Landscape Systems Modelling: A Disturbance Ecology Approach

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ABSTRACT

This paper reports on research which explores the modelling of landscape systems over time using multi-agent simulation (MAS) software called NetLogo.

Two case studies investigate a disturbance ecology approach to the recovery of Pacific Island settlements after cyclonic events.

First, the natural tropical forest sequence of colonisation-succession-disturbance which operates on Pacific Islands subject to frequent cyclonic events is modelled according to the rules of forest recovery. Then, rules derived from the tropical forest model are applied to a Pacific resort to explore design possibilities as the resort responds to cyclonic disturbance.

There are two useful outcomes: the possible impact of a cyclone on a resort is modelled, and new patterns of resort design emerge.

The research shows that MAS can not only model natural landscape systems but also be used to explore an infinite number of 'what-if' design scenarios. The results show the potential for MAS in landscape architectural practice.

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INTRODUCTION

Landscapes are complex adaptive systems. They are created and shaped by dynamic processes which interact with each other in a myriad unpredictable ways. Landscape systems evolve and adapt in response to the forces and flows of energy and material within them. A coastline or beach, a national park, an urban precinct, a suburban street; each of these is to be understood as, among other things, a landscape system, and each has its unique patterns of organisation, boundary conditions and ecologies. Most significantly they are all self-organising systems.

The move from considering landscape as a static canvas to conceiving it as a dynamic set of systems is relatively recent. The systems approach, imported partially from ecology and partially from nonlinear dynamical theory, has been investigated by a number of landscape architects and allied researchers over the last ten years, particularly in the fields of urban studies and catchment management (eg Corner, 1999; Waldheim, 2006; Berger, 2006). Landscape architects now recognise that it is critical to understand landscape systems and to work with them to ensure that their design interventions reflect the complexity and dynamism of the systems with which they engage.

The growing emphasis on landscape systems has precipitated a need to re-think the way that landscape is depicted. Landscape architects conventionally draw plans, maps and diagrams both to represent the terrain they are working with, and to illustrate their design intent. These techniques are poorly equipped, however, to represent the manifestation of multiple landscape processes occurring over time. The complex adaptive systems inherent in landscapes elude easy capture in two dimensional graphic form. How can these complex processes which interact, change and evolve be represented when they are so difficult to depict by means of conventional techniques? The issue, in fact, is not simply one of graphic representation of dynamic processes, but of dealing with open-endedness and unpredictability in the design process. There is a larger question then: how is it possible to work with these systems in more interactive ways? Representing landscape process entails not only a move from two-dimensional mapping to three-dimensional modelling, but to modelling in time, that is to say, by means of animation. If the nonlinear characteristics of landscape systems can be modelled and design interventions introduced into the models, then alternative outcomes can be tracked and evaluated, and the best schema selected for development.

The most basic model of an environment is the map. Cartography is universally used as a representational tool to enable landscape interventions to be formulated and depicted graphically. Maps can be extremely sophisticated, as Graphical Information Systems (GIS) data maps demonstrate. GIS captures multiple layers of information and displays it at a wide scale-range in very sophisticated forms. Crucial elements missing from GIS data maps however are the feedback loops that drive self-organising systems. Positive and negative feedback loops are of central importance in all living systems (Capra, 1997). Landscape systems are no exception; they regulate the biotic and abiotic elements present within them at all scales, including the planetary scale (Lovelock, 1979). It is the presence of these two forms of circular causality that makes systems dynamic and unpredictable, but it is this that is missing in conventional ways of representing, and therefore thinking about, landscapes.

FEEDBACK LOOPS

In the 1960s chemist Ilya Prigogine developed an influential theory about self-organisation while studying systems under conditions of non-equilibrium. According to Prigogine nonlinear systems not only maintain themselves in a stable state far-from-equilibrium, but may actually evolve. When the flow of matter-energy through them increases, they may go through new instabilities and transform themselves into structures of increased complexity. These structures were termed 'dissipative structures' (Prigogine and Stengers, 1984). Prigogine showed that the instabilities and jumps to new forms of organisation that characterise these systems are the result of fluctuations amplified by positive feedback loops.

Feedback is a characteristic of any system in which the output, or result, affects the input of the system, thus altering its operation. Positive feedback (known as auotcatalysis) is a property of dissipative structures (or nonlinear systems). The study of feedback loops has enabled researchers to distinguish between the pattern of organisation of a system and its physical structure. A system may be chaotic, but not random.

Such systems have three main features. First, they are open and part of their environment, and yet they can attain a structure and maintain it in far-from-equilibrium conditions. These systems run contrary to the second law of thermodynamics, which states that such systems move towards disorder rather than order. Second, the flow of energy in these systems allows them spontaneously to self-organise by developing novel structures and new modes of behaviour. Self-organising systems are therefore said to be 'creative'. Third, dissipative structures are complex. Their parts are so numerous that there is no way a causal relationship between them can be established. Instead, their components are connected by networks of feedback loops operating at different levels, different scales and different rhythms.

Landscape systems, we suggest, are dissipative structures. This paper outlines current work that is been undertaken by a group of Unitec researchers who are modelling landscape systems and evaluating the effectiveness of this modelling for design. The research centres on a series of studies undertaken in Pacific island countries. It uses disturbance ecology as a theoretical driver for the development of a new approach to the design and planning of Pacific Island settlements subject to periodic devastation by cyclones.

TROPICAL FOREST DISTURBANCE DYNAMICS IN THE PACIFIC

In a move away from Clemensian ecological theory many ecologists see disturbance as a necessary part of landscape development. Clements viewed ecosystems as closed, stable, self-regulating systems, which develop relatively enduring ecological communities with a defined climax community (Clements, 1936). There is now a general consensus among ecologists that vital, stable ecosystems are open systems which are in a constant state of flux, operating at the edge of equilibrium (Keller and Golley, 1999; Odum, 1997). This flux is due to disturbance, both natural and human-induced, which is now understood as a key factor in the maintenance of ecosystem health.

Accordingly, the disruption of Pacific ecosystems by cyclones can be seen as essential to the health of those ecosystems – they *require* disturbance to maintain their vitality and integrity. In Pacific environments both marine and land-based ecosystems recover remarkably quickly from even quite devastating natural events. Their health and resilience are as much products of the ability to reorganise after catastrophic change (positive feedback) as they are effects of preservative (or negative) feedback systems.

The ability of ecosystems to recover quickly after extremes of damage can be clearly seen in Niue, which was struck by tropical cyclone Heta on January 5th 2004. The cyclone was of such force that the whole southern part of the capital Alofi was completely devastated. The damage included the complete destruction of the southern part of the town and its entire associated infrastructure. What was most extraordinary about the extent of the damage was that it was so unexpected. Alofi is perched at the top of a sheer cliff over 28m above sea level, seemingly far above the worst storm waves. The force of cyclone Heta was such that it pushed huge quantities of water before it, causing localised sea-level rise. Massive waves then surfed on the top of the elevated sea, crushing everything before them. The entire coastal edge was stripped of vegetation, and huge quantities of rock and topsoil were dragged by waves into the sea. Wind speeds exceeding 300km per hour caused extensive damage over the whole island. The forest, even on the leeward side of the island, was completely stripped of leaves, and vegetation over the entire island was either wind-burnt, salt-burnt or snapped off. The destruction was seemingly complete.

About three months after the cyclone, while the community was still in a state of shock, and the massive job of cleaning up was still a long way from completion, it was interesting to note that the vegetation, even in the most affected areas, was beginning to recover. Plants were re-sprouting and seeds were germinating. Plants regenerated not only from snapped off stems but also from root fragments lodged in rock – all that remained of the extensive coastal vegetation. Leaves reappeared on trees and grass began to re-grow in the salt-drenched soils.

It was this systemic landscape resilience which first suggested to us the possibility of using disturbance theory as a generator for developing a model for Pacific settlement design. If ecological systems can self-organise after disturbance events, why can't this same model be applied to the recovery of human settlements? Alofi has struggled to recover after Cyclone Heta. The rebuilding has been fraught with difficulties, the most prominent being economic; Niue has a very small population (approximately 1500) and a fragile economy which is heavily reliant on aid and remittances. The economic burden of re-establishing Niue's infrastructure is enormous, and aid has been difficult to secure. It was clear from the outset that it would not be possible to simply rebuild what was lost in the cyclone. Also, it may not be desirable. Pre-cyclone Alofi, while tiny in population, sprawled along five and a half kilometres of road and was without a discernable centre (Riddell, 1992).

The research team postulates that Pacific islands require urban infrastructures that can operate under dynamic, fluctuating conditions. If they were conceived as socio-spatial patterns that can evolve and change, rather than as ordered, rigid distributions of architectural objects, then cyclone-devastated urban areas might self-organise into resilient urban ecologies. The colonisation-succession-disturbance process offers a way of responding positively to the process of evolutionary change – an alternative to the model of formal intervention-based cultural aesthetic models which are currently the norm. Instead of seeing cyclones as a necessary part of the system and therefore to be assimilated, typical urban settlements attempt to resist cyclonic events. The system tries to expel them.

In a previous paper (Barnett and Margetts, 2005) we outlined what was required in order to test whether the colonisation-succession-disturbance model is a useful and generative approach to this problem. In that paper we suggested that a first step would be the modelling of a traditional Niue village. This would describe housing typologies, linkages between activities and spatial patterns, the point centres of village life (market, church, clinic, chief's dwelling, etc) and the relationships between these and the natural ecologies that constitute the larger morphological patterns and networks of Niue settlement. A model of traditional village structure would also show the patterns of social, economic and cultural flows in which the codes of Pacific life are embedded, and the limits imposed on development by traditional land tenure systems.

While all this information was considered essential to the development of a robust model, we quickly realised that not only was such fine-grained information going to be quite difficult to obtain, but that its inherent complexity was beyond our current skill level to model. We needed to find a more simplified 'village' to work with first, which we could then use as a basis for more complex modelling. It occurred to us that tourist resorts fitted our criteria quite well. They are subject to the same cyclonic disturbance as villages, but operate in a comparatively simplified manner. Resort communities organise around fairly well-defined patterns according to rules associated with tourism, and it can be argued that they are essentially consumption-based systems. Pacific island tourist resorts operate without the additional complexities of land tenure, chiefly systems, religious structures and so on that are present in many Pacific villages. Even though resorts are relatively simplified community systems, there are still a great number of interactions to deal with. Importantly for our research, Pacific island tourist resorts almost always instantiate the resistance model – the settlement system does not include the cyclone.

MODELLING LANDSCAPE SYSTEMS

Models are abstractions or simplifications of reality, used to gain insights into how a particular 'world' operates (Batty, 2007). Digital modelling has become relatively widespread in a number of disciplines in recent years, brought about by advances in computer technology. Batty suggests that 'in terms of many systems that exist in the real world, the only kind of experimentation that is possible is through computer simulation' (Batty, 2007: 8). Models are tools for looking into the future; they are able to answer multiple 'what if' questions about the system of interest. Most real world systems, of course, are infinitely complex and are subject to multiple subtle and unpredictable interactions that are impossible to identify in their totality. Despite the fact that models must necessarily be gross simplifications of any given system, they nevertheless have been shown to be useful tools to identify emergent properties of complex systems.

Multi-Agent Simulation (MAS) techniques are currently considered one of the more effective methods for modelling complex systems, and have been used extensively in large-scale urban planning. MAS are capable of modelling the collective dynamics of interacting objects in both space and time. They are particularly useful for constructing dynamic simulations at different time-scales. Much of the current research using spatial simulation technology is occurring in fields such as computer science, physics, chemistry, ecology, biology, mathematics and urban planning, but there is none that we can identify in landscape architecture. While translating work undertaken in other discipline areas for application into landscape architecture is not without difficulty, this research project demonstrates that it is possible and useful results can be obtained.

To commence the experimental modelling of landscape systems, an appropriate computer modelling environment had to be identified. Since most modelling software packages are products of research institutions and universities, they frequently require advanced computer programme skills. However, of the environments in the public domain, NetLogo was selected for use in this project as it is relatively easy to learn (an important consideration given that the research team are landscape architects, not computer programmers), and has a large model library (much of which is based in ecology) that we considered could be used or adapted in our particular project. NetLogo is a multi-agent programming language and modelling environment for simulating natural and social phenomena. It is particularly well suited for modelling complex systems evolving over time.

After developing some initial models to gain confidence with the software and explore NetLogo's potential in landscape architecture, a tropical forest model was constructed. This model created a simplified tropical forest, comprising soil with variable suitability for tree growth and two types of trees, one whose seeds are distributed by wind and another by birds. Three sets of rules were developed. The first were those that govern tree growth, distribution and interactions with the environment. When the model was run, the development of the forest could be observed over time. Trees would grow, reproduce, interact with their environment, and die. NetLogo allows for each of the variables to be changed, for example the number of seeds produced by trees, their rate of growth and so on. Second, rules for the effect of cyclonic damage and subsequent recovery were introduced into this model. These rules governed a variety of factors such as the force of the cyclone, the extent of damage that trees suffer, the effect of wave damage, and the change of environment after inundation by salt water. Finally, recovery rules were developed. Trees could recover not only by normal reproductive strategies to do with seed distribution, but also by plant fragments and re-growth of damaged trees. Again, each of these variables was adjustable so damage and recovery could be observed according, for example, to different cyclone strengths.

While in many respects quite simplified, this model did show that it is possible to simulate a landscape system and to show how it reacts to disturbance. One of the key observations made was that each time the model was run, even under identical conditions, the outcome was somewhat different. The outputs of the model are emergent patterns, rather than predictable, reproducible outcomes. This result coincides with our understanding of landscapes as autocatalytic systems in which non-linear interactions occur.

Having established that NetLogo can be used to model natural landscape dynamics the next task was to apply the model to a resort. An opportunity arose to work in conjunction with a developer who was planning a resort in Fiji. The developer, Krukziener Properties Ltd, provided their plans and designs for the proposed resort at Sovi Bay and a small research team went to Fiji, accompanied by a number of fourth-year Unitec Bachelor of Landscape Architecture students and a representative from the development firm. The students were directed to undertake a number of surveys and analyses of the landscape conditions in place there, including a catchment survey, ecological analyses, tree surveys, a hydrological analysis and a survey of comparative resorts in similar coastal conditions.

The Sovi Bay resort design appears to follow the same basic pattern as similar developments in Fiji. The underlying system based on consumption is evident. Villas (bures) are located in gradated proximity to the beach, while service and entertainment hubs such as pools, bars and restaurants are designed to meet a range of criteria for maximum patronage. The proposal for the Sovi Bay resort is formulated to fulfil certain underlying requirements of both the visitor and the operator, and is arranged in a fairly standard way when compared to similar resorts examined along the same coast.

The first step in the modelling process was to build the resort site in NetLogo by importing GIS data and input physical data gathered by the research team and students. The proposed resort design was then located on the site, rules were developed to guide the response of the built structures to wind and wave damage, and the cyclone destruction model was run. After this, a recovery model (based on the tropical forest colonisation-succession-disturbance rules re-worked to fit a resort context) was introduced to see what would happen if the resort were allowed to re-configure to these rules subsequent to cyclonic intervention.

The resort model's central components are villas (accommodation) and hubs (activity centres such as restaurant, bar, swimming pool, kids club and so on). Rules were developed around proximity to beach, the popularity of hubs, movement patterns and tree reproduction (which were governed by 'gardener' rules, rather than by natural system rules). Again, as in the tropical forest model, the outcomes of the resort model were general patterns, rather than a single new resort design. The rules which governed the various interactions taking place within the model were formulated to satisfy a set of objectives, and these objectives would be the same however the designer approached the design. They include aspects such as the minimum distance that a villa can be located near a hub, the maximum distance a villa can be away from the beach, the location of paths with respect to both villas (not too close) and hubs (easy access). The model shows us in a systematic way that these requirements can be met by many means, and when variables change, such as environmental change due to cyclonic disturbance, new patterns of possibility emerge for the design of the resort. Running the model with periodic cyclonic events shows an interesting response to changing conditions. Instead of simply rebuilding what has been destroyed, the model demonstrates that the resort can adapt and respond to the changing conditions. Dynamic qualities emerge as a direct response to disturbance, while still seeking to satisfy the predetermined set of 'consumption' objectives.

CONCLUSION

When the results for the tropical forest and the resort are taken together they show us that natural landscape systems *can* be modelled and these models can respond to disturbance events. Human systems can also be modelled, although the unpredictability of human behaviour limits the degree of complexity of the rule-based interactions. Having said this, it is important to note that the resulting outcomes of the models are not designs, but open up new ways of thinking about the design possibilities. In the Pacific resort situation, widely predicted increases in sea-level rise and an associated increase in cyclones means that resorts which can be more responsive to these events will have an advantage. Critically, and most usefully, possible new resort forms emerge from the complex interaction of the feedback loops operating within the NetLogo model. Multiple what-if scenarios can be explored in the initial stages of the resort design, and the outcomes of such explorations can not only help to inform the final resort design, but also to plan reconstruction scenarios after cyclonic damage occurs. This result indicates to us that it may be possible now to extend the model to account for the more complex interactions occurring in Pacific villages.

In a more general sense we have demonstrated that the modelling of landscape systems can play a useful and hitherto unexplored role in planning and design. We realise that this is just the beginning of the research required to investigate the possibilities of multi-agent simulation modelling in the discipline of landscape architecture, but the work we have undertaken to date indicates its potential to work directly with complex systems.

References

Barnett, R. and J. Margetts (2005). "A Disturbance Ecology Model for Pacific Urbanism: Education at the Sustainable Edge". *Indigenous Technologies and Sustainable Development,* http://www.esc.auckland.ac.nz/People/Staff/smit023/SPPEEX/#2005Wananga.

Batty, M. (2007). *Model Cities*. CASA Working Paper Series, ISSN 1467-1298. http://www.casa.ucl.ac.uk/working_papers/paper113.pdf

Berger, A. (2006). *Drosscape: Wasting Land in Urban America,* ISBN 978-1568987132

Capra, F. (1997). *The Web of Life,* ISBN 0 00 654751 6

Clements, F. E. (1936). “Nature and Structure of the Climax.” in *Foundations of Ecology: Classic papers with commentaries* (1991) Real, L. and Brown, J. H. (eds) ISBN: 978-0-226-70594-1.

Corner, J. (1999). *Recovering Landscape: Essays in Contemporary Landscape Architecture*. ISBN 978-1568981796

Keller, D. and Golley, F. (1999). *The Philosophy of Ecology: From Science to Synthesis.* ISBN 978-0820322209

Lovelock, J. E. (1979). *Gaia: A New Look at Life on Earth*. ISBN 978-0192862181

NetLogo, http://ccl.northwestern.edu/

Odum, E. (1997) *Ecology: A Bridge Between Science and Society,* ISBN 978-0878936304

Prigogine, I. and Stengers, I. (1984). *Order Out of Chaos: Man’s New Dialogue with Nature,* ISBN 978-0394542041

Riddell, R. (1992). *Urban Planning Need for a Capital Centre at Alofi with Emphasis on a Retail Centre,* Suva, South Pacific Bureau for Economic Cooperation.

Waldheim, C. (2006). *The Landscape Urbanism Reader,* ISBN 978-1568984391