

Strengthening Urban Resilience

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INTRODUCTION

Despite the composed 'predict and provide' attitude displayed in the National Urban Policy Paper towards change in Australian Cities, our cities have been more vulnerable to an increasing range of events and trends. The experience of the last year alone is a clear indicator that prediction along traditional lines is an increasingly unreliable way of managing cities. Instead, planning policy and frameworks will have to reckon with the need to strengthen contingency and resilience in cities, whether for rapid deployment or on a larger timeframe as an essential part of a national conversation about the future of Australian cities.

The aim of this paper will be to consider how the concept of urban resilience could be better embedded into the urban process of decision-making and policy development and therefore result in more resilient cities. In addressing this question we aim to unpack the principles of resilience and establish how resilience can be incorporated as a key criterion for built environment quality and to demonstrate why they are critical. How can we measure resilience? What quantitative and qualitative indicators should we employ? How can we reframe the planning and policy discourse to include a conversation about the inclusion of resilience not only into cities but the networks on which the cities depend such as people, infrastructure and supply chains?

We will argue that this new emphasis on resilience, enabled by networks in part, will necessitate a renewed engagement and rethinking of the policy frameworks that have delivered the cities we now have. A radically different approach will have to tackle not only adaptation of existing cities but how ongoing development can be envisaged through the lens of resilience and inform current planning and design decisions.

METHOD

By reviewing analysis of the impact of recent natural disasters to Australian and New Zealand cities, social unrest in UK cities natural disasters and studies of socio-economic vulnerability in Australia we can identify a number of trends in the way in which cities are unprepared for and vulnerable to such 'shocks'. This paper will draw on a number of key concepts in this analysis:

- Systems-of-provision, which we are using to describe supply chains of human and natural resources, infrastructure and goods and services that support cities;
- Whole-of-natural-system approach, which we are using to describe the way in which cities and their systems of provision can be assessed in-toto and as part of an interlinked and dynamic system;
- Resilience and vulnerability – which we are using to describe the city system's capacity to withstand stresses and shocks and its relative vulnerability to these stresses and shocks.

Our analysis of resilience responses to these shocks includes an assessment of the way in which cities can be organised spatially to improve resilience and the systems of provision which are necessary to enhance resilience. This analysis considers the question of the city as a system and the system-wide capacity to respond to impacts.

URBAN PLANNING SYSTEMS AND URBAN RESILIENCE

Urban planning systems have evolved over thousands of years. A linear and tiered interaction of property rights, land-use planning and law, and strategic planning and policy-making, many urban planning systems are widely considered to be deficient in addressing the increasingly complex demands of large city-regions. Within Australia it is broadly recognised that traditional, hierarchical, and sometimes cumbersome planning systems are under strain and are failing to grasp and effectively address crosscutting and emerging issues

such as climate change, disaster response, and managing population distribution. Systems of urban governance, urban taxation regimes and urban infrastructure provision as sub-sets of urban policy-making are all the subject of debate in the context of significant challenges to city-regions. Our siloed decision-making processes and governance structures work against the capacity of governments to think holistically about city-regions, encapsulating all of these interacting functions and actors. While governments are grappling with the need for balanced decision-making, they lack the conceptual tools which enable holistic decisions to be made.

Resilience systems theory originates from environmental science, where it is widely recognised that the capacity of eco-systems to adapt to stresses and shocks is a key indicator of ecosystem health. A system, in this context is a network of interrelated and interdependent organisms and environmental factors.

A broad definition of resilience within a system as understood in systems theory is therefore the capacity for the system to withstand stresses and shocksⁱ. More recently resilience theory has been adapted from environmental science as a useful rubric for understanding the dynamics of other systems, including urban systemsⁱⁱ. In this context, a city-region, with its complex interactions of natural and human environments can be considered as a network of interdependent actors, or a system.

Urban resilience theory is gaining momentum in Australia and notable recent contributions include the collaboration between the CSIRO, Stockholm University and Arizona University to develop a research prospectus (the aim of which is to engender many research contributions to urban resilience against four themes: metabolic flows, governance networks, social dynamics and built environment)ⁱⁱⁱ, work by Cork 'Resilience and Transformation, Preparing Australia for Uncertain Futures'^{iv} and the recent work by Australian authors Walker and Salt, entitled 'Resilience Thinking: sustaining ecosystems and people in a changing world.' Much work is also occurring within the realm of practitioners, some of which remains confidential, but within this context, we will note examples where systems theory and in particular resilience theory is influence practitioner application.

Resilience theory provides an opportunity to consider a paradigm in which the city as a system operates within a set of system-wide rules and tolerances. Within this paradigm, decision-making about the city must understand this network in order to effect decisions which are fundamentally sound.

The principles to guide urban resilience coined by Walker and Salt are particularly useful in how urban systems can be conceptualised; drawing on the complexity of the world and the non-linearity of system behaviour, the concept of a system threshold at which it behaves differently, and the speeds and different spatial scales at which adaption and change occurs. These act as useful underpinnings in unpacking the concept.

We will consider these underpinnings of resilience in relation to Australian cities' capacity to withstand shocks brought about by disaster, but also the longer-term system wide shocks we may see emerging from the effects of climate change and global socio-economic turmoil.

CITIES AND THE GLOBAL POLITY

Recent international events, nearly all of which have occurred at the heart of cities, point to the signs of a crumbling global social and economic model. The second wave of global financial instability, the movement for greater economic and democratic freedoms in the middle-east (the so-called Arab spring), the direct democracy demands of the Occupy Movement, and recent rioting in cities across Britain are being discussed in the one breath as symptoms or symbols of a potent time of change. As we write, debate is raging in the UK over whether the 2011 summer riots had their origins in 'pure greed', criminality or wider social disparity^v. What motivates an 11 year old to steal a rubbish bin, or another to take a pack of water? While the initial statistics demonstrate that the unrest was not primarily orchestrated by gangs, there is significant evidence that those involved were comparatively more disadvantaged^{vi}. The riots were, in a sense, a shock to those cities in the UK which were subjected to them. Buildings were battered down, transport systems were disrupted and people went home early to avoid potential or actual unrest. The causes of the unrest are still being argued about and we do not suggest that we have any definitive conclusion, however we would posit

that there is a significant common thread that runs through the UK riots, the Occupy Movement, and even the Arab Spring.

The affluence that was experienced by many in the west during the 1990s and 2000s is now receding. Yet the vision of cheap-priced consumer goods available to anyone is still ubiquitous. In the Middle East, communities are now demanding access to democratic and consumerist freedoms experienced in the west.

Yet, there is a fundamental disparity at work even in the west: rising costs of living are^{vii} now preventing many from attaining the consumerist dream. Not only can many no longer afford it, but they have watched others seemingly 'steal' the dream, in particular bankers who have received disproportionate bonus payments at a time when banks have been bailed out by governments (within the UK Directors' bonuses and pay packages reported to have risen by 50% in 2010-2011 during which time the UK Government used tax payers money to recapitalise several major banks)^{viii}.

The disconnect between consumerist desire and reality is not just a problem of culture; it sits at the heart of our cities. How, on one hand, can 'the best city in the world'^{ix} London be preparing to showcase itself and the great regenerative power of concerted spend on new infrastructure, stadia, housing and neighbourhoods for the London 2012 Olympic and Paralympic Games, while on the other, be a city brought to its knees for three days by angry youths kicking off a network of conflagration and mayhem? For the young people rioting in Britain, anecdotal evidence suggests that limited employment and life prospects for many involved is compounding the cycle of marginalisation, envy and 'greed'. A clearer example could not be found than the number of local young people who could not read or write and who applied for jobs with the new Westfield at the heart of the East End^x. What are the links for a society which, on the one hand, encourages excessive consumption and greed and, on the other, fails so many young people in providing them with the most basic of literacy and numeracy skills? What are the causes and effects of these disparities and disjunctures as they sit within our world cities?

The relationship between physical form, economic conditions, cultural expectations and our collective capacity to be resilient to such shocks is clearly complex. The social challenges present in Britain may not yet be entirely shared in Australia, but they point to a key tenet of the reason for cities. As huge markets, cities are places of activity, growth, and exchange. If people living in cities have little to do and even less to hope for, civil unrest is one likely outcome. With the majority of the world's population now living in cities, unpacking the potential and challenges of urban life is no longer important for the few, it has become the reality for the many.

RECENT AUSTRALASIAN 'SHOCKS'

Australian and New Zealand cities while not engulfed in the shocks of rioting and less affected by international global uncertainty, have experienced numerous shocks brought about by fire, flood, cyclone, earthquakes and storms. The challenges facing the City of Christchurch following a series of destructive earthquakes on 4 September 2010 and on 22 February and 13 June 2011 are apt examples. The impact has been devastating with over 180 people killed and over 5000 homes to be demolished.^{xi} Since the first earthquake in September the "red zone" a large areas of the Central Business District has been cordoned off with no public access. The long term rebuilding of infrastructure in the city centre will include roads, footpaths, water, sewer, electricity, street and traffic lights and communication networks.^{xii} The impact on the day to day life in the City was highlighted by the story a mother told of her small child drawing a picture of his house. On asking the purpose of the small box in the picture the child responded "that's the port-a-loo". For this 4 year old every house needed a portable toilet, the expectation of a working sewer system had disappeared.

Similarly the flooding in Brisbane in December 2010 and January 2011 resulted in over 35 deaths and large numbers of properties being inundated. Dan Hill's blog on his City of Sound website^{xiii} brings the destruction back to a series of human experiences from living with power failure, the inability to get supplies and the challenges of navigating the flooded city. Watching the destruction Dan Hill comments "It's only our inflexible, non-adaptive infrastructure that can't cope with this. And the infrastructure is failing for sure. Everything feels very contingent, very fragile."

In both Brisbane and Christchurch, the impact of these natural disasters on the local infrastructure can be considered in the context of the lack of adaptability of these systems of provision. Typically our cities are planned to run highly efficiently. Any redundancy in the system is ironed out to maximise efficiency. This results in systems of provision which are taut and which have little spare capacity. The impact of major shocks is system failure. The economic impact of these shocks is so large that they can affect the economic outlook for the entire nation. The New Zealand treasury estimates that the Christchurch earthquakes will cost over \$15 Billion dollars and reduce the countries GDP by 1.5 percentage points. The longer-term impact may be even more far-reaching, particularly if they are compounded by further disasters.

The capacity of cities to respond to shocks brought about through civil unrest, or through natural disasters are similar. Immediate response is of course the realm of the disaster response teams – emergency services and support workers. This is swiftly followed by remediation services including clean-up, repair and rebuild teams. As we have seen in Brisbane, Christchurch and Clapham the community's desire to be involved in this phase of response is evident, and arguably an important element in maintaining or building community cohesion – an important piece in the resilience paradigm.

Throughout time no society however sophisticated, developed and resourced has accurately been able to predict its future but the evidence is strong that whatever happens the future will not look like the past. The challenge planning policy is facing today is what principles, resources and systems will be needed to evolve the cities of today to become the cities of the future?

CONSIDERING RESILIENCE FROM A PLACE OF VULNERABILITY

When discussing the concept of resilience, it is useful to recognise its common shadow: vulnerability. The concept of vulnerability implies a lack of resilience and has been very effectively applied in Australian urban studies.

Contemporary urban vulnerability

Much has been written in recent times about Australian cities and the vulnerability which they engender for certain population segments. The VAMPIRE index^{xiv} is perhaps the best known of this work and it serves to highlight the spatial relationship between economic vulnerability, mobility and housing choice. By mapping mortgage stress in conjunction with journey time and petrol price rises, the index brings together a powerful coalescing of factors that increase the vulnerability of the households in question to economic failure.

We can use the example the VAMPIRE index provides to explore a whole chain of vulnerability, and therefore its implied flip-side of resilience. The chain clearly demonstrates the interconnectedness of decision-making about people, infrastructure, place and resources in our cities.

Seen from an individual household perspective, the prospect of economic failure is of course a whole of life experience: the potential to default on a mortgage and become homeless; constraints on household budgets including an inability to properly feed and clothe the household, to pay heating, water and power bills, or even to afford the petrol to drive to work. The knock-on effects are significant: the potential to lose the home, the job and schooling for the children as well as the untold impacts of stress on the health of all concerned. (Of course it is important to note that the vulnerability of individuals who have diminished skills or who are otherwise marginalised can also be seen to be a factor separated from mortgage stress and oil vulnerability as has been demonstrated in London).

Collective vulnerability within a city to the impact of the factors highlighted by VAMPIRE or lack thereof is far harder to ascertain. Where, after all, do we start? We could begin by counting the collective loss of productivity that results from mortgage default. We could cycle back a few steps in this 'supply chain of vulnerability' to the point at which the decision was (not) made to release new homes in suburbs which were not adequately supported by public transport. We could go back a little further to the point at which governments decided it was not politically possible to raise the funds from the public purse to support extensive transport infrastructure and its ongoing operational costs. We could go one step more to the point at which Australians somehow collectively set their hearts upon the house and garden, set apart from their neighbours, with neat garages and a car available for every home, thus defining the overriding spatial scale

of Australian suburbs as famously identified in 1942 by Sir Robert Menzies in his *The Forgotten People* Broadcast.

“Your advanced socialist may rage against private property even while he acquires it; but one of the best instincts in us is that which induces us to have one little piece of earth with a house and a garden which is ours: to which we can withdraw, in which we can be among our friends, into which no stranger may come against our will.”

It is at this point that much debate resides: to what extent does the scale of the city hinder or help its inhabitants to move about its reaches? Newman and Kenworthy^{xv} famously have defined the tipping point of car dependency as the primary way in which we should understand the scale of our cities. The measure, a way to calculate gross regional density, demands that there be a minimum of 35 people plus jobs in order for an area to be able to escape the gravity of car dependency. Others argue that a similar tipping point away from car dominance could be achieved by increasing petrol prices, restricting road building and increasing public transport spending^{xvi} or strong decentralisation away from major cities and the development of strong regional centres^{xvii}. The debate has perhaps been unhelpfully polarised and while density and design is one very critical element in helping to define city resilience, and as such, a part of a kit of solutions, the debate is perhaps one of the delimiters on what makes our cities resilient.

The implications of choosing to replicate car-dependent cities are wider still. If we consider Australia's position in the league table of carbon polluters per capita, we find ourselves uncomfortably close to the top out of major countries behind just the United States and the rich oil producing Arab states^{xviii}. Many would argue that this is simply a symptom of our resource-producing status. As a nation of miners we are supplying much of the world's materials. Yet, a cross-check against the amount of carbon dioxide we are each personally responsible for in how we live our lives soon puts paid to this excuse. Our homes, on average, are significantly bigger than any others on earth^{xix}. Consuming on average 18 tonnes per household^{xx} we are responsible for twice more CO₂e per household than our near neighbours in New Zealand^{xxi} and 3 times more than our Vancouveran^{xxii} friends when transport and housing emissions are combined.

So, by taking a single cross-cutting issue of carbon emissions, we can trace one contributory factor back to the spatial policies governing our cities. If we take a vulnerability lens to these carbon statistics, we can argue that we are twice as more inefficient than NZ. We are therefore far more vulnerable, economically at least, to pricing impacts on fuel and utility bills. Taking an economic viewpoint, we can also consider what might be the macro-economic impacts of such inefficiency. If we are burning far more resources than needed to achieve the same economic output, we are surely, in the realms of the bottom of the league table. This is a 'leaky bucket' effect where we are using far more resources than needed to achieve the same desired effect. While we have used only one example here of this chain of causes and effects, there are many such chains at work within cities and which have complex effects in city-regions. Obesity amongst city-dwellers, for example, is closely correlated to car-dominance and associated urban form^{xxiii}. The relative 'slow-motion' effect of obesity on public health budgets and on human health is a shock to our city-system but one which is being experienced over a life-time rather than a day or a few hours.

A sharper shock and one which can occur through disaster, is of course the complete interruption in the supply of transport fuel, either because no new supply is being provided, or because supply lines are disabled. This scenario is far more acute as a cursory review of our economy reveals how deeply dependent we have become on transport in every facet of life. Not only are many households highly car dependent but our food supply chains, and our energy supply is almost entirely reliant on road or air-based transport^{xxiv}. The level of immediate resilience to a breakdown in supply is of course the size of the fuel stockpile at strategic locations.

Cycles of production

In better understanding the extent of our vulnerability, it is useful to consider how cycles of production have changed through globalisation and what fresh challenges this poses. The globalisation of economic activity and in particular production of goods means that first tier economies have, to a large extent, lost their

domestic manufacturing industries to countries where the cost per unit to manufacture the product is cheaper(est). The impact on Australian cities was felt over several decades as manufacturing jobs went offshore, factories closed, and the quality and variety of the consumer product changed. While domestic manufacturing is still occurring, any growth that has occurred in the sector has been significantly outstripped by other sectors^{xxiv}. The business model for high street fashion stores for example is now markedly different focusing, according to industry experts, on the triangle of cost, time and quantity, rather than cost, time and quality^{xxv}. As such, bulk product arrives in-store and is aggressively sold for a narrow window before being replaced by the next line. The unwanted product is then on-sold or dumped^{xxvi}. Ironically, Australia is still supplying much of the raw material for use in clothing and footwear manufacture – cotton, wool and leather. In food manufacturing, product that might be grown in Australia can be shipped to one country for processing, another country for packaging and to destination countries including Australia for sale. Australia's reputation as a primary producer continues, while it imports much of its own product back after it has been value-added overseas.

This globalised cycle can only continue to work effectively under three key conditions:

- That there is somewhere in the world where the costs of production are sufficiently differentiated to enable offshoring of a production cycle;
- Global first tier economies remain buoyant and therefore demand for cheap goods remains steady;
- The natural systems which support this approach are sufficiently resilient to be able to fuel such a model.

All of these elements, we would argue, are under threat. China (a key trading partner and one of the BRICS economies), is beginning to offshore its own production by engaging in a buy-up of land (particularly in Africa) in order to extend its means of production. The question must be asked, how long before Africa's economic conditions follow the trajectory of China, India and south-east Asia and it becomes no longer cost-effective produce the goods at the cheapest unit-cost on that continent?

The global economy has seen two significant economic shocks in the past four years. To put things crudely, the first was prompted by excessive consumption matched by unsupported borrowings; the second was caused by a lack of economic growth, brought about by excessive debt. The combined impact of these events are still being played out but the reversal of fortunes for first tier economies means that there is simply less being consumed and inflation and cost of living is on the rise.

The Earth's natural systems are under threat as evidenced by the impact of accelerated climate change.^{xxvii} We do not propose to re-enter this debate for the purposes of this paper, but rather, we accept the balance of evidence that the Earth is experiencing rapid climate change and that the impacts of this are already being felt around the globe. The future impacts are not entirely known, but few scenarios leave room for optimism that our civilisation will continue to follow its current trajectory. If we consider the issue from a risk management perspective there are limited options available. With only one planet there is little opportunity to transfer the risk and with the ambition that Australia and the world community would work together to reduce the risk looking less and less likely, the only remaining risk management strategy would require us to accept the consequences of our actions and begin to plan for an uncertain and dramatically different future.

Australia's addiction to over-consumption and fragile environment places us in a unique position of vulnerability when broader global factors are considered (explored below).

REFRAMING THE DEBATE AROUND RESILIENCE

The apparent collision course we are all on requires a circuit breaker and a long-term altered trajectory thereafter. We, like others (see for example Jackson^{xxviii}), argue that central to this intervention is a reframing of global objectives from those rooted in contemporary capitalism to one which places our collective survival and rejuvenation ahead of profit and 'growth'. We make the assumption here that by collective we mean all species on the planet. To make this intervention, we need to frame some principles against which a framework of interventions can be made that work holistically to deliver a different outcome.

There has been much work done recently on resilience and systems-thinking. One approach which has influenced our work in particular is Janine Benyus's book *Biomimicry*^{xxix} which sets out a number of principles for our future drawing on the lessons which can be learnt from natural processes and cycles. Peter Head's^{xxx} application of these principles in an engineering context demonstrates that globally we have the technical solutions to hand to resolve the challenges posed by climate change, population growth and to some extent, economic disparity. The significant missing strand is the spatial, economic and governance framework which allows us to turn away from our current trajectory and embrace a different way of living.

We have identified a number of concepts, bringing together principles from Benyus and our own experience, as a basis for exploring what this new framework might look like.

These include:

Learning from example

Adaptive reuse

Diversity

Distribution (over centralising)

Optimisation (over maximising)

Redundancy and interdependency

Fractal replication (over unnecessary complication)

Balance

Virtuous cycle of benefits

Overarching these individual principles, we draw on the concept of biomimicry itself to act as a super-framework guiding the application of these individual principles.

Biomimicry

Benyus's work biomimicry is based on the premise that nature has evolved complex cycles of exchange and flows which ensures that it is resilient in the context of stresses and shocks within bounds. The concept is inherently holistic: a whole-of-system ecology that efficiently transports and uses resources to transform these into vastly interconnected life forms which in turn transform into the raw materials for new generations over time. The groundbreaking element of Benyus's work is in the identification of principles which underpin this cycle and their application to human cycles. This analysis reveals that human society, far from mimicking nature is in many cases, is employing systems of operation which are completely countermanding of natural cycles. One obvious example is the way in which we have used resources without considering how to replenish them. The carbon dioxide entering the atmosphere from human activities is being emitted at such a rate that the Earth's natural capacity to sequester carbon is insufficient to maintain an appropriate balance of carbon in the soil, water and atmosphere.

A fundamental challenge is to capture and save energy rather than allowing it to go untapped as a renewable resource, or to use it wastefully. By using as little energy as possible, we counter the leaky bucket effect, making our systems of production more effective and less costly.

The concept of waste comes from a linear analysis of the use of resources. Nutrients in and waste out was a fundamental principle of 19th and 20th century city planning. For hygiene reasons people were separated from sewage and garbage and significant progress was made in population health as a result. We are now in a position where our waste products not only hold highly valuable raw material (such as phosphate and urea), but we have the technology to ensure that resource re-use and remanufacture is a reality, while down-cycling and dumping are the result of poor design and corner-cutting. However, to truly optimise the virtuous

cycle of resource use and reuse, the multiple value of mining 'waste' as a resource needs to be recognised, not just in economic terms but to the environment and society.

Learning from example

Cities are made and remade constantly or so the theory goes. Eating themselves, they are in a constant state of change. For many large cities, there is some truth in this rule of thumb. There are many high profile examples of district-wide urban regeneration in US, UK and Australian cities. While this process can be loosely aligned to some kind of morphological renewal, a deeper question is whether the fundamentals of cities change in this process. Furthermore, what needs to change in contemporary cities for them to become more resilient? One way to answer this question is to examine why some cities have been obliterated from the face of the planet and why others continue to carry on thousands of years after their birth.

What can we learn for example from London and Rome in their longevity and what fatal flaws existed in Machu Pichu? Both London and Rome share some characteristics including large populations, a built form which in general does not extend beyond 4-5 storeys, a neighbourhood structure which is built around local villages and a shared influence from the ancient Romans. Both are slightly inland although London is founded on estuary land and both have large and fertile hinterlands providing abundant harvests as well as large areas of urban green space.

Recent work on the resilience of ancient Constantinople^{xxxii} identifies a number of traits that enabled the city to survive successive waves of invasion. The authors have summarised these lessons as:

"Our message from having revisited the resilience history of Constantinople during more than three millennia is that the keeping of green space for tacit co-production and community-based relationships to land and water have been essential properties for long-term survival and success"^{xxxiii}

The principle of learning from past examples does not necessarily mean slavishly reapplying blueprints but rather, understanding the critical thresholds that meant the difference between survival and destruction and extrapolating from these to understand how they could be reinterpreted in contemporary living. The Constantinople experience emphasises how important flexible green space is for cities. Sometimes referred to as 'green infrastructure' (see for example the London Plan^{xxxiii}) the regenerative power of urban green space and its capacity to meet many co-existing demands make it a vital component of an adaptive city.

Optimise not maximise

As communities have become wealthier the trend witnessed around the world is for an increase in consumption of goods and services in step with increases in wealth. The growth in global consumption is in part fuelled by the globalisation phenomenon we have briefly described: by sourcing goods at a cheaper unit cost, a race to the bottom is established where it is the cheapest priced good, produced in the greatest quantity and in the shortest amount of time that will find its way onto the shelves and hangers of the wealthy first tier nations. Production and consumption cycles have therefore sped up. Where once, we might have had a single mobile phone in any 12 month period, young people are now being encouraged to 'upgrade' every few months. Clothing used to be things that were made to last for years, but fashion clothing today is designed to be worn only a few times before it is discarded. As cycles of consumption have sped up, and the amount we consume has increased, we have effectively 'mined' the world of resources in a way that has never been seen before. Sustainability theorists and organisations such as WWF argue that we have reached and exceeded the Earth's carrying capacity on a per capita basis – in essence moving beyond our global limits^{xxxiv}. The only reason we are able to still survive is that this new-found consumer wealth is grossly skewed in favour of the wealthy consuming nations. Optimising resources as opposed to maximising, recognises inherently that for a resource to be optimised it must continue to be available on a sustainable basis into the future. We must therefore find a way of slowing down our rate of consumption and using the resources we have differently. Both of these strategic tasks require this principle of optimisation.

Diversity

A key biomimicry principle is to avoid monocultures. If we consider this spatially we might recognise that one of the challenges of Australian suburbs is not the 3-4 bedroom detached house as a typology but dominance of the typology (some Sydney suburbs are over 97% of only one type, the detached dwelling). Another challenge is the intertwining of the 'Australian Dream' with a single dominant access mode, the private car, resulting in threats to this 'species' being viewed as an attack on our intrinsic way of life. Diversity is a critical concept in ecosystems where it ensures that there is a rich genetic material and that ecosystems are not highly reliant on a small number of species to remain healthy. The principle of diversity in city-regions can arguably be applied in similar ways on a spatial level, but also in terms of the nature of the activity that cities promulgate.

Distribution

Our current city-system planning generally centralises the provision of power, water, food and even jobs within urban structures that often seem impersonal and belonging to someone else. Power, water and food are typically sourced from outside the city while jobs tend to be provided in city centres and sub-centres. Big imposing city centres create spaces where the authorities are in charge. 'Official' spaces such as houses of parliament, war memorials, hospitals and the like are found at the heart of our cities. Distributed models of provision are often rejected as inefficient (for example few cities in Australia have distributed water storage, or truly multi-nodal transport infrastructure). Yet, shocks to centralised systems tell us that by centralising or concentrating resources in one area or through one main piece of infrastructure we make ourselves highly vulnerable to high magnitude interruptions.

A whole-of-natural-systems approach to the question asks of the system: how can all resources be fully optimised and how is this system mutually self-supporting? Under shock conditions, one element of a city may be disabled, but in theory, the distributed nature of the system means that other quadrants would continue to provide, thereby spreading the impact of the shock over greater resources and reducing its acuity.

Adaptability and reuse

Recently as part of a competition to redesign Christchurch the Arup/Opus team were inspired by the possibilities of the humble lego block. One of the major challenges for the city is the need to replace broken underground infrastructure and with earthquakes continuing this repair may need to happen again and again. The idea was to rethink infrastructure as segmented rather than linear allowing repairs to occur more quickly. As one of the authors of this article was involved in this process, we believe lego could be considered more widely as a prototype for resilience. Unlike the many modern children's toys which only have a single use and are thrown away once damage or boredom have set in, lego has stood the test of time. A city based on a lego prototype would have built in flexibility, with the same objects able to be used in different ways to create a wide variety of objects. It would be adaptable, with pieces able to substitute for another piece which may or may not share the same characteristics. It would enable creativity, personalisation and originality while at the same time retaining a consistent and recognisable form.

Human optimisation

Humans as part of this systems-of-provision approach should also be fully optimised. This means that we find meaningful and fulfilling work for everyone of every working age and ability. How can we do this under current economic conditions? While the Australian economy is experiencing the effects of a mining boom, this may be masking much underlying activity in other sectors – such as the agricultural sector which has seen negative growth. Another way of approaching this issue is to ask what level of unemployment is acceptable to society? First tier economies seem to be able to keep unemployment at around 5% when economies are tracking well. This is considered to be 'full employment'. Yet something is clearly not working well when there are so many in society who remain disaffected. The Commission for a Sustainable London 2012 when asked to consider whether the London 2012 Programme had delivered local and permanent employment for the people of East London in developing the Olympic Park devised a definition for a sustainable job, recognising that there is more to a job than simply its tenure or its location.

A sustainable job is one that improves an individual's life chances and benefits the community – environmentally, socially and economically.^{xxxv}

Taking this definition in the context of systems of provision, we might ask of contemporary Australian cities whether they are providing the appropriate conditions to deliver sustainable jobs that improve life chances as well as delivering wider integrated sustainable benefits. We do not purport to have the analysis to support a discussion of the extent to which jobs meet these criteria and part of the reason is that there are no national measurements for happiness in Australia, nor has there been an analysis of the environmental impact of individual employment roles for example. This begs the question: why not? The answer lies in the frame of the question of course – our current means of measuring productivity, wealth, city growth, city planning do not encompass concepts of resilience, or of a systems based approach.

Redundancy and interdependency

Redundancy is an important concept in resilience theory as it provides the spare capacity necessary for the system to adapt to changes or to shocks. Our cities tend to be designed to deliver maximum efficiency and minimum redundancy. The desire for complete self-sufficiency (which was an early sustainability principle) has proven to be ultimately quite dangerous as it allows little room for any spill-over should there be a high magnitude disturbance to the system. Redundancy within a system can be addressed to some degree through distribution (by mitigating the impact of catastrophic events), but other forms of redundancy may also be needed. One way to achieve this is to increase two-way feedback loops so that resources can flow back as well as forwards in an interdependent system. Redundancy can then be stored across an entire system rather than in nodes. This principle is being employed in electric vehicle design whereby vehicle batteries act as storage for electricity thereby offering distributed networks some redundancy which could be drawn upon at times of peak demand.

Fractal Replication

Leonardo Da Vinci is famous for having applied the golden mean or the Fibonacci code – the balance of proportions replicated throughout nature which we find highly attractive in people, buildings, and in nature^{xxxvi}. The application of Fibonacci in artwork is an example of the power of fractalism, or the imperfect repetition of patterns at different scales^{xxxvii}. Fractal patterns, not just the Fibonacci code can be found throughout nature. Fractal replication has tended to have been designed out of cities through large, centralised systems of provision. Rather than systems which can be upscaled from the household through to street, the neighbourhood and the suburb, centralised systems effectively remove the capacity for local provision to operate in tandem with larger systems. Systems of provision can however be ordered fractally, so that there is a level of replicability at whichever scale the system is operating. Using food provision as an example, local production can result in produce arriving fresher to the table than if it has to be transported long distances before being distributed to retail outlets. Significant cooling is required for the latter along with the application of preservatives. Local production can be up-scaled from back-yard outfits to community gardens, through to city-farms and even eco-cities (see for example Wuhan^{xxxviii}). The argument against fractalism is that economies of scale make some processes redundant. While this is true in many cases, the power of fractalism to also cut out processes (such as large-scale cooling and the application of preservatives in the case of food production) means that it is a concept to be re-explored in assessing the efficiency of different systems of provision.

Balance

The concept of balance in any system of provision or whole of natural cycle is important once resources are considered against their full lifecycle. The growing of timber for commercial purposes provides a renewable resource for the construction industry as well as the energy industry. Timber absorbs carbon dioxide while growing and can be used as a sink for the carbon dioxide emitted in its commercial preparation. However, if the timber grown is not sufficient to replace the timber harvested the cycle of production is interrupted. Likewise, the capacity for plants to fix carbon into soils thereby sequestering it from the atmosphere is a natural system which could be optimised to bring back into balance the level of carbon in the atmosphere versus that in plants, soils and water. Once the world industrialised nations collectively lost contact with the

local and bio-regional balances for the resources we each were consuming. Globalisation now makes it extremely difficult to track resources in terms of bioregional balance. Restoring balance, and systems of measuring balance is a critical task for city-regions.

Virtuous cycles of benefit

The whole-of-natural-system approach relies on there being multiple cycles of benefit operating across the system in intersecting patterns. Each cycle can begin anywhere within the system and delivers mutually beneficial outcomes other links within the cycle. Within cities, we are now beginning to explore limited examples of these cycles of benefit. Using biomass to generate methane which can then be burnt to generate energy is one way in which products that were previously considered waste catalyse other processes^{xxxix}. Waste to energy plants can also use domestic rubbish and can provide a number of by-products including water, recyclates and sequestered carbon in the form of biochar. These cycles of benefit can be far expanded but only where the systems of provision that intersect with them are recognised as part of many virtuous cycles. For example, public investment in pedestrian and cycle infrastructure is often called into question on the grounds of the theoretical cost per user. Yet, by providing the infrastructure we create an opportunity to reduce health costs simply by allowing more people to incorporate physical activity into their daily routine. Reductions in costs to the public health purse allow for more investment to be freed up for other priorities while the ancillary benefits for people walking and cycling including improved mental wellbeing create more vibrant, active and positive communities. These benefits 'belong' to three separate but intersecting government interests: planning, health and treasury.

MEASURING AND EMBEDDING RESILIENCE

Testing such principles requires consideration of how they would be applied after a shock to a city. As we have indicated the initial response to shocks in urban areas is fairly similar, requiring some form of emergency response. Once the immediate shock is over, the longer-term challenges are many and varied. For the purposes of this paper, we consider the intersection of these in a spatial context.

Drawing on the concept of a system of provision, we can see both people and resources as part of a provision system. Key questions (most essentially are not new but we contextualise them here as part of the resilience debate) are as follows:

- Can people easily access work, housing, food and services (and what proportion can do this through walking or cycling or without the need to travel thereby employing a principle of local access)
- Is food affordable and able to be sourced locally and regionally (what redundancy is in this system using the distributed model of provision)
- What level of self-sufficiency is available for domestic water supplies and what regional support is available (self-sufficiency and redundancy)?
- How much non-renewable material is being used for each citizen of a city and how much renewable material is freshly circulated each year (optimising resources)?
- Are local species increasing or decreasing in numbers and diversity?
- How much energy is used per person and what percentage is from renewable sources?
- How many jobs could truly be considered sustainable?
- How does the spatial form engender rather than abrogate personal responsibility (optimising each actor)?
- How does spatial form engender rather than abrogate civic responsibility (optimising the synergy of collective individuals)?

The current proposals by the Council of Australian Governments to identify ways to measure quality of life go some way to being able to measure city-wide resilience. What is missing is the theoretical underpinning that recognises and measures the deep interconnections between people, the economy, the society and the environment. As we have identified, this requires a recognition of the system-wide interactions and interdependencies. These can be effectively measured and understood in the context of contemporary computational capacity.

GOVERNING FOR RESILIENCE

Optimising resources

To optimise all resources effectively requires a way to understand what resources are available and how they can be optimised. This has significant implications for land-use and strategic planning in cities.

As part of technical work to support the development of the NSW Metropolitan Plan ^{xi}, these authors proposed the Government support approaches to overlay or incorporate integrated resource assessments into land-use planning processes, to optimise carbon reduction. This approach is aimed at developing a comprehensive new land-use planning layer to incorporate carbon reduction goals into all strategic city decision-making. It could be made more holistic and address energy, water, waste and materials in this way. The implementation of new ways of organising resources, for example, opportunities to share waste products across property boundaries (ie Industrial symbiosis) urgently require enabling planning approaches so that any legal and physical obstacles to their implementation can be resolved.

Governance that is fit for purpose

The development of modes of governance which mirror the flows of resources and their networked interactions is one possible way to ensure that governance always considers cross-cutting issues appropriately. Research into models of governance in the context of resilience has included for example the comparison of polycentric and centralised governance in two US cities: Baltimore and Seattle. This study notes the considerable benefits that networks of governance deliver ^{xii}. While not always practical, networks of issues (as opposed to governance structures) at least enable us to track issues and impacts through a system.

Being able to consider cross-cutting issues at a strategic level therefore requires more than embedding single issues comprehensively within the planning framework. It also requires a way in which these issues can speak to each other. Work underway within Western Sydney (soon to be published) aims to embed a number of priority issues in a cross-cutting framework for the region and to analyse these cross-cutting impacts. By creating such a framework at the most strategic level, there is an opportunity to track these cross-cutting resource flows, and the implications of policy decisions down to the most local level.

New ways of providing legal, financial and commercial governance are also being explored for example in the energy market. Renewable energy in particular requires different governance models to ensure that the upfront cost of investment is able to be recognised across the life of the project. Models which sign energy users to long-term contracts, or which provide exclusive and compulsory sign-up conditions are all being explored in various cities around the world.

Given the length of this paper we would like to use a single example of food to demonstrate the full power of a resilient, systems-based approach to cities.

Food

Using food as a focus for this discussion, we can start by recognising that current fresh fruit and vegetable production for Australian cities is largely concentrated in a handful of large growing areas across the nation (south east Queensland and Northern NSW, the Murray, Tasmania, southern West Australia and the Adelaide Hills) ^{xiii}. Australia is a food exporter including of fresh fruit and vegetables. It exports more than it imports. However, despite Australia's significant output, its food baskets are highly vulnerable precisely because they are so concentrated. For example, when Queensland's tomato seedling industry was

sabotaged, the nation's commercial stock of tomato seedlings was significantly delayed by four to six weeks^{xliii}. When cyclones and floods hit Queensland, the nation's supply of tropical fruit was critically undermined^{xliiv}.

As the frequency of natural disasters increases, so too does the likelihood that more critical interruptions to parts of the fresh food supply chain will occur. To mitigate this, there is a strong argument for increased product diversity within the food growing regions, and greater distribution of fresh food growing closer to urban centres. Diversity of food production could greatly improve the ecological value of farmland (through allowing for greater crop rotation) while reducing the risk of spread of disease^{xliiv}.

Approaching this point from another place within the production cycle, local sourcing of food implies that not only is it available to the family within their neighbourhood at an easy walk's distance, but at a regional scale, that it is grown within a regional hinterland. Not all food is in season all the time so this framework requires us to re-examine what is acceptable in terms of the variety of food provision. What proportion of food coming from outside of the local region could be considered acceptable within a framework of resilience? In addition, what level of food storage is required for a city in the event of interruption to food supplies? Where is food stored and whose responsibility is it to maintain an emergency food distribution network?

A common complaint of agriculturalists is that local food growing is inefficient, poorly regulated and does not replace the core demand for fresh fruit and vegetables. However, even 5-10% improvement in the amount of locally available food reduces pressure on food imports from outside the region and therefore improves resilience. Indeed, diversity of food sources is precisely what is required to spread risk and minimise the potential for a critical failure of the systems of provision.

Food growing can be labour intensive and provides the opportunity for local jobs fostering a local economy. There are many unfortunate examples of places which have lost their local food growing tradition and food economy in favour of expensive imports. Many remote Indigenous communities are hostages to poor quality and expensive food imports, while many Pacific Island nations have had their local food economy hijacked by cheap, poor quality dumped product from larger nations such as the US and Australia. In both cases, the lack of affordable, nutritious food is causing significant health issues including increased morbidity and mortality rates. While not city examples, these stories serve to highlight the perverse outcomes on populations when fresh, affordable and locally grown food is no longer available (for whatever reason). Food industries within cities can provide economic opportunities for farmers, packaging and wholesaling workers, cooks, retailers and food preservers. Food waste can be collected and used as compost or as an energy source.

The distribution of food within cities is at present highly organised. Fresh fruit and vegetables are sold primarily through supermarkets which rely on large distribution centres. Deliveries to local supermarkets are coordinated and optimised to reduce trip times and lengths. A distribution pattern which is far more multi-nodal and therefore smaller in scale has the potential to produce perverse outcomes for air quality and fuel consumption (as more trips are potentially made). However, alternative systems of distribution are possible, everything from households picking up their groceries from the 'farm-gate', to small-scale electric delivery vehicles being used throughout the city, and including delivery push bikes for loads of under 100 kilograms (which is a familiar sight in London). The pattern and nature of the distribution network benefits from this diversity of approach by, on the one hand bringing people closer to the source of production, and on the other, bringing workers back into the community equation.

The amount of food households waste is another perverse outcome which can be challenged through a more resilient approach. At present, food is thrown away having been purchased and not been eaten.^{xlivi} There are many possible causes for this food wastage including the infrequency of shopping trips and therefore the amount that is bought, a disconnect between food purchasing and food planning, and premature food spoiling. By moving away from infrequent but large food purchasing expeditions to daily and local food purchasing, households could avoid significant waste because choices would be more closely aligned with plans for cooking and there would be far less time for food to spoil before being eaten.

To fully understand the impact of a resilient urban food system of provision, one needs to undertake more than a cost benefit analysis. It requires an assessment that measures wellbeing and happiness levels in people engaged in food growing or preparing, changes to urban wildlife from an increase in fruit, nut and seed producing plants, changes in waste going to landfill, impacts on local employment, innovations in the transport and logistics industry and in the packaging industry, and the measurement of urban vibrancy in places where food markets become the norm.

This kind of assessment needs to be undertaken before the results can be understood. For now, all we can do is point to individual examples of good practice. However, we have argued that without an understanding of whole-of-system impacts, individual case studies do not give a true indication of the overarching benefits or impacts of system-wide changes.

CONCLUSION

Our core mission for this paper was to explore ways to strengthen urban resilience. We have made the case that resilience to natural and socio-economic shocks is critical. We have argued that there are many global incursions on resilience at work in and on our cities at present, many of which relate to perceived imbalances in wealth, access, consumption and production of goods and services and in cities themselves (buildings, transport, views, amenity). Drawing on the significant contribution of resilience theorists, we argue that whole systems of provision must be reviewed in the context of the natural systems to determine how resilience can be bolstered. We have put forward a number of principles and questions to guide this work, and given a number of examples where governance can be enhanced to allow for resilience principles to be embedded into our planning systems. We have given a hypothetical example of how a system of provision might be transformed to be more resilient, focussing on the fresh fruit and vegetable industry; and we have argued that this assertion needs to be tested at a system-wide level to truly understand the benefits and indeed the impacts.

We believe that there is little time for Australian cities to embark on this exercise. The natural and socio-economic challenges we face are becoming more intractable the longer we delay in forging a systemic response. Planning and governance of Australian cities has typically been iterative and quite piecemeal. This needs to change urgently and in so doing, re-examine our planning goals to incorporate resilience as a key aim.

Our assertion is that resilience theory offers a challenging but potential transformative paradigm for reconfiguring cities and all within them. This is not the purview of planners alone and must be a task that is supported by all of government, businesses and the community.

REFERENCES

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- ⁱⁱ Resilience Alliance 2007 Urban Resilience Research Prospectus, CSIRO Australia, Arizona State University, Stockholm Institute Accessed 02/09/11 http://www.resalliance.org/index.php/urban_resilience Accessed 02/09/11
- ⁱⁱ Holling CS 2001 Understanding the complexity of Economic, Ecological and Social Systems *Ecosystems*, 4:390-405
- ⁱⁱⁱ Resilience Alliance 2007 *ibid*
- ^{iv} Cork S 2010 Resilience and Transformation Preparing Australia for Uncertain Futures CSIRO Publishing
- ^v Cameron 2011 15 August David Cameron on riots: Broken Society is top of my political agenda <http://www.guardian.co.uk/uk/2011/aug/15/david-cameron-riots-broken-society?INTCMP=ILCNETTXT3487> Accessed 04/09/11
- ^{vi} Ministry of Justice October 2011 Statistical Bulletin on the public disorder of 6th to 9th of August 2011 – October update <http://www.justice.gov.uk/downloads/publications/statistics-and-data/mojstats/august-public-disorder-stats-bulletin-241>
- ^{vii} Hosain N et al March 2011 Impact of the Global Economic Downturn on communities and poverty in the UK Joseph Rowntree Foundation <http://www.jrf.org.uk/sites/files/jrf/experiences-of-economic-downturn-full.pdf> Accessed 04/09/11
- ^{viii} BBC News 28 October 2011 <http://www.bbc.co.uk/news/business-15487866> downloaded 2 Nov 2011
- ^{ix} Johnson B 2010 May 13 Boris Johnson hails London cycle super highways <http://www.guardian.co.uk/politics/2010/may/13/boris-johnson-blue-cycle-superhighways> Accessed 04/08/11
- ^x Evening Standard 01/09/2011 <http://www.thisislondon.co.uk/standard-olympics/article-23983067-bosses-shocked-by-hundreds-of-games-staff-who-cannot-read-or-write.do> Downloaded 2 Nov 2011
- ^{xix} The Star, Canterbury
- ^{xii} Draft Central City Plan, Christchurch City Council August 2011
- ^{xiii} <http://www.cityofsound.com/blog/2011/01/flood.html>
- ^{xiv} Dodson J Sipe N 2008 Unsettling Suburbia: The new landscape of oil and mortgage vulnerability in Australian suburbs. Griffith University. http://www.griffith.edu.au/data/assets/pdf_file/0003/88851/urp-rp17-dodson-sipe-2008.pdf Accessed 02/09/11
- ^{xv} Newman P Kenworthy J 1999 Sustainability and Cities Overcoming Automobile Dependence Island Press
- ^{xvi} Kirwan R 1992 (1992) Urban form, energy and transport: a note on the Newman – Kenworthy thesis, Urban Policy and Research
- ^{xvii} Troy P 1992 Let's look at that again Urban Policy and Research
- ^{xviii} http://www.nationmaster.com/graph/env_co2_emi_percap-environment-co2-emissions-per-capita Accessed 02/09/11

-
- ^{xix} Commsec 2009 Australian homes are biggest in the world. Economic Insight November
<http://images.comsec.com.au/ipo/UploadedImages/craigjames3f6189175551497fada1a4769f74d09c.pdf>
Accessed 02/09/11
- ^{xx} Australian Greenhouse Calculator http://www.epa.vic.gov.au/AGC/r_emissions.html#! Accessed 02/09/11
- ^{xxi} Vancouver's Shrinking Footprint 2011 BC Climate Action Toolkit <http://www.toolkit.bc.ca/success-story/vancouver-s-shrinking-footprint> Accessed 02/09/11
- ^{xxii} Giles Corti B 2006 The impact of urban form on public health
<http://www.environment.gov.au/soe/2006/publications/emerging/public-health/index.html>
downloaded 2 Nov 2011
- ^{xxiii} BITRE 2009 Australian Transport Statistics Yearbook 2009
http://www.bitre.gov.au/publications/10/Files/BITRE_TRANSPORT_STATS_YEARBOOK_2009.pdf
Accessed 02/09/11
- ^{xxiv} Parliament of Australia 2007 Australian Manufacturing: today and tomorrow House of Representatives
Standing Committee on Economics, Finance and Public Administration Commonwealth of Australia
<http://www.aph.gov.au/house/committee/efpa/manufacturing/report/front.pdf> Accessed 02/09/11
- ^{xxv} Weller S October 2007 Retailing, Clothing and Textiles Production in Australia
<http://www.cfses.com/documents/wp29.pdf> downloaded 2 Nov 2011
- ^{xxvi} Kellock Jo 24 August 2010 Presentation A case of Waste – Designing a Solution
http://wasteinthecity.wikispaces.com/03_Seminar downloaded 2 Nov 2011
- ^{xxvii} IPCC 2007 Climate Change 2007 Synthesis Report IPCC
- ^{xxviii} Jackson T 2009 Prosperity without Growth Routledge
- ^{xxix} Benyus J 1997 Biomimicry: Innovation Inspired by Nature. William M Morrow
- ^{xxx} Head P 2008 Entering the Ecological Age: the Engineer's Role. The Institution of Civil Engineers
Brunel Lecture Series
- ^{xxxi} Barthel S et al 2011 Innovative Memory and Resilient Cities: Echoes from Ancient Constantinople Studies
in Global Anthropology 15 Uppsala University Press
- ^{xxxii} Archdeacon 2011 Constantinople: An example of urban resilience
<http://www.sustainablecitiesnet.com/research/constantinople-an-example-of-urban-resilience/> Accessed
03/09/11
- ^{xxxiii} Mayor of London 2011 The London Plan
<http://www.london.gov.uk/thelondonplan/policies/3d-08.jsp> downloaded 2 Nov 2011
- ^{xxxiv} WWF 2010 Living Planet Report
http://wwf.panda.org/about_our_earth/all_publications/living_planet_report/ downloaded 2 Nov
2011
- ^{xxxv} Commission for a Sustainable London 2012 2010 A Clear Run to Employment pp 2
http://www.cslondon.org/wp-content/uploads/downloads/2009/01/2009_Employment_and_Skills_Review.pdf
Accessed 02/09/11

-
- xxxvi <http://library.thinkquest.org/27890/applications6.html> downloaded 2 Nov 2011
- xxxvii <http://en.wikipedia.org/wiki/Fractal> downloaded 2 Nov 2011
- xxxviii Wu Zhiling, Jos Verweij, Bert Smolders 2006 Framing urban development; spatial strategies by sister-cities Wuhan, China and Arnhem, Netherlands http://www.isocarp.net/Data/case_studies/1160.pdf downloaded 2 Nov 2011
- xxxix Alternative Energy News <http://www.alternative-energy-news.info/waste-renewable-energy-source/> downloaded 2 Nov 2011
- xl NSW DoP 2011 Metropolitan Plan for Sydney 2036, Climate Change Chapter pp 175 http://www.metroplansydney.nsw.gov.au/portals/0/pdf/METRO2036_G_CLIMATECHANGE.pdf Accessed 04/09/11
- xli Romolini M, Grove M 2010 Polycentric networks and resilience in urban systems. A comparison of Baltimore and Seattle. ESA 2010 Meeting. Presentation <http://precedings.nature.com/documents/5222/version/1/files/npre20105222-1.pdf>
- xlii Horticulture Australia Value of Horticulture http://www.horticulture.com.au/areas_of_Investment/Environment/Climate/value_horticulture.as downloaded 2 Nov 2011
- xliii Sydney Morning Herald Seedling sabotage destroys millions of tomato plants 8 July 2010 <http://www.smh.com.au/national/seedling-sabotage-destroys-millions-of-tomato-plants-20100707-100q3.html> downloaded 2 Nov 2011
- xliv The Australian 3 February 2011 <http://www.theaustralian.com.au/in-depth/cyclone-yasi/australian-banana-price-crisis-looms-again-as-cyclone-yasi-wipes-out-crop/story-fn7rj0ye-1225999542538> downloaded 2 Nov 2011
- xlv Ouma G, Jeruto P Sustainable horticultural crop production through intercropping: The case of fruits and vegetable crops: A review <http://scihub.org/ABJNA/PDF/2010/5/ABJNA-1-5-1098-1105.pdf> downloaded 2 Nov 2011
- xlvi NSW DECC Love Food Hate Waste <http://www.nsw.gov.au/articles/love-food-hate-waste> Accessed 04/09/2011