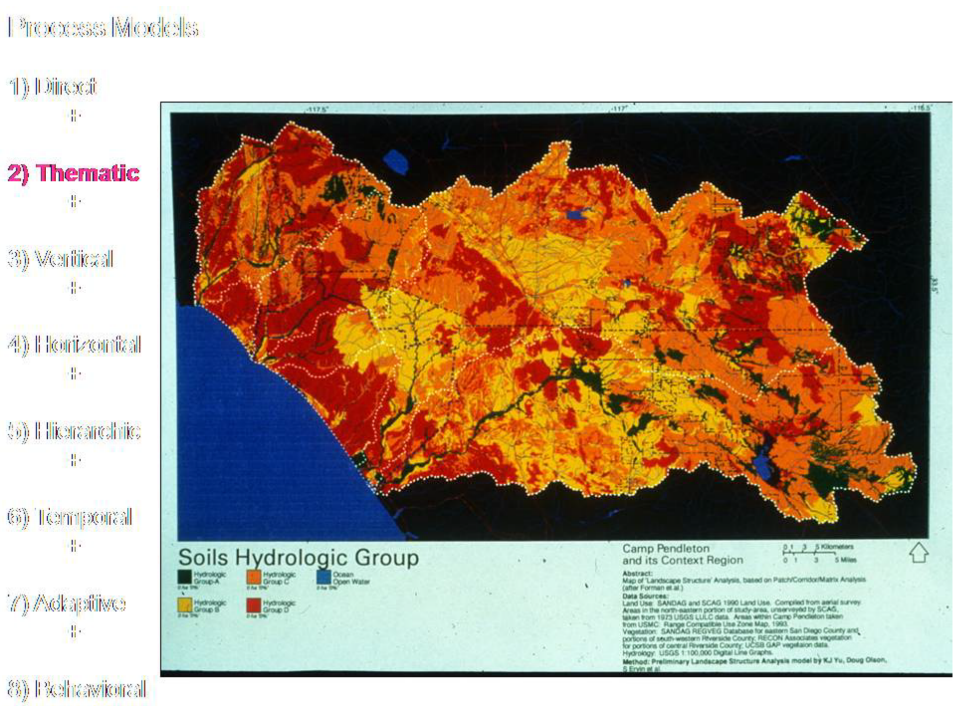
What difference might the changes cause? This question is answered by impact models, which are information produced by the process models under changed conditions.

How should the landscape be changed? This question is answered by decision models, which, like the evaluation models, are dependent on the cultural knowledge of the stakeholders and responsible decision-makers.

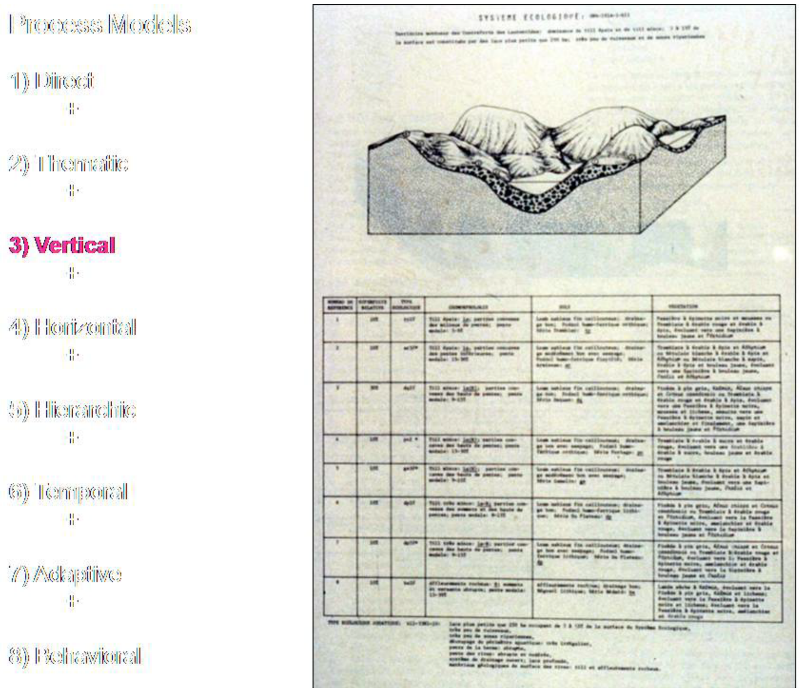
I believe that there are eight levels of analytic complexity associated with process models. Each of the eight levels is organized to answer a cumulatively more complex set of questions. I think that the larger the scale and the consequent greater risk, the more the analytic methods should aim to achieve more complex levels. The smaller the scale and less the risk, simpler analytic levels may suffice.



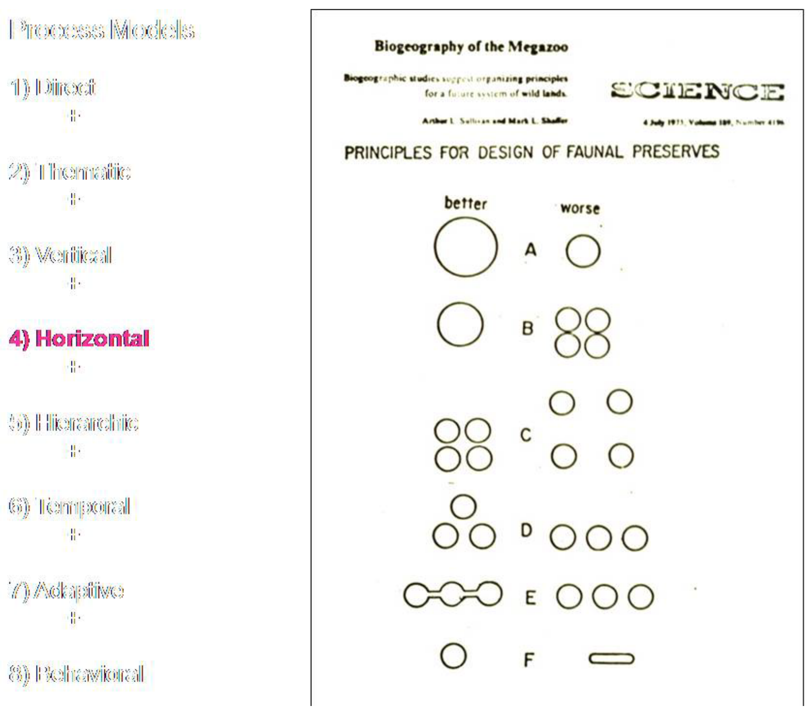
Direct models ask "What is here?" They are based on direct personal experience. If your feet are wet, don't build here.



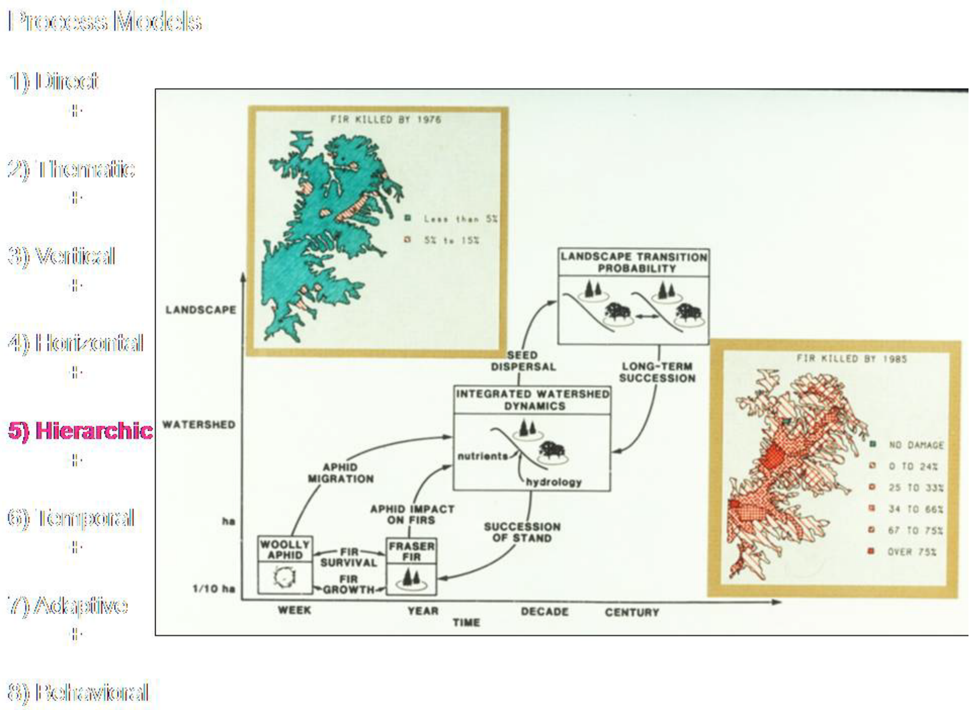
Thematic models add "Where and how much?" The example is a soils map from the region of Camp Pendleton.



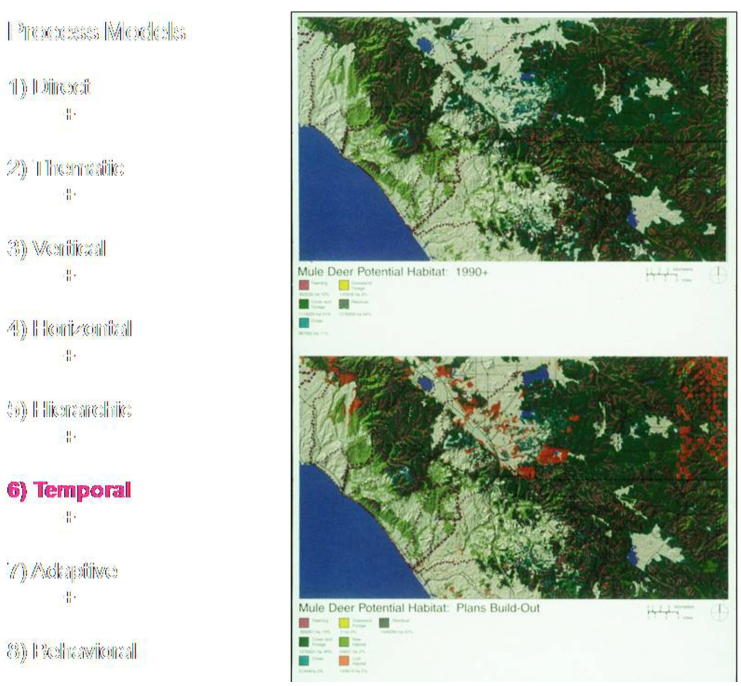
Vertical models add "What else?" They are normally seen vertically, such as this example which relates geomorphology with soils and vegetation productivity.



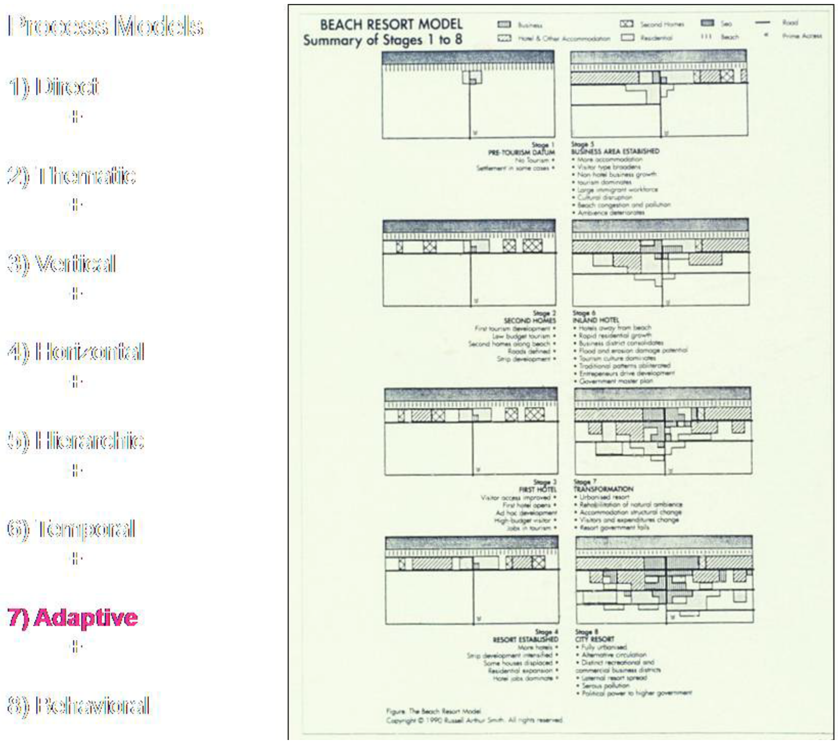
Horizontal models add "What size and shape?" In this example from Sullivan and Schaeffer, it is better for a faunal preserve to be large than small, one large than many small, compact than spread, etc.



What happens at different "nested scales?" In this example from Virginia Dale at Oak Ridge, different phenomena related to aphid infestation in the southeastern pine forest are investigated and related at their appropriate scales.

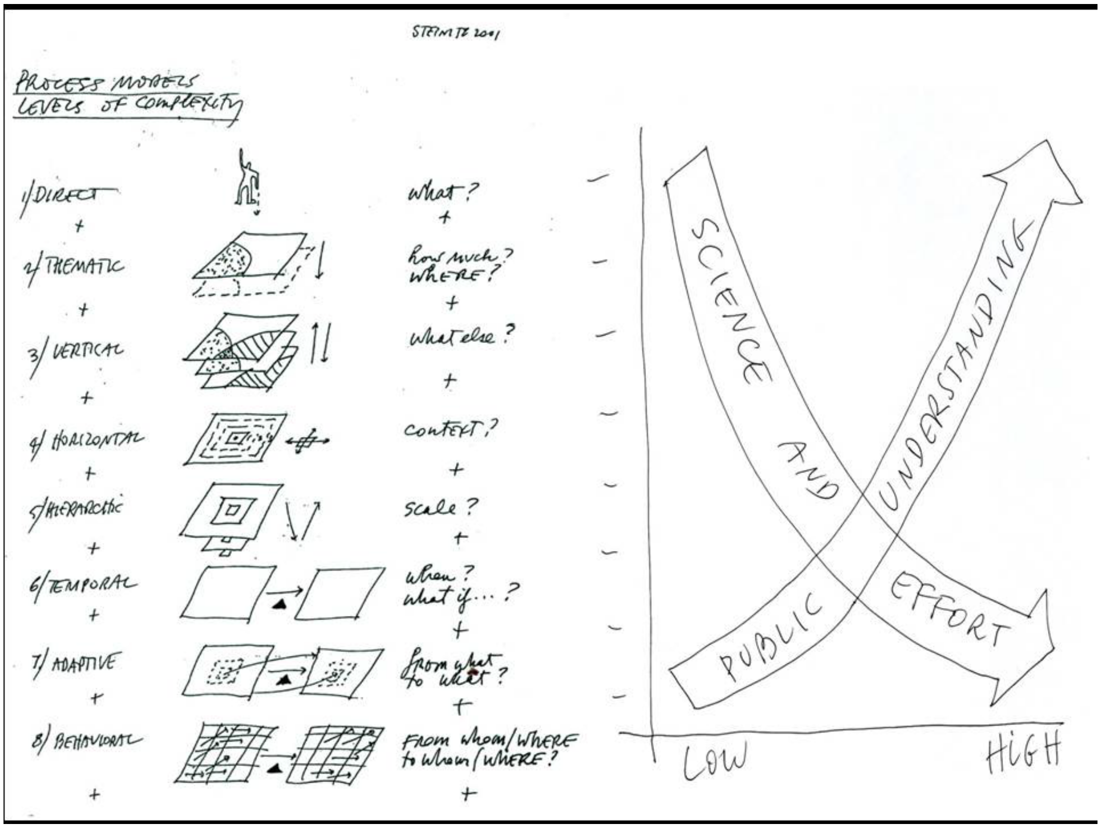


Temporal models add "What if . . . and when?" In the example, mule deer habitat change over a thirty year period is projected for the region of Camp Pendleton.

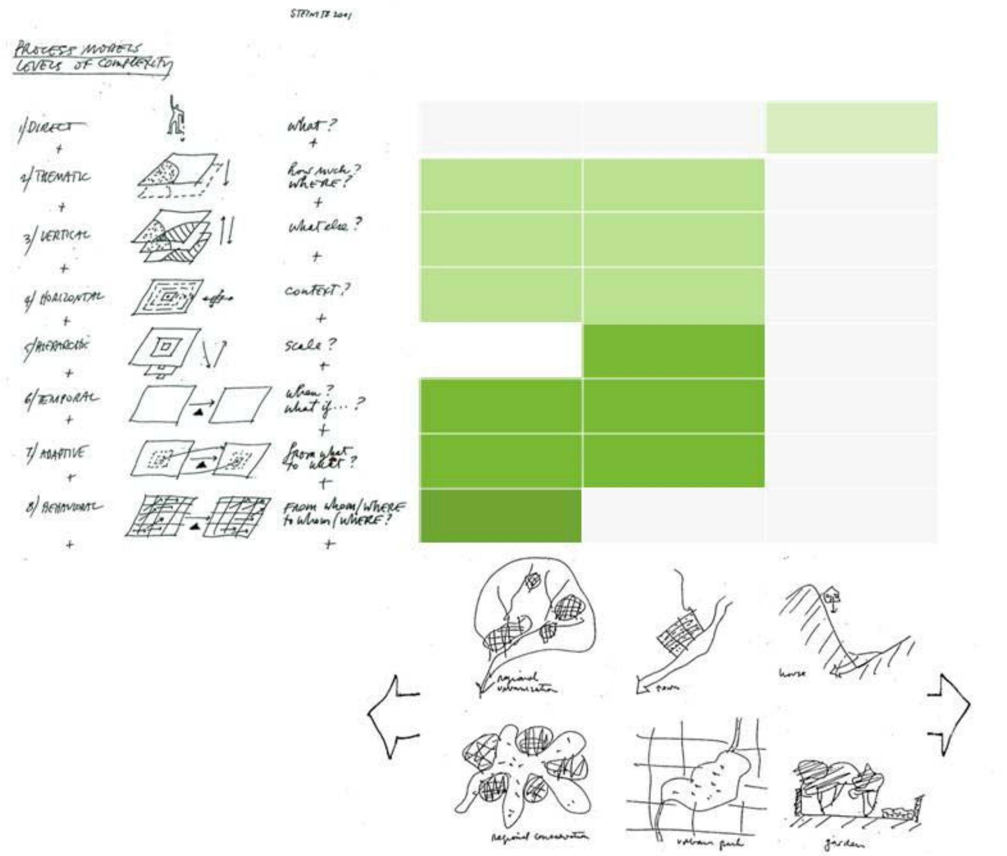


Adaptive models add "From what and where to what and where?" This example is Russell Smith's eight stage model of the transformation of tropical beach resorts.

Behavioral models add "From whom and where and when to whom and where and when?" The example is Michael Flaxman's fire progression model, which accounts for hazard and fire management strategies.



Finally, the "bottom line"—What are the spatial-analytic needs of "designers"? It all depends on scale and complexity. There cannot be one answer. At its simplest, and frequently at smaller scales, the direct personal experience of the designer may be sufficient, and without ANY formalized analysis. At the other large scale extreme, it will frequently require a very complicated and costly effort, and yet it also may suffer from a lack of public understanding. Answering this dilemma and deciding on the appropriate methods and their level of complexity requires judgment and experience . . . there is no other way at this time.



However, there is a potentially important research study which can derive from this situation. There are many models of processes such as erosion, hydrology, forest succession, traffic, air pollution, noise and visual preference. Comparing the efficiency and efficacy of process models across scales and levels of complexity might result in a better understanding of which combinations are the most appropriate fit for any design problem. This comparative research, and the resulting ability to categorize the applicability of the many analytic models which already exist, would be a significant step towards the theme of this conference. It would certainly help the very broad-ranging community of “designers.”

“It is the mark of an instructed mind to rest satisfied with that degree of precision which the nature of the subject admits, and not to seek exactness where only an approximation of the truth is possible.”
Aristotle

“Be as simple as possible, but not more so.”
Albert Einstein

From "GIS for Design" to "Design for GIS"
Preliminary Thoughts on Designing a Curriculum for Spatial Thinking

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1. GIS for Design: To what extent are the fundamental spatial concepts that lie behind GIS relevant in design?

The fundamental spatial concepts that lie behind GIS, such as location, distribution, neighborhood, scale, etc., are highly relevant in design–at least the landscape level. As demonstrated by Silbernagel (2003), the spatial concepts (such as composition, interspersion, and edge) embedded in Leopold's conservation design principles are quite compatible with those implemented in GIS. In fact, the development of GIS during the formative years was driven by a group of pioneers who were trained as landscape architectures and designers (Chrisman, 2006). Ian McHarg's manual overly technique, widely used in landscape design practices before the birth of GIS, provides the conceptual inspiration for the various versions of overlay functions in GIS, and is still the standard fair in core GIS training today. Because of this cartographic heritage rooted in landscape design, spatial concepts in GIS are quite relevant and compatible to certain design tasks, especially at the landscape level.

However, design is a much broader field than the pursuit of multiple map overlays at the landscape level. When we think about issues in architectural or industrial design or design problems in different domains (such as design of web sites or algorithms), I believe that the relevance of spatial concepts in GIS for design is rather limited for two reasons: (1) Spatial concepts beneath the field and object views of space as implemented in GIS are still rigidly defined by Cartesian coordinates following the axioms of Euclidean geometry, which may not necessarily be ideal for addressing many issues in design practices. The current generation of GIS is still unable to process data using spatial concepts as defined by non-Euclidean geometry; (2) The current GIS user-interface is not designed in a way that engages users in creative design processes. Some recent advances, such as the concept of a second earth (combination of Google Earth and Second Life) are changing the situation (Sui, 2008).

2. Design for GIS: To what extent can the fundamental spatial concepts of design be addressed with GIS?

I know at least two previous efforts by designers that try to engage the geospatial community with a focus on the convergence of design and mapping–The 2002 Yale Symposium on Mapping in the Age of Digital Media (Silver and Balmori, 2003) and the edited volume by Janet Abrams and Peter Hall (2006) on "Else/Where: Mapping new cartographies of networks and territories." From these two earlier efforts, it seems to me that more and more designers have come to realize that the process of design has been increasingly converged with the process of mapping.

Since the most important end product of GIS operations is maps (among many other things), not surprisingly GIS has been used for addressing issues related to design from a mapping/visualization perspective. More precisely, these efforts reflect the trend of growing efforts of using space/place as a metaphor to map/visualize non-spatial data –a process known as "spatialization" within the geospatial community (Skupin and Fabrikant, 2003). As demonstrated by both GIS researchers and designers, lots of interesting work have been conducted following the "spatialization" tradition. My concern is that "spatialization" implicitly assumes that we can translate any design problems or non-spatial data into a Cartesian coordinate system as defined in Euclidean geometry, which does not necessarily have adequate ontological or epistemological justification. Gunnar Olsson (2007) warned the danger of committing such a fallacy dictated by pure cartographic rationality.

If not all the fundamental spatial concepts of design can be adequately addressed with the current generation of GIS, it seems to me that one viable path to move forward is to consider and discuss the following question during this meeting: to what extent the fundamental spatial concepts of design can be used to facilitate the development of GIS? I believe many fruitful results can be achieved if we pursue this route of research. Spatial concepts embedded in the design process are quite diverse and some of them are not necessarily Euclidean in nature, but I believe many of them are relevant for GIScientists to rethink about some of the fundamental issues GIScience. Just like Ian McHarg's spatial concept in design inspired the development of GIS as we know it today, a quite different GIS may be developed if the fundamental spatial concepts were grounded in, let's say, Kevin Lynch's work. Several researchers have demonstrated the potential of using Lynch's conceptualization of space to develop GIS (Banai, 1999; Al-Kodmany, 2001; Stevens, 2006).

Generally speaking, fundamental spatial concepts in GIS are rather narrowly defined, only reflecting a fraction of the vast human spatial experience and conceptualization (Sack, 1980). In contrast, spatial concepts embedded in the diverse design practices are rather fluid, open, imaginative, and even emotional (Jenks, 1997; Puglisi, 1999; Norman, 2004), which can be a new source of inspiration for developing future GISystems and GIScience. I think the key issue is how to transform GIS from being an analytical tool for problem-solving to becoming a more creative tool for design and creation. For example, Corner (1999) proposed four thematic ways of realizing mappings' projective/creative capacities by drawing on diverse design practices, which may be used as a springboard for us to think about developing a versatile GIS:

- *Drift:* where mapping acknowledges open-ended, even goal-less, movement across space;
- *Layering:* which superimposes spatial elements and experiences, less exposing than intervening imaginatively in their inter-connections;
- *Game-board:* which recognizes and enables the actions of contesting agents across a design space;
- *Rhizome:* realizing graphically the metaphor of non-centric, organic spatiality.

Instead of McHarg's concept of overlay, we need to develop a new GIS that is capable of performing design tasks that are related to drift, layering, simulation (game-board), and rhizome.

3. Thoughts for a New Curriculum: Developing spatial thinking in both GIS and design

Designers have recognized the crucial importance of spatial thinking in their curriculum (Dillion et al, 2003). The common thread for a new curriculum that stimulates spatial thinking in both GIS and design will be a renewed emphasis on creativity–one of the defining characteristics for future minds (Gardner, 2006). We need to develop a new strategy that transcends disciplinary boundaries and motivates students to think critically about the dynamic relationship between space, time, and our social practices. I have argued else where some time ago for a more humanistic GIScience in the context of the emerging third culture (Sui, 2004, 2005). The core argument is that so far, the development of GIScience has been squarely grounded in traditional science and engineering. The next phase of GIS research and education should be broadened and involve fields in arts and humanities, especially the diverse, creative design practices. Humanistic GIScience attempts to integrate multiple, alternative human conceptualizations of space and time with the key issues related to spatial data representation, analysis and visualization. Instead of emphasizing accuracy by trying to minimize or eliminate uncertainty, humanistic GIScience adds the human subjective and imaginative dimensions of experience to facilitate the processing and understanding of the world.

Artists' renditions of the world–real and imagined–in novels, poems, paintings, movies, music and songs can be rich sources of inspiration for GIScience researchers and students exploring alternative conceptualizations of space, place, time, environment, region and scale. In addition to the common representations of space framed by Euclidean geometry, humanistic GIScience is attempting to find novel ways to handle the textures of place as articulated in the humanistic tradition as well as the structures of space. As the quest for new means of analysis and modeling via computers has been increasingly intertwined with the persistent search for deeper meanings of such activities, we can reasonably expect more synergistic activities between GIS and design for both research and education.

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Linking Space and Place: A Methodology for Geospatial Design

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In this paper, I consider the practical applications of linking the design of the human realm (built environment) with geospatial technology. This includes the development of tools for spatial decision support, tools that integrate design with scientific knowledge and evidence, and tools that allow users to examine the outcomes of decisions in a spatiotemporal context.

Design in the human and urban realms is intrinsically spatial. Integration with geospatial research involves structuring the analysis and presentation in terms of spatial layers, where design interventions are generated through an exploratory, interactive process, turning layers on and off and varying spatiotemporal scale to generate design alternatives. This increases the ability to make design options—their consequences and tradeoffs—explicit and meaningful.

In its current mode, design in a spatial context is hampered by the following:

- Non-spatial information applied to resolving design issues that are inherently spatial
- Failure to capitalize on local knowledge and deep understanding of spatial environments
- Failure to adequately resolve design trade-offs, especially trade-offs concerning spatial knowledge (example: introduction of increased density, which can vary by spatial context and spatially-derived capacities)
- Focus on green building technologies that are often aspatial and don't adequately consider spatial context and other locational information (e.g., "green" Walmarts analyzed apart from implications of their spatial context)
- Models and methods are for flat and static maps

Geo-spatial design could help resolve:

- How to combine objective data with contributed information (local, vernacular knowledge); how to capitalize on user-generated knowledge
- How to integrate 2-dimensional and 3-dimensional data more seamlessly and in a way that responds quickly (on-the-fly) to proposed design interventions
- How to use geospatial research/technology to stimulate better-informed public debate that incorporates design trade-offs and integrates spatial knowledge
- How to improve dynamic support tools that incorporate visualization in spatial contexts and in the public decision-making arena
- How to better integrate design interventions proposed at different spatial and temporal scales. A geospatial approach facilitates design at a range of telescoping scales. For example, there are large scale design issues involving entire regions, and small scale design issues involving single urban spaces. Urban design issues range from the more general to the more specific, and the range of applicable design elements and strategies vary by spatial and temporal scale. These variations need to be treated in a more integrated way.

The following areas illustrate the kinds of geospatial design topics that need to be pursued:

- Delineation of the spatial boundaries of neighborhoods with social, cultural, and economic meaning. Neighborhoods within a regional framework may have or require spatial delineation (size, shape, centrality).
- Refine spatial strategies for promotion of local means of production (of food, for example)—the application of which varies considerably by spatial scale.
- Refine analytical methods that organize and preserve the integrity of different types of urban and rural environments, varying along a continuum that ranges from less intensity – rural – to high intensity – urban.
- Analyze strategies for increasing connectivity, such as those that constrain or promote passive social and economic contact. Incorporate variation by scale, type of route, and destination.
- Analyze the geographic centrality, extent, and boundedness of urban population sub-groups and the relationship to design concepts and strategies with social, cultural and economic meaning.
- Identify the spatial extent of urban edges, their positive role as spatial delineators, and the interventions that could mitigate their harmful effects.
- Evaluate spatial proximities as a means of social justice; investigate spatial accessibility as a method for improved jobs/housing balance.
- Evaluate land use diversity and associated design interventions that support and enhance sustainable social and economic mix at different spatial scales.
- Evaluate spatial proximities and propose design interventions that increase desirable proximities and decrease negative ones.
- Analyze the spatial context of density and how it varies in intensity, opportunity, and effect depending on a range of two and three dimensional variables.

Spatial Delphi: Geo-Collaboration and Participatory GIS in Design and Planning

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One of the fundamental aspects that is rapidly changing in design and planning is the process itself by which designs are generated and developed. In this transition, the design process itself—rather than its output—is becoming the focus of design and planning products. This is particularly true in those design and planning challenges at the larger city and regional landscape scale, which my position refers primarily. This change supposes fundamental transformations in which the "designer agency" is expanded to incorporate new actors and players, which must be able to manipulate, interpret and propose spatial concepts. In this regard, the product(s) of design processes is also reformulated and reinterpreted to accommodate a new set of values. The intention behind those new design and planning products is to become more dynamic in order to accommodate emerging and rapidly changing values, circumstances that characterized our constantly changing societies and environments. I argue through this position paper that this transformation provides an important opportunity to generate, reformulate GIS with design and planning.

There are two fundamental conditions that I consider to be aligned and which can propitiate a necessary tided-coupling between design and GIS. First, there is an established awareness of the increasing complexities designers and planners deal with today and the inefficiencies of traditional tools, methods, and ultimately education have in assisting the generation of robust solutions. This awareness comes from a renew alignment and emerging re-established relationships of design and planning to fields such as ecology, geography, energy, and phenomena such as the global market economy and climate change. It represents a reaction to the recent claim made by design disciplines on the larger territorial subjects traditionally associated with geography and planning (Waldheim, 2008). In this regard concepts of adaptive management and complex systems are invading the vocabulary of designers and planners and serve as evidence to new dimensions of the design agency.

Second, there are the demands placed on design and planning by the changing relationship between governments, the market and civil society, which demands new social and professional processes by which design is approach and solutions are developed. This indeed has resulted in the ultimately displacement of "inter" and "multi"-disciplinary approaches to more democratic and enfranchising "transdisciplinarity" approaches. Processes that are today rapidly institutionalized from global multi-lateral institutions to local policy agencies. Under the transdisciplinary model, planning may become more integrated with research, enabling the multidimensional challenge of sustainability to be understood more rigorously with many disciplines involved, and the public (i.e., stakeholders, elected officials) are similarly involved in planning and decision making.

In summary the "knowledge base" designers and planners must employ to develop their propositions have be expanded while processes to synthesize knowledge—for the basics of efficiency and clarity—have increased in complexity. This has occurred by incorporating a number of new players in the design process which spatial thinking and synthetic capabilities need to be recognized.

My position—based of the conditions previously mentioned—argues that one of the most important aspects for the integration of GIS in design and planning is the support of spatially-explicit collaborative and participatory design processes. I suggest that in order to accommodate the emerging complex systems nature of design problems and the transdisciplinary demands place upon the new design agency, we need to incorporate the concept of "Spatial Delphi." Spatial Delphi suggests a model for more collaborative and participatory design practices which is examined and instrumentalized through geospatial systems and technologies (GIS). The Delphi method[1] is based on the assumption that group judgments are more valid than individual judgments. Participation in this context entails integrating a variety of stakeholder positions into the design and planning processes to propitiate more democratic and inclusive solutions aiming to integrate their vision and knowledge into decision making.

While it is recognized that participatory-based design and planning approaches have considerable advantages over traditional planning and design practices, they by definition require the participation of a diverse group of citizens and other agents, many without scientific, design or physical planning background. These conditions place a challenge as well as an opportunity to re-conceptualize the integration of spatial concepts to a wider group of users. In particular, citizens, non-governmental organizations and firms have become more and more critical and self-confident in defining their needs, ideas and wishes, which in turn contributes to the growing complexities of spatial planning and design and the increasing amount of information that need to be processed (Van Den Brink, Van Lammeren, Van De Velde, Dane, & (eds.), 2007).

Through my research I have explored some of the conditions laid out earlier in the paper which I consider representative of participatory and collaborative Spatial Dephi. In particular I developed during my doctoral dissertation directed by Carl Steinitz at the Harvard University Graduate School of Design, a framework that integrates participatory planning methods

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[1] The Delphi method was developed at the beginning of the cold war to forecast the impact of technology on warfare (Helmer & Dalkey, 1999). In 1944, General Henry H. Arnold ordered the creation of the report for the U.S. Air Force on the future technological capabilities that might be used by the military. Two years later, Douglas Aircraft Company started Project RAND to study "the broad subject of inter-continental warfare other than surface" (Brown, 1968). Different approaches were tried, but the shortcomings of traditional forecasting methods, such as theoretical approach, quantitative models or trend extrapolation, in areas where precise scientific laws have not been established yet, quickly became apparent. To combat these shortcomings, the Delphi method was developed by Project RAND during the 1950–1960s (1959) by Olaf Helmer, Norman Dalkey, and Nicholas Rescher (Rescher, 1998).

(particularity participatory mapping (PM), with GIS tools. The system was employed to solve the complex design problem of planning for conservation and development in a rapidly changing and contested regional landscape.

Fieldwork conducted in the Osa Region of Costa Rica, captured through multiple community and individual participatory mapping workshops, land use distributions from 40 participants representing two groups: (1) stakeholders from the region of study called "local experts," and (2) participants from academic, scientific and government groups called "nonlocal experts." The study captures in real time, digital land use allocations from each stakeholder employing a framework for direct geospatial scenario digitization. I employed digital pen and interactive display screen technologies over a full portable GIS operating from a laptop. Results captured directly in the geodatabase, are analyzed and presented back to the all participants allowing multiple rounds of scenario refinement, and knowledge and information exchange. The method generated two important advances in transdisciplinary- oriented design and planning practice: First, it allows stakeholders to directly sketch land use change scenarios in a collaborative and participatory manner in a Delphi Method into a geodatabase for further evaluation through spatial statistical analysis. Secondly, it allows the exchange of information and knowledge about the management and associated impacts of alternative uses of land resources, among decision-makers (government), scientist, and local community and regional groups. Final results define and categorize through an indicator system, geographic areas presenting different levels of spatial agreement and disagreement—both of land use types and stakeholder groups. This method proved highly informative for national and local planning authorities, scientist and local groups, improving capacity building, governance and ultimately informed decision making.

Based on this research I suggest here that If GIS ought to serve as medium for the exploration of spatial concepts in design and planning problems where various "design agents" have to manipulate and explore spatial concepts. Sketching, diagramming and 3-D modeling are among the most useful mediums of inquiry and exploration in design and planning. GIS must integrate conceptual ways to manipulate space in the way we do manipulate other mediums of design inquiry and enhance them through analytic support.

ESRI began few years ago to explore the possibility to "sketch up" in GIS. The result was ArcSketch 1.1 ™, a sample extension to ArcGIS that allows the user to quickly create, or "sketch," features in ArcMap using easy-to-use drawing tools and symbols. In my teaching I use Sketch Up with design and planning students not as a way to enter data into a geodatabase, but rather as a way to explore spatial concepts over geography in rapid fashion. There are a series of limitations in terms of relating spatial entities as you do in design processes, although the basics are there. My current research and teaching explores a combination of spatial concepts in regional landscapes through ArcSketch but linking back to model-builder models that function as services through ArcGIS Server. We are testing these methods in a course I co-teach with Prof. Michael Flaxman at the MIT Department of Urban Studies and Planning. This is allowing us rapidly explore design ideas and to link back to the analytics of GIS modeling to be able to inform and design propositions.

Ultimately, the explorations I conduct in my research and teaching, respond to the international escalating institutionalization of participatory development and planning and design which demands from today's designers a new "expert-facilitator role"; a role which aim is to contribute in the mediation and advice of the complex system debate of land resource design and planning between experts and non-experts in a collaborative manner where the idea is to co-generate better knowledge for design.

Thanks to the organizers for the opportunity to share my thoughts on this topic.

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