A Disturbance Ecology Approach to Post-Cyclone Reconstruction in Pacific Settlements

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Abstract

Recent natural hazard management research highlights system resilience as a measure for managing environmental risk. Resilience is a function of the capacity of a system to adapt to disturbance and recover in such a way as to minimize future disturbance. This research explores a disturbance ecology approach to post-cyclone reconstruction in Pacific islands. It investigates the proposition that the recovery of urban environments after disaster can be enhanced by the development of adaptive infrastructures using the natural model of tropical forest system recovery. Can the natural forest sequence of colonization, succession and disturbance provide directions for the development of integrated protective measures in Pacific Island settlements subject to cyclonic damage?

A multi-agent simulation (MAS) computer modelling environment was used first to model tropical forest recovery in Niue and then to apply the emergent patterns of recovery to settlement planning in Fiji. The research found that the focus of such modelling should be on the landscape systems within which the settlement is situated, rather than on its architectural elements, if resilience is to emerge from the process. Catchment (watershed) modelling is shown to be invaluable for the design of resilient settlements in Pacific islands.

Keywords: Disturbance ecology, Pacific, computer modelling

Introduction

There has been much discussion about system resilience with respect to natural hazard management as a measure for managing environmental risk (Gunderson 2000, Resilient Organisations 2006). However there has been precious little input into these discussions from the landscape architecture profession. Landscape architecture as a discipline is ideally situated to contribute to environmental disaster recovery as it deals specifically with the relationships between human and natural environments. It is particularly suited to contribute to the design of human environments to increase their resilience, since it has a tradition of taking its design cues from natural landscapes, and many natural landscapes are excellent examples of resilient systems. Wetlands, coastal dune systems, alpine fields, lakes and rainforests can all be viewed as complex adaptive systems which are created and shaped in response to the flow of energy and material within them (De Angelis 1980, Holling 1986, Carpenter and Cottingham 1997). Dynamic processes (fire, weather events) interact with landscape structures (soil type, lake chemistry) to produce emergent patterns of recoverability in ways that suggest that many landscapes' adaptive capacity to recover from disturbance is a function of their requirement for it.

This paper reports on a research project that draws on the one hand from the work of Ilya Prigogine with dissipative structures, and on the other from disturbance ecology, to develop a model for resilient Pacific settlement design.

The Pacific problem

The ability of ecosystems to recover quickly after catastrophic disturbance can be seen on the Pacific island of Niue, which was in the direct path of a category five cyclone that struck on January 5th 2004. Cyclone Heta hit Niue from a westerly direction, damaging the natural coastline and devastating the southern district of the capital, Alofi. Wind speeds of 300km per hour were recorded prior to the measuring device disintegrating. Infrastructure damage included the complete destruction of the hospital and nurses' home, the museum, the main hotel and all associated services. Additionally, the entire coastal edge was completely stripped of vegetation and the rainforest over the rest of the island was either wind-burnt, salt-burnt or snapped off. There was also a massive loss of landscape structure as the waves sucked rock and topsoil into the sea.

Cyclones like Heta are a familiar part of Pacific life, particularly for those who live on the eastern side of islands. Traditional village patterns of settlement and infrastructure design have over the centuries adapted to regular cyclonic depredation, and customary lifeways have developed an integral resilience to it, expressed in the agricultural, horticultural, architectural and social systems that have evolved over time. With the advent of modern technologies and knowledges, however, this traditional resilience has broken down. Western architecture and infrastructure now dominate most villages and towns, even small family-based settlements.[1] Economic development has meant that techniques of animal husbandry and crop management have also changed, and traditional methods for the maintenance and care of landscape structures and systems have been modified in the process.

In terms of resilience to cyclone damage this has caused what we call 'the Pacific problem.' About three months after Heta hit Alofi the community was still in a state of shock. Seven million dollars in aid had been pledged, and clean-up equipment such as bulldozers and trucks had been shipped in, but the huge job of restoration and recovery was still a long way from completion and adequate funds for any meaningful reconstruction work far from secure. The town's infrastructure was still dysfunctional.

The natural infrastructure, however, even in the most affected areas, was beginning to recover. Plants were re-sprouting and seeds were germinating. Vegetation 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. This is the 'colonisation' phase of the colonisation-succession-disturbance cycle which characterises robust ecosystems. The contrast of this Pacific rainforest resilience with patterns of urban recovery could not be

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[1] For instance in the village of Vatukarasa on Viti Levu in Fiji (population 300), 90% of the dwellings are non-traditional, and all the villagers are in some kind of paid employment.

greater. 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.

Research background

It was the systemic landscape resilience observed at Niue that first suggested the possibility of using disturbance theory to develop a model for Pacific settlement design. If ecological systems can self-organise after disturbance events, why can't human settlements? Landscape architects have worked with ecosystem dynamics for decades (see, for instance McHarg 1992; Thompson and Steiner 1997), but in landscape architecture the application of the ecosystem model to urban projects has mostly been confined to natural systems restoration rather than to the forging of new strategies for the development of complex urban systems such as greenfields subdivisions and inner city redevelopments. With the advent of complex adaptive systems modelling this has all changed. Complex adaptive systems theory (or CAS) is the umbrella paradigm for disturbance theory in ecology. The concept of self-organisation is a critical component of both.

In the 1960s, chemist Ilya Prigogine developed his work on self-organisation while studying systems under conditions of non-equilibrium. He discovered that as a system moves further away from equilibrium it reaches a point of critical instability, at which a new pattern emerges. This is self-organisation, a characteristic of what he termed 'dissipative structures' (Prigogine and Stengers, 1984). Prigogine introduced the concept of dissipative structures to emphasise the paradoxical close relationship between structure and order on the one hand and dissipation on the other. In classical 19th century thermodynamics the dissipation of energy was regarded as waste. Prigogine changed this view by showing that in open systems dissipation becomes a source of order.

According to Prigogine, dissipative structures (or 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. Prigogine showed that, while dissipative structures receive their energy from outside, the instabilities and jumps to new forms of organisation that characterise them are the result of fluctuations amplified by positive feedback loops. The so-called runaway feedback, which had always been regarded as destructive in cybernetics, appeared as a new source of order and complexity in the theory of dissipative structures.

Dissipative structures 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 molecular disorder rather than order. Second, the flow of energy in these systems allows them spontaneously to self-organise (creating and maintaining a structure in far-from-equilibrium conditions) 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, scales and different rhythms.

Landscape systems can be viewed as dissipative structures which exhibit systemic resilience to perturbation. As Dalziell and McManus (2004) identify in the case of organisational structures, resilience is a function of ‘both the vulnerability of the system and its adaptive capacity’ and this, we propose, is equally applicable to landscape systems, which are both complex and adaptive.

In a move away from Clemensian ecological theory, many ecologists – partially as a result of Prigogine’s work - now 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, 2000; 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. Disturbances are described by Forman (1995) as events that significantly change patterns in the structure and function of landscape systems.

Disturbance events may be minor, or catastrophic. Shugart (2005 p36) notes that small or frequent disturbances are incorporated into the environment of the ecosystem, but when disturbance events are sufficiently large and infrequent, they are catastrophic, and landscape dynamics become less predictable. The ecologies eventually may fall back into their previous state; they may not – it is impossible to predict. Pacific landscapes which are frequently exposed to dramatic disturbance by cyclonic events, fit into this latter category and exhibit unpredictable landscape dynamics.

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 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. Once disturbance-prone Pacific landscapes are conceived as complex adaptive systems they can be modelled as such.

Research methods

Research question

- Can the colonisation-succession-disturbance cycle present in natural forest systems be used to design Pacific settlements that are resilient with respect to cyclonic disturbance?

Developing a model

The research question was explored by means of a computer model. The modelling had to be tackled in two stages, the first informing the second. The research objectives then are as below:

Research Objectives:

- To build a tropical forest model in NetLogo and test its recovery after successive cyclonic disturbance
- To use the tropical forest model as the basis for modelling a Pacific community.

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 (Batty 2007). MAS are capable of modelling the collective dynamics of interacting objects both in space and in 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 it is not in widespread use 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 well-suited for modelling complex systems evolving over time.

Modelling settlements

Niue has a very small population[2] and a fragile economy that is heavily reliant on aid and remittances. Given that the economic burden of re-establishing Niue's infrastructure was placed at NZ$23m over five years (Relief Web, 2004), it was clear from the outset that it would not be possible simply to rebuild what was lost in cyclone Heta. Also, it may not be desirable: pre-cyclone Alofi, while tiny in population, sprawled along five and a half kilometres of road and, as Riddell identified in an urban planning study in 1992, was without a discernable centre (Riddell, 1992).

Pacific islands like Niue require urban infrastructures that can operate under dynamic, fluctuating conditions. If they are 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.

A previous paper (Barnett and Margetts, 2005) 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 it was 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.

Research results

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 in order to demonstrate forest recovery patterns. This model created a simplified tropical forest, comprising soil with variable suitability for tree growth, topography, and two types of trees, one whose seeds are distributed by wind and another by birds. Rules were developed to govern the way trees grow, reproduce and interact with their environment. When the model was run, the development of the forest could be observed over time. Rules for the effect of cyclonic damage and subsequent recovery were introduced into this model. Each variable within the model was adjustable to allow different permutations to be explored.

While in many respects quite simplified, this model did show that it is possible to simulate a landscape system and demonstrate 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 different. The outputs of the model were emergent patterns,

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[2] The current population stands at around 1500 people, of which, about 800 are permanent residents.

rather than predictable, reproducible outcomes. This result coincides with our conception of landscapes as autocatalytic systems in which nonlinear interactions occur.

Forests, however, do not arrange themselves according to cultural norms. Villages do. Socio-cultural issues determine how settlement organization and structure occurs, often in response to environmental conditions. While social information, of course, would be essential to the development of a robust model, it quickly became apparent not only that such fine-grained information was going to be difficult to obtain, but that its inherent complexity was beyond our current skill level to model. A simplified ‘village’ was required with which to work first. This could then be used as a basis for more complex modelling. Tourist resorts fitted the criteria quite well. They are subject to the same cyclonic disturbance as villages, but operate in a comparatively simple 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 the research, Pacific island tourist resorts almost always instantiate the resistance model – the settlement system does not include the cyclone. A resort proposed for Sovi Bay in Fiji was modelled (with the approval of the resort developer Krukziener Properties). The model was based on 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 resort site was built in NetLogo by importing GIS data and entering physical data gathered by the research team. The architectural components of the resort were then located on the simulated 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 forest rules re-worked to fit a resort context) was introduced to see what would happen if the resort were allowed to reconfigure to these rules subsequent to cyclonic intervention. The model showed in a systematic way that operator and visitor requirements can be met by many means, and that when variables change, due for instance to cyclonic disturbance, new patterns of possibility emerge for the design of the resort. Running the model with periodic cyclonic events revealed an interesting response to changing conditions. Instead of simply rebuilding what had been destroyed, the model demonstrated that the resort could adapt and respond to the changing conditions. Dynamic qualities emerged as a direct response to disturbance, while still seeking to satisfy the predetermined set of ‘consumption’ objectives.

After the successful modelling of the resort (the simplified village) the more complex task of modelling a Fijian settlement was undertaken. Vakukarasa Village, located next to Sovi Bay but within the same catchment, was selected. Much of the landscape information gathered for the resort model was directly applicable to the village model, and additional information was gathered on the village layout and the social structure which determined the organisation of the buildings within the landscape. Traditional family groupings still strongly influence this Fijian village which is laid out around a central open space or *rara*.

When the model was run a different result to that of the resort was obtained. The rules within the village model ensured that the orientation of the *rara* was maintained, as were the traditional positioning of the family dwellings. This constrained the outputs of the model, and the resulting layout possibilities of the village were less open to new configurations. Certain assumptions about the importance of these elements had been made (for pragmatic reasons), and the finding (unsurprisingly) was that developing the rules for the model needs to be done in conjunction with the community being modelled. One of the useful features of such a model, however, is its ability to allow the community to see the possible results of decisions that they make. As always, the model won't derive a single 'solution', but instead indicate general patterns that may emerge under the different 'what if' scenarios. What if the *rara* were allowed to reconfigure perpendicular to the coastal edge, rather than parallel to it? What would happen if the chief's family dwellings were at one end of the *rara*, rather than the other? Each of these decisions/possibilities will evolve into a different village structure, adapting to the changing conditions.

Discussion and conclusions

The results of the resort and village models taken together showed that new patterns for redevelopment emerged in response to the changing environmental conditions. What *didn't* emerge from the models, however, was increasing resilience. The resort and village systems each responded to the disturbance, but they did not evolve in a way that offered increased resilience to the disturbance in the first place. This was because the research had focused on the buildings (houses, church, hall) and the arrangement of these buildings, conceiving of these as the systemic elements that undergo change and therefore provide the resilience. In reality, it is the *environment* within which the community buildings are arranged that actually affords the resilience: the project had taken the wrong elements as its subject.

Fortunately, however, the modelling had taken place at the level of the catchment (or watershed). The researchers were well aware that catchment analysis is frequently used in landscape architecture (Coxhead and Shively 2005), but had not made the connection between this and the effects of cyclonic disturbance on settlement design. It is now understood that the catchment should be the unit of analysis. After all it is widely agreed that the management of hydrological systems within catchments is one of the key factors in maintaining their health (Ewert 2005, Chanan 2006). Catchments with poor water management processes are prone to erosion and flooding leading to degradation of landscape structures, water quality, and productive capacity. There has been a lot of research into the links between catchment management and agricultural production (e.g. Santelmann *et al* 2001, Coxhead and Shively 2005), but it is not only productive capacity which is affected by poor catchment management. Human settlements within catchments are also affected. It was McHarg (1992) who first clearly illustrated the relationship between catchment processes and urbanisation, and the adverse effects poor planning of water processes can have on urban areas.

The research has shown the direction the project should next take. The modelling can now move away from village architecture and return to the familiar territory of landscape architecture. It has become clear that the resilience of the settlement is dependent, not so much on the buildings or their layout and location, but on the landscape systems within which they are placed. Landscape management principles should be applied to Pacific settlement catchments – initially, and most importantly, to riparian planting around stream and river sides, planting of coastal edges against erosion, and the introduction of wetlands to help guard against flooding and to maintain water quality. After a NetLogo model has been developed to account for different management strategies introduced on the basis of integrated catchment management principles, it can be run to see the effect these strategies might have on the village and resort. As with the other models, each of the variables can be changed. For example, different types and scales of riparian planting can be tested, as can the size and shapes of wetland areas. The model can be run through various 'what if' scenarios to see the effect of different approaches to catchment management on the built structures and from this, recommendations can be made. In this approach, the resilience of the settlement is inextricably linked to the environment. And this resilience extends beyond the architectural component of the settlement to the productive systems. Good catchment management practices offer substantial benefits to agricultural production in addition to protecting the water quality – important in areas such as Vatukarasa where drinking water is sourced within the catchment.

The architectural elements of Pacific villages are key components of settlement systems, but not in terms of settlement resilience. Prigogine had identified self-organisation as a characteristic of dissipative structures. This research discovered that the arrangement of architectural elements is capable of self-organisation, but not in a way that contributes to the inherent resilience of the village as dissipative structure. Such resilience can be found only in the adaptive capacity of the natural systems that support and interact with the built elements.

Key Lessons Learned:

- NetLogo can effectively model complex adaptive systems.
- Modelling on a catchment level is an appropriate way to assess the effect of cyclonic damage on a Pacific community.
- Resilience of settlements is not a function of the architecture or layout of the settlement, but is instead embodied in the landscape system in which the settlement is located.

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Photos: