From Metaphor to Model: Expanding Ecologically-Informed Design

In recent years, practitioners and researchers in the fields of architecture, landscape architecture and urban design have become increasingly interested in developing ecologically-informed design strategies. Within this setting, ecology is not simply a synonym for the environment, nor does it necessarily suggest a 'green' agenda; instead, it emphasizes a system-based holistic perspective of a given context.

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INTRODUCTION

Contemporary definitions of ecology foreground the importance of natural processes, defining the discipline as the study of "patterns and processes influencing the distribution of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy, matter and information".[1] With such a definition in mind, a growing body of work acknowledges lessons acquired from ecological science, presenting natural systems as dynamic, interconnected, resilient, complex and indeterminate, and attempts to situate strategies for design within this flux. In particular, the discourse surrounding Landscape Urbanism proposes that design should not set itself in opposition to such natural processes but instead be, in and of itself, inclusive and responsive by operating on principles of synthesis and encouraging hybridity across natural and engineered systems.

Yet, the tools and methods currently used by designers with which to advance such work are limited. The familiar practice of mapping, in formats such as spatial maps, timelines, organizational diagrams, and other modes of visualization, is the central driver currently used in presenting, synthesizing and mobilizing ecologically-oriented, systems-based design interventions. However, in most cases, such drivers are offered as-is, with little explication of their validity, assumptions and limits, and, as a result, are fundamentally bounded by the limits of ecological metaphor.

Surpassing the boundaries of ecological metaphor demands a set of tools which can deal with managing the dynamic processes and forces, flows and feedback loops, which characterize ecological systems. While current techniques are helpful in isolating and abstracting certain aspects of these ecosystems, much of their inherent complexity is lost due to our human limits in managing and working with complex, parallel relational chains. Herein rests an opportunity for computational design to appropriate ecological modelling, as a point of access to the full technical richness of ecological science. In this context, the computational designer is able to abstract a problem for initial action and then, relying on the machine as an automatic accountant, incrementally rebuild the lost complexity, thereby allowing the relevant characteristics of the problem space to be maintained.

With this in mind, an appropriation of ecological modelling into design practice offers a parametric and relational framework for advancing ecologically-informed design as a process of formation, which can afford both generative and exploratory opportunities to the development of landscape infrastructure. Here, hybrid models, which couple multi-disciplinary parameters and characteristics, can offer a mechanism for simulating emergent ecological-urban possibility spaces. As exploratory tools, such models might also offer an opportunity to extend a designers ability to both navigate and cultivate epigenetic[2] potentials, toward the formation of a synergistic territory where human-centered needs and ecosystem logics coexist to mutual benefit.

LANDSCAPE URBANISM: REEMPHASIZING A SYSTEMS VIEW

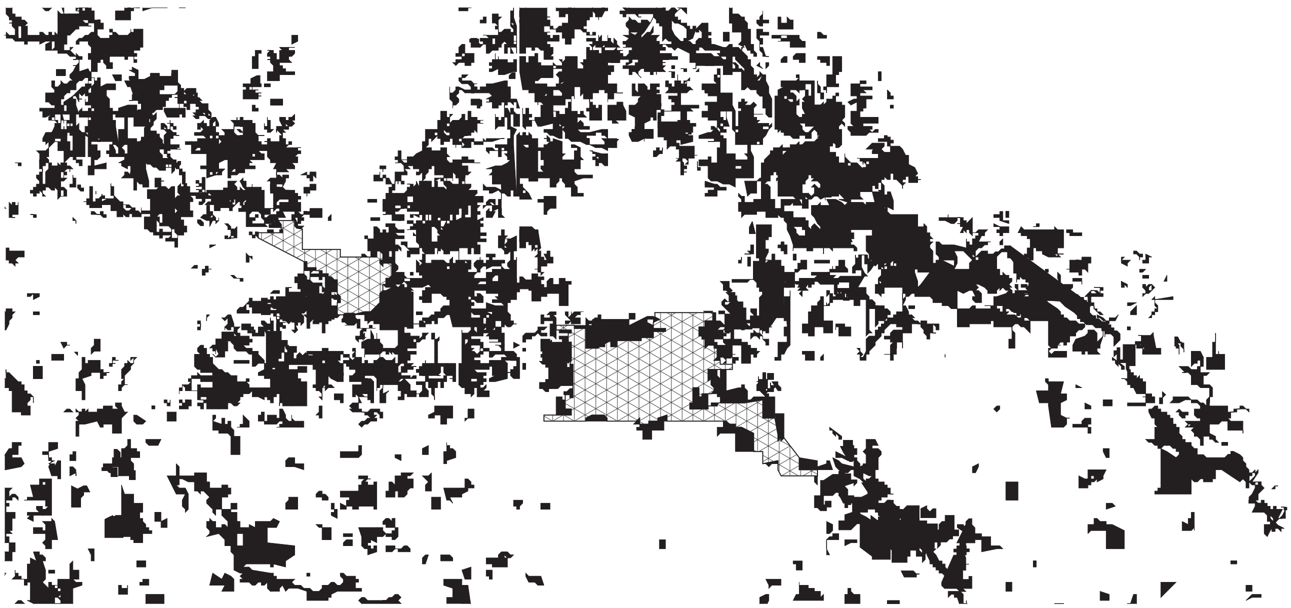
Among the dominant themes present in the Landscape Urbanism discourse is the implied value of a systems-based perspective. With an interest in operations and process over achieving specific aesthetics[3], the work leading up to and supporting the Landscape Urbanism discourse could be described as pursuing an interest in spatial systems. In particular, Ecological Urbanism, a direct descendant of Landscape Urbanism, advocates a design practice wherein the project is seen to both affect and be affected by an inclusive set of environmental, social and economic factors.

To name some significant examples, Keller Easterling pursues a description and analysis of environments generated more by the systems of forces and flows – climatic, economic, social and political – than by willful formal acts.[4] Along similar lines, Alan Berger positions Systemic Design as a design framework which seeks to interact with environmental, economic and programmatic stresses across regional territories. Berger claims that a systems-oriented relationship with design will lead to more intelligent project scenarios to address the most pressing challenges of our time.[5] James Corner's seminal landscape projects propose the transformation of site through an ecologically-informed methodology. The proposals are conceived as the result of intensive mappings of the existing and proposed conditions and agents. These works are supported by Corner's writings on designing with process in time[6]: highlighting the proposed transformations as dynamic processes characterized by terms like fluidity, feedback, and non-linearity. By privileging these over such qualities as stability, predictability or rationality, Corner positions ecologically-informed concepts as essential to the designer.

Corner's *Fresh Kills* grapples with the desire to represent and mobilize the complexity of dynamic systems into an implementable design proposal. Given the concerns of this and other projects, their appropriation of the term ecology is generally appropriate. However, the degree to which the principles of ecology are in fact pursued within a design practice, and the opportunities found in this appropriation, are left unarticulated. Each of these precedents examines the opportunities of site by recognizing multiple agents, site diversity, dynamic forces and non-determinism; and each proposes a design strategy that acknowledges an interconnected, relational context. However, the integration of design practice with ecological methodology is relatively superficial. Consequently, each of these projects is, for the most part, bounded by the limits of metaphor; the authors assert the presence and agencies associated with Ecological Urbanism's suite of concerns while most often stopping short of direct confrontation with the actual complexity represented.

LAND RESERVATIONS: HITTING METAPHORICAL LIMITS

To further illuminate the limitations of relying on ecological metaphor, consider the following example. *Land Reservations* is a speculative project, well rooted within the realm of Landscape Urbanism, which serves as an example scenario where there may be much to be gained by incorporating a more rigorous utilization of ecological strategies, methods and tools into design practice.[7] The intention of the work is to respond to the fragmentation of open space networks which often results from urban development, by recognizing a potential for landfills to be utilized as a strategic connector within these spaces.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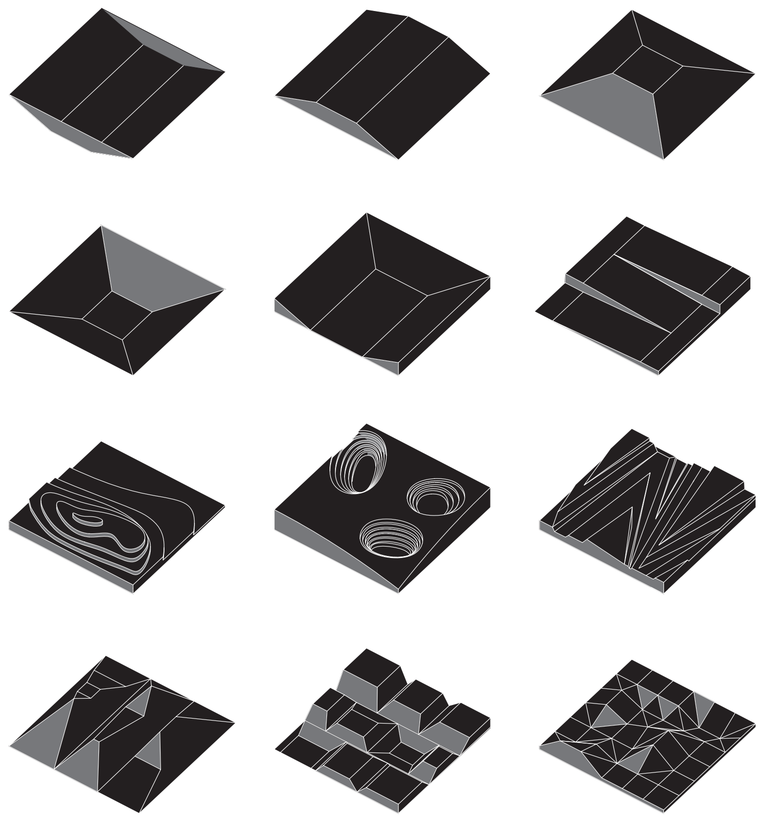
The project suggests that with urban expansion and development, there is a significant and undesirable reduction in the connectivity and continuity of open spaces, which are typically comprised of wetlands, cultural parks, grasslands, and active agricultural lands. Here, landfills, a necessary component of any urban system, might be strategically placed, and evolved from industrial to recreational use over time, to bridge these spatial gaps.

This premise relies on the notion that a continuous network of open space is ecologically beneficial and desirable, which is true to ecological principles in a general sense, and serves well as a basis for a design proposal. However, as the project develops it relies on this metaphorical relationship to ecological science, stopping short of employing practices which are able to calibrate specific elements of the proposal to their live contextual counterparts, or validate the cascading effects of their implementation to the systems with which they are connecting.

For example, as the morphology of this space is developed (See Figure 2), there is no mechanism within the design process which might anticipate how these forms might affect the flow or migration of relevant species across these surfaces, or how they might affect predator prey interactions, or how the introduction of such a vast source of potential food might affect species carrying capacities and population distributions. That relationships such as these are left unattended in

Figure 1: *Landfill as Connector.* Landfill sites are strategically deployed to reverse this process, stitching islands of open space into a continuous fabric.

the design process is a product of an over reliance on broad ecological metaphor, useful in positioning project intentions, but without agency in anticipating or supporting project outcomes.



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As this example suggests, the relationship between design and ecology, to date, has been based mostly in metaphor; a notion which is not surprising, as metaphor is a likely point-of-entry for an appropriating discipline into the world of a specific science.[8] Yet, while metaphor is a useful communication tool across disciplines, as it can succinctly and accessibly summarize a mind frame, a general approach, a set of values, or a concept, we are reminded that there is a "rich technical world" that stands behind each metaphor, which might hold much potential for ecologically-informed design practice.[9]

BEYOND METAPHOR: LEARNING FROM ECOLOGICAL SCIENCES

In his piece entitled "The Agency of Ecology", included in the foundational text *Ecological Urbanism*, Chris Reed calls "for a fuller, more engaged approach to the ecological aspect of ecological urbanism".[10] This statement, paired with the notion of the "rich technical world" outlined above, suggests activities centered on developing a deeper knowledge of ecological science's concerns, methods and tools and their appropriation into a design context represents a frontier of design research within the context outlined above.

Given the systems-based view of a project space outlined earlier, systems ecology, a sub-discipline of ecological science, serves as a point of entry for this knowledge advancement. Systems ecology shares a concern for achieving an inclusive, holistic, view of system interactions, with a focus on ecological and

Figure 2: *Cell Morphology.* The basic building block of a landfill is a cell—the active dumping site within the landfill bounds. The filling sequence is planned to optimize the capacity of the site as a whole, and is limited primarily by waste materials' angle of repose. When considerations are expanded to anticipate post-landfilling programs, a much wider variety of geometries becomes plausible.

biological systems. Central to this field is the concept of an *ecosystem* – defined by the network of interactions among living components, and between organisms and their environment. Thus, the overlap in interests between systems ecology and the suite of concerns raised by Landscape Urbanism and its descendant discourses is obvious at a metaphorical level. As we examine the framework and assumptions at work in systems ecology, we can confirm that there is more to learn. Specifically, systems ecology has developed eight principles that characterize ecosystems further.[11] The translation of these principles to a design context is not immediately obvious, however, they do introduce a deeper characterization of potentially overlapping concerns and offer a language to use in their exploration. While some of these principles are highly technical and fall outside the scope of this paper, four, outlined below, have been identified as immediately relevant to the previously recognized themes, and may serve as a basis for developing a renewed set of tools capable of confronting them.

Ecosystems are open systems. This means that all ecosystems are open to exchange energy, matter and information with their environment. It's interesting to note that this current view, which established itself as the prevalent perspective in the 1980s, contradicts an earlier perspective which viewed ecosystems as closed and converging towards a state of equilibrium.[12] Today, ecological systems are seen to follow a Non-equilibrium Paradigm, which suggests, among other things, that ecosystems are not converging to a single point of equilibrium. Instead, the systems are potentially regulated by outside forces and processes, which, due to their externality, result in continual shifts in balance. Openness greatly increases the complexity of the system. Instead of moving energy, material, and information between ecosystem components in a closed world, dynamic qualities are amplified by way of external imports and exports. These dynamics place emphasis on issues of heterogeneity, non-determinism and stochasticity.[13]

Ecosystems are organized hierarchically. Given the principle of openness, and its recognition of internal and external forces and processes, hierarchical organization is directly implied. In the context of systems ecology these hierarchies are differentiated by spatial and time scales. Within an ecological context the hierarchical levels range from atoms to the ecosphere, with at least nine incremental steps between them. Systems ecology is concerned with how variations (disturbances) cascade through the hierarchy in both directions, up and down.

Ecosystem components form ecological networks. Ecosystems recycle elements as a way to increase biomass production. Such recycling is supported by the formation of synergistic connections between system elements. As the number of such couplings is increased, the network's efficiency also increases.

Ecosystems have emerging holistic system properties. Ecosystems are not just a collection of components but are systems with holistic, self-organizing and self-regulating properties. Ecosystem properties such as complexity, evolution, flows and processes, feedbacks and controls, synergism, openness and dissipation are just some of the characteristics that need to be understood when confronting the system behind the ecosystem.

With these principles in mind, it is important to note that all concepts and principles within the ecological sciences, such as those introduced above, have three dimensions: metaphorical appropriation, technical definition, and model.[14] The principles outlined above are presented through the lens of *metaphorical appropriation*, as it is useful in conceptualizing and communicating, at a high level, issues at hand. However, if we wish to transcend the limits of such metaphor, we need to pay attention to the remaining two dimensions.

The second dimension, *technical definition*, is a key component of ecological concepts. We can look to one of the above mentioned principles, namely the principle of openness, to understand what a technical definition of a concept may look like. In this case, the definition of openness is supported by a strategy for its quantification. How open is an ecosystem? Quantifying the rate at which exchange can occur between an ecosystem and its host environment is crucial in understanding and eventually modelling an ecosystem. While it is beyond the scope of this paper to explain the basis of this quantification, openness is defined as being proportional to the area available for exchange, relative to the volume.[15] A more important consideration herein, however, is that such a definition is the result of synthesizing a collection of ecological principles and laws, and that the discipline and care required to mobilize these dimensions remains foreign to the conventional methods employed within design practices such as Landscape Urbanism. With this in mind, the designer is faced with questions about when and how such definitions may be valuable within a design process, and whether it is reasonable to exercise the same concern for such technical definitions, beyond a utilization of metaphorical appropriation.

In light of such questions, the third dimension offers a familiar point of exchange between ecological science and design, and thereby, an opportune point of access for designers to explore such extra-disciplinary appropriation. The third dimension contains the models by which a concept is applied to the material world, pointing to the field of ecological modelling, another, deeply related, sub-discipline of ecological science.[16]

The need and general intentions of modelling are shared by both design and ecological science. A *model* is a simplified representation of a complex phenomenon. Our human ability to manage the increasingly complex networks of causal relationships is limited, and complexity can become overwhelming and disabling for the designer and the ecologist. To combat such inhibition, abstraction can be used to make the problem more manageable through a process of reduction and elimination. Through modelling, relevant aspects of a phenomenon or scenario are highlighted and support a focused action by the model's user.

While the general intention, to support action by way of abstraction, is shared, ecological modelling is a more mature practice with respect to addressing the inter-connections and dynamics associated with the subjects' complex phenomenon. Ecological modelling places emphasis on processes and playing out their dynamics in time and space by relating states of system components to the processes that affect them.[17] Contrarily, traditional design models often propose and represent desired forms and the interactions that *should* be.[18]

CASE STUDY: SPATIAL HETEROGENEITY, PATCH DYNAMICS AND THE HERCULES SYSTEM

As an example implementation of ecological modelling within a model-based design practice, consider Patch Dynamics and The HERCULES System. Patch Dynamics is a framework and modelling strategy that addresses changing spatial heterogeneity over time. Here, spatial heterogeneity refers to a property attributed to a landscape which is characterized by an uneven distribution of elements (both biotic and abiotic) across space.[19]

Through the Patch Dynamics perspective, a patch is defined as a "recognizable area on the surface of the Earth that contrasts with adjacent areas and has definable bounds".[20] A landscape can therefore be understood as a complex array of contiguous patches, where variation in patch properties such as size and composition across the matrix is expected. Key to this framework is the acknowledgement that patches change over time and this change can occur in two primary ways: 1) a shift in patch boundary delineation or 2) a shift in internal patch composition. Occurring simultaneously or in isolation, these two types of shifts suggest that the entire matrix of patches, the patchwork, is potentially dynamic.

Employing Patch Dynamics, ecologist Mary Cadenasso, has offered work presenting analytical field strategies that expand ecologically-informed design approaches. Specifically, HERCULES (High Ecological Resolution Classification for Urban Landscapes and Environmental Systems), is a system supporting methods for recognizing, analyzing, representing and designing ecological heterogeneity.[21]

The system is presented as an alternative to existing methods used for documenting urban heterogeneity, which is typically accomplished through a functional classification system highlighting various land uses, such as residential, commercial, industrial, and so on. In this regard, the HERCULES system is focused on land cover rather than land use. Land use describes the socio-economic function of a landscape fragment and, from an ecological perspective, such classification is less useful, as groups that exhibit similarities in land use may have entirely different ecological functioning. The example used by the authors of the system points to 'residential' as a common land use class and goes on to explain that "all residential land is not structurally the same due to the fine scale variation in building density, vegetation and the amount of impervious surfaces".[22] Such information, lost in the land use-centered approach, is considered potentially relevant in the understanding of ecological functioning. Contrarily, a land cover approach foregrounds elements that influence ecological processes by referring to the physical pattern of biophysical structures present across a landscape. Specifically, HERCULES, focusing on urban heterogeneity, presents three basic biophysical elements (building, surface materials, and vegetation) which are subdivided into additional features (vegetation type, surface type, building types). This is identified as a strategic set of properties, known as the system's characteristics of interest, hypothesized to be relevant to the problem at hand, in this case, the ecological functioning of an urban landscape.

The HERCULES system suggests a paradigm shift in how designers recognize, analyze and represent urban conditions. The tool foregrounds structural heterogeneity as a key property in understanding urban conditions from an ecological perspective and keeps track of this property across a variety of scales. This shift demonstrates the potentials of transdisciplinary approaches to design. The tool, developed by an ecologist, recognizes the urban designer as being an influential agent in determining the spatial heterogeneity of urban systems and contributes an additional lens through which the designer understands site. As such, the tool biases a reading of the site that foregrounds its potential ecological functioning. With this in mind, it is reasonable to assume that the availability of such a tool could support the expanding, inclusive set of interests identified by the ecologically-informed design approach.

ECOLOGICAL PARAMETRICS IN PLANNING & DESIGN: REVISITING THE LAND RESERVATIONS PROJECT

While the HERCULES system holds potential to be a seminal development in ecologically-informed urban design, much opportunity exists to advance such a

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Figure 3: *The Organizational Ecology of a Landfill.* In addition to ecological concerns, landfill operations are affected by numerous other forces and flows.

strategy. In particular, a computational approach to Patch Dynamics, driven, for instance, by spatial cluster analysis, could offer greater access to multivariate and multi-scalar data sets and types, and thereby offer a wider lens through which to perceive spatial heterogeneity.

Similarly, basing such a system within a computational design process could open it up to novel, parametric, hybrid potentials. Hybrid ecological models are those that combine two or more model types,[23] which could be expanded to include not only a combination of ecological models, but also models of potential design interventions. Within such a model, associative relationships between designed interventions and contextual ecological systems can serve as a basis for a parametrically driven design process.

For a number of reasons, hybrid ecological models are well suited to the development of ecological parametrics in planning and design. Firstly, hybrid models are inherently associative, as they interrelate ecological and designed sub-system components. Similarly, hybrid models offer the potential to simultaneously cover a wide range of the systems, forces and flows which characterize a complex urban-ecological context. Lastly, hybrid models can be conceived of as extendible, offering the possibility to gradually increase their complexity, by expanding their scope of representation throughout the course of a design process.

Referring back to the ecological principles introduced above - openness, hierarchy, networks and emergence - in reference to the Land Reservations project, these potentials can be further illuminated. Firstly, one might consider how ecological and design components within a network, are related according to hierarchy and system scale. Within the Land Reservations example, using a patch dynamics model as a basis, a nested set of associative models could parametrically relate ecological system components across scales ranging from a regional landscape down to, for instance, a fish population or sediment flow. As such

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factors interact with a design component within such a parametric model, a designer can explore the emergent ecosystem properties, tendencies and capacities which are driven by the design intervention.

Similarly, hybrid ecological-design models hold the potential to expand their scope beyond their typical function, to include social, political and economic considerations, and thereby further explore the epigenetic potentials of a design context. Ecological modelling offers a set of strategies, methods and techniques suited toward ecosystem projection and analysis, yet, the specific systems and components with which they operate remain open to any number of possibilities. Again, referring to the Land Reservations project, such atypical system components could include things such as garbage transportation proximities and costs, economic policies such as those that regulate cross border material flows, or environmental policies which guide material handling (See Figure 3).

Given the principle of openness, the components which are relevant to an ecological system, such as those considered herein, can never be determined with absolute certainty. As such, the components considered relevant to a system model at the beginning of a design process might evolve as a design context & scope becomes better understood. In this regard, the extendibility of hybrid models can facilitate an adaptive renegotiation of system components as a project progresses, gradually building toward a desired system representation and complexity.

As these examples suggest, appropriating ecological modelling techniques can offer an improvement from the status quo, in representing and managing complex ecological systems within a design context. Hybrid ecological-design models can form the basis of a parametric approach to planning which facilitates a utilization of ecological principles that transcends metaphorical interpretations. By offering a richer technical world from which to base design decisions, and a

Figure 4: *Land Reservations*.

ENDNOTES

1. Pickett, S.T.A., M.L. Cadenasso, and Brian McGrath. 2013. "Ecology of the City as a Bridge to Urban Design." In *Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities*, edited by S.T.A. Pickett, M.L. Cadenasso and Brian McGrath, 7 - 26. Springer.

2. "Epigenetic" is defined by the New Oxford American Dictionary as "resulting from external rather than genetic influences." Within a design context, the term has been used to describe how differentiated form might emerge from an environment as a result of external forces acting upon it (Kwinter, Soft Systems, 1993 in Sheppard, From Site to Territory, Bracket Goes Soft).

3. Landscape Urbanism's seeming lack of interest in aesthetics is challenged by Ian Thompson in Thompson, I. H. (2012). "Ten Tenets and Six Questions for Landscape Urbanism". *Landscape Research*, 37(1)

4. Easterling, Keller. 2005. Enduring Innocence: : Global Architecture and Its Political Masquerades. Cambridge: The MIT Press.

5. Berger, Alan. 2009. *Systemic design can change the world*. Amsterdam: SUN Publishers.

6. Corner, James. 2006. "Terra Fluxus." In *The Landscape Urbanism Reader,* edited by Charles Waldheim, 23-33. New York: Princeton Architectural Press.

mechanism for incremental development, ecological modelling offers a means by which designers can expand ecologically informed design, promoting an elaboration of design research practices.

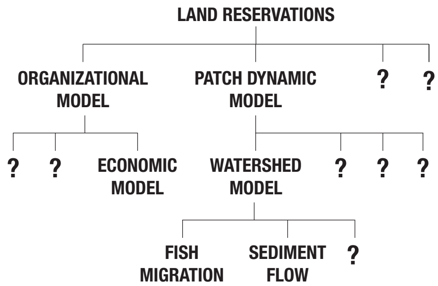

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Figure 5: *A Hyrbrid Perspective.* One of the challenges of developing an ecologically oriented perspective lies in defining the characteristics of interest for a given context and the relationships between these characteristics.

7. Przybylski, Maya. 2011. “Land reservations: Landfill as connector.” *OnSite: Dirt* (Association for Non-Profit Architectural Fieldwork) 26: 30-33.

8. Pickett, et al. 2013.

9. Ibid.

10. Reed, Chris. 2010. “The agency of ecology.” In *Ecological urbanism*, 324-329. Zurich: Lars Muller Publishers.

11. See Jørgensen, S E. 2012. Introduction to Systems Ecology. New York: CRC Press. for a detailed description of ecosystem principles.

12. Tarlock, A. Dan. 1994. “The Nonequilibrium Paradigm in Ecology and the Partial Unraveling of Environmental Law.” *Loy. L.A. L* 1121-1144.

13. Wu, Jianguo, and Tong Wu. 2013. “Ecological Resilience as a Foundation for Urban Design and Sustainability.” In *Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities,* 211 - 229. Springer.

14. Pickett, et al. 2013.

15. Jørgensen, S E. 2012.

16. Soetaert, Karline, and Peter M.J. Herman. 2009. A Practical Guide to Ecological Modelling: Using R as a Simulation Platform. Springer.

17. Ibid.

18. Pickett, et al. 2013.

19. Cadenasso, Mary L. 2013. “Designing Ecological Heterogeneity.” In Urban Design Ecologies (AD Reader), by Brian (Ed) McGrath, 272-281. London: John Wiley & Sons Ltd.

20. Pickett, S.T.A., and Kevin H Rogers. 1997. “Patch Dynamics: The Transformtion of Landscape Structure and Function.” In Wildlife and Landscape Ecology, by (ed.) J. S. Bissonnette, 101-127. New York: Springer-Verlag.

21. Cadenasso, Mary L. 2013.

22 Ibid.

23 See Jørgensen, S E. 2009. *Ecological modelling: An introduction*. Boston: WIT Press. (p. 29-39) for expansion on model types.