Curtin University Sustainability Policy Institute

Transitioning to Regenerative Urbanism

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Author's declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

[Author]

Statement of contributors

All of the written materials submitted as part of this PhD by Publication (Hybrid) were conceived and coordinated by Giles Thomson. I also undertook the majority of the writing and case study analysis for each publication.

Signed detailed statements from each co-author relating to each publication are provided as appendices at the back of this volume (Appendix A).

Signed:

Giles Thomson, PhD Candidate

Professor Peter Newman, Principal Supervisor

Date: December 2016

Abstract

This thesis examines regenerative urbanism as a pathway for transitioning to greater planetary sustainability. The global impact of conventional human lifestyles and activities is unsustainable, with the resulting adverse impacts upon the biosphere transgressing or threatening several planetary boundaries. This thesis argues that cities, as geographic concentrations of human activity and governance, are the appropriate locus for attention to rapidly address planetary sustainability.

The thesis focuses on possibilities for shifting the normative model of “western” cities. The conventional model has evolved out of the dominant Modernist planning paradigm, which results in relatively liveable, but highly unsustainable cities. In the thesis, emphasis is placed upon (infra)structural transitions with limited discussion of the associated cultural transitions that are necessary to transform cities. This thesis argues that the process for the structural transition of urban fabric from suboptimal performance to regenerative performance is *regenerative urbanism*. Regenerative urbanism represents a new planning paradigm capable of delivering liveable *and* sustainable cities that can operate within planetary boundaries, mitigating the environmental risks that cloud the horizon of human civilisation.

The thesis consists of seven publications supported by an exegesis. In combination, they explore the physical attributes and urban planning approaches necessary for regenerative urbanism within a planetary sustainability framework. This is achieved by describing the planetary systems within which we exist, and identifying the strategic guidelines, actions and tools necessary for the delivery of regenerative urbanism.

The thesis applies the concept of *urban metabolism* to evaluate urban sustainability performance. Urban metabolism involves the measurement of material inputs and outputs required to construct, operate and support life in a city. The urban metabolisms of different (walking, transit and automobile) urban fabrics in Perth, Australia, are analysed. Understanding the performance of the different fabrics provides urban planning with a basis for enabling major reductions in metabolism, and is an original contribution of this thesis. By optimising *urban fabric* and applying a *regenerative design* overlay, this thesis argues that it becomes possible to deliver highly liveable and sustainable urban development. Integration across systems (energy, transport, water, waste, food, biodiversity) and scales (plot, precinct, city) can deliver sustainable, and potentially even *regenerative,* urban environments.

Genuinely regenerative cities may offer solutions to a number of the “wicked problems” and “grand challenges” – such as climate change, resource scarcity, biodiversity loss and social inequity – that will confront humanity in this coming century. Currently, no existing city can

claim to be regenerative. However, the thesis draws upon multiple case studies, mostly at the precinct scale, to illustrate approaches that are regenerative in one or more areas (e.g. energy, water, waste, food or biodiversity); case studies are also evaluated to describe the *processes* that define regenerative urbanism.

Global interest in regenerative cities is growing rapidly, but to date the approach remains niche. For city redesign to have a meaningful effect on sustainability at the planetary scale, a global network of regenerative cities will be necessary. To achieve this, the thesis argues that regenerative urbanism will need to move from being a niche activity to becoming a *mainstream* approach that is applied rapidly and at scale. Mainstreaming regenerative urbanism has the potential to deliver regenerative cities that can offset and repair negative human-induced environmental impacts on the biosphere, and reframe human impact in the Anthropocene as a positive force for hope.

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Dedication

I would like to dedicate this thesis to Jayne Bryant, my unofficial supervisor, for indulging my need to write words when I should have been focusing on planning our wedding. I appreciate all your support, guidance and love – thank you for everything.

Publications submitted as part of this thesis

Below is a bibliographic list of the publications representing the body of research for this PhD thesis.

Refereed Articles

1. **Thomson, G.,** Newman, P. (2016) Geoengineering in the Anthropocene through Regenerative Urbanism. *Geosciences*. *6,* 46; doi:10.3390/geosciences6040046
2. **Thomson, G.,** and Newman, P. (2016) Urban Fabrics and Urban Metabolism – From Sustainable to Regenerative Cities. *Resources, Conservation and Recycling* (invited paper, accepted)
3. **Thomson, G.,** Newton, P., and Newman, P. (2016) Urban Regeneration and Urban Fabrics in Australian Cities. *Urban Regeneration and Renewal*. 10:2 Henry Stewart, London

Book Chapters

4. **Thomson, G.** and Newman, P. (2016) Sustainable Infill Development. In: *WA Infill Housing Futures*. Rowley, S., Ong, R., Duncan, A. (Eds). (accepted, forthcoming)

Conference Proceedings (Peer Reviewed)

5. **Thomson, G**. (2016) Material Flows, Information Flows and Sustainable Urbanism. *9th International Urban Design Conference Proceedings*, Canberra, Australia
6. **Thomson, G**. and Rauland, V. (2014) GRID: A new governance mechanism for financing eco-infrastructure at the district scale. *7th International Urban Design Conference Proceedings*, Adelaide, Australia
7. **Thomson, G**., Newman, P., and Matan, A. (2013) A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia *State of Australian Cities 2013 Conference Proceedings.* Sydney, Australia

Other relevant publications (not submitted as part of this thesis)

Referred articles

1. Webb, R., Bai, X., Costanza, R., Griggs, D., Moglia, M., Neuman, M., Newman, P., Newton, P., Norman, B., Ryan, C., Schandl, H., Stafford Smith, M., Steffen, W., Tapper, N., **Thomson, G.** (2016) Identifying priority areas for urban research and practice towards sustainability: a co-design approach (invited paper in preparation for international journal)

Book chapters

1. **Thomson, G.,** Hampson, K., and Newman, P. (2016) New Technologies and Processes for Infill Development. In: *WA Infill Housing Futures*. Rowley, S., Ong, R., Duncan, A. (Eds) (accepted, forthcoming)
2. **Thomson, G.** and Newman, P. (2016) Infrastructure for Infill. In: *WA Infill Housing Futures.* Rowley, S., Ong, R., Duncan, A. (Eds) (accepted, forthcoming)
3. Newton, P. and **Thomson, G**. (2016) Urban Regeneration in Australia. In Roberts, P. and Sykes, H. (eds), *Urban Regeneration: A Handbook*. Sage, London, UK.
4. Rauland, V. and **Thomson, G**. (2015) Mainstreaming Sustainable Precincts: Sharing Experiences. In Perinotto, T. (ed.) *Creating Sustainable Precincts*. Fifth Estate E-Book

Reports

1. Stocker, L., **Thomson, G.,** McKellar, R., Rooney, A. (2014) *Greater Curtin, Climate Adaptation Plan*, Curtin University Properties, Facilities and Development. Perth, Australia.
2. **Thomson, G.** (2014) *A Review of Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia*. Scoping Study. Cooperative Research Centre for Low Carbon Living, Sydney, Australia.
3. **Thomson, G**. and Twomey, P. (2014) *Sustainable Built Environment – Global Leaders.* Desktop Review, Cooperative Research Centre for Low Carbon Living, Sydney, Australia.
4. **Thomson, G**., Irger, M., Ding, L, Dave, M. (2015) *Benchmarking the CRC-LCL: An overview of current global research activity in the field of low carbon living and the built environment*. Cooperative Research Centre for Low Carbon Living, Sydney, Australia.
5. **Thomson, G**. and Kraatz, J. (2016) *Valuing Social Housing Data Case Study*. Sustainable Built Environment national research centre project 1.41 (PSG steering group report). June. Perth, Australia.
6. **Thomson, G.** and Newman, P. (2016) *Perth, Scenario Planning Project, Big City Planning.* Sustainable Built Environment national research centre project 1.44. Perth, Australia.

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List of abbreviations

BAU	Business as usual.
BIM	Building information systems
CDR	Carbon dioxide removal
CRC-LCL	Cooperative Research Centre for Low Carbon Living
CO_2e	Carbon dioxide equivalent (as a metric for measuring GHG)
CUSP	Curtin University Sustainable Policy Institute
Dw/Ha	Dwellings per hectare (residential density metric)
ESCo	Energy service company
Gha	Global hectares (a per capita measurement of ecological footprint)
GHG	Greenhouse gas
GRID	Greening regenerative improvement district
ICLEI	Local Governments for Sustainability (Formerly 'International Council for Local Environment Initiatives')
IGC	International Geological Congress
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable development goals (released by the United Nations in 2015)
TCI	Technology and construction innovation
TIF	Increased tax increment
TIPUM	Towards an interdisciplinary approach to urban metabolism
TOD	Transit oriented development
UN	United Nations
WA	Western Australia (state)
WFC	World Future Council

Chapter 1 Introduction

Regenerative urbanism is an emerging theory and practice. It is less than a decade old and its parameters are still being defined. This thesis explores regenerative cities and how regenerative urbanism may be used as an organising principle for urban development practice (Girardet 2010, p.18). I use the term as a transdisciplinary concept that combines the following knowledge domains:

- ***regenerative design***: a design approach that takes nature-based strategies and applies them to human systems with the intention of designing systems that minimise destructive ecological impact and seek opportunities to regenerate the biosphere. This approach requires a shift from a mechanistic worldview to an ecological world view (Benne & Mang 2015; Mang & Reed 2012; du Plessis 2012)
- ***urbanism***: the study of the processes of change in towns and cities (Cowan 2005), and approaches to city making.

Regenerative urbanism applies regenerative design principles to urban planning and city making processes. The term was first used in 2010 by Girardet (2010) in a brochure prepared for the World Future Council outlining the urgent need for a new sustainability paradigm for city planning and design – Girardet called the new paradigm the *regenerative city*. Regenerative urbanism is the process of creating regenerative cities.

This hybrid thesis by publication explores these ideas by seeking opportunities and leverage points for scientific research to influence the professional practice of urban planning and design. A number of case studies are used to understand, categorise and illustrate current best practice in terms of urban planning and existing examples of regenerative urbanism or projects with the potential to be regenerative. Examples of typical issues to be avoided are also used, but sparingly. Seven publications comprise the bulk of the thesis; the full publications are included at the end of this thesis. Each publication responds to a different aspect or scale of urban redevelopment to describe how a city may transition towards becoming a regenerative city.

Supporting the publications is this exegesis (Chapters 1–7 of the thesis). The exegesis provides an explanatory overview. Its aims are to place the key ideas of the thesis within the broader context of the field of study and to link the publications to form a coherent narrative. The structure of the exegesis sets the context by outlining the background and research questions (this chapter), describing the research design and methods (Chapter 1), and providing a literature review (Chapter 3). It then offers a brief summary of each of the papers (Chapter 4), before discussing the key observations (Chapter 5), conclusions (Chapter 6) and recommendations for further study (6.1). The publications are provided in full after 6.1.

1.1 The need for this research

Once constructed, urban environments are slow to change. Buildings typically last for decades and infrastructure such as roads and pipes can potentially last for centuries. Therefore, design for urban elements should be "robust" (Hall 2013). Robust design delivers resilient and adaptable urban form. Structures should not only meet the needs of today, but, ideally, also meet the social and policy needs of the future.

However, the future is increasingly uncertain. The world is currently undergoing a period of rapid change, ecologically, socially and economically. Rapid change and uncertainty are associated with the so-called "grand challenges" of climate change, resource scarcity and social inequity (Bina et al. 2016). This uncertainty makes problem definition difficult (Wittmayer et al. 2014). This is particularly true of complex systems, like cities, which, due to the complex interdependencies of multiple subsystems, lead to "wicked problems" – problems that offer no simple solution (Rittel & Webber 1973).

However, uncertainty also presents new opportunities by creating space for the emergence of new narratives that can shape new more desirable futures (Inayatullah 2015). The uncertainties presented by the grand challenges tend to be polarising and lend themselves to fostering fear; but in times of fear, positive narratives can generate momentum for collective action to deliver a more hopeful future (Inayatullah & Milojević 2015). Regenerative cities offer such a narrative.

This research offers a framework, comprising a series of principles, that can assist with the translation of the regenerative cities concept into a broadly replicable model of urbanism – a regenerative urbanism.

The growing interest in sustainable cities corresponds with the rapid rise in mainstream environmental consciousness seen over the last two decades. As awareness of environmental issues has grown, so has the sustainable cities agenda become increasingly important for national and international policy directions. Significant steps have been taken towards forging international agreements. These include the announcement of the Sustainable Development Goals (SDGs) in September 2015 (United Nations General Assembly 2015) and the "Paris Agreement" (COP21) in December 2015 (United Nations 2015a). However, the process for meeting these agreements is not so clear. Cities, especially where delivered through a regenerative urbanism, can function as a central plank in addressing the grand challenges of climate change, resource scarcity and rapid population growth (Bai et al. 2016).

Although the infrastructural components of sustainable urbanism are well documented, the processes that lead to successful delivery are not so widely documented. Yet knowledge of delivery may be the key to unlocking sustainable development. This thesis focuses upon expanding theory on the regenerative city and highlights delivery lessons from successful case studies with the intention of determining pathways to elevate regenerative urbanism from a niche activity to becoming a mainstream practice.

In October 2016, the *New Urban Agenda* announced at Habitat III called for a "new paradigm" that will "redress the way we plan, finance, develop, govern and manage cities and human settlements, recognizing sustainable urban and territorial development as essential to the achievement of sustainable development and prosperity for all". Actions to achieve this outcome would include "integrated urban and territorial planning and design … to optimize the spatial dimension of the urban form and to deliver the positive outcomes of urbanization" (United Nations 2016, pp.3–4). I hope to contribute to such an agenda with this thesis.

This research is needed because:

- There is a need for a new urban paradigm (United Nations 2016). This research seeks to determine whether regenerative urbanism could be this paradigm and, if so, how it could be delivered and operationalised at scale.

- There is a need for greater translation of science into policy (Norman 2016; McPhearson et al. 2016; Bai et al. 2016). This research aims to link ecological systems thinking within planetary boundaries to the practical field of urban planning.

- Rapid population growth could lead to an additional three to four billion people by the end of the century (United Nations 2015b). Current research indicates that some planetary boundary thresholds are already being transgressed (Steffen, Richardson, et al. 2015). New sustainable patterns of living need to be developed to counter the looming crisis of continued population growth and resource demand in an already threatened world (Rockström et al. 2009; Steffen et al. 2011; Rees & Wackernagel 2008). This research will look at how the design of cities can assist with decoupling consumption from liveability, which may allow this growth to occur, while avoiding an existential crisis[1]. An existential risk is "one where humankind as a whole is imperilled" (Bostrom 2002). Bostrom (2002) in an analysis of human extinction scenarios explains that environmental considerations such as runaway global warming and resource depletion or ecological destruction are among these risks.

- To transition from conventional to sustainable patterns of living is incredibly complex (Geels & Schot 2007; Geels 2002; Loorbach 2010; Roorda et al. 2014). This research determines possible leverage points and builds a case for those that I argue have the

1 The Oxford University Future of Humanity Institute website (http://www.existential-risk.org) lists the two dozen most important papers written on existential risk.

greatest potential to catalyse urban sustainability transitions.

1.2 Other research in this area

The pursuit of sustainable cities is not a new area of investigation, with earlier contributions from academics such as Beatley (2009; 2011), Droege (2008; 2010), Girardet (1996; 2000; 2004; 2015), Lehmann (2010), Newman and Kenworthy (1999; 1989; 2015), Newton (2008; 2014; 2012) and Norman (2016; 2009; 2010), among others. Each of these has written extensively about the various physical elements of, and the processes for delivering, sustainable cities. However, interest in this field has grown considerably over the last couple of decades, and with this increased interest has come an explosion of concepts relating to sustainable, smart, resilient, low carbon, ecological and green cities (de Jong et al. 2015).

In turn, a range of *urbanisms* have been promoted as potential solutions to shape the discourse and practice of delivery of these aspirational end states. These include, ecological urbanism (Mostafavi et al. 2016), green urbanism (Lehmann 2010; Beatley 2012; Beatley & Newman 2012; Newman & Matan 2013), sustainable urbanism (Farr 2012; Ritchie & Thomas 2013; Calthorpe 2010), new urbanism (Talen 2013) and landscape urbanism (Waldheim 2012). Many of these concepts are less than a decade old demonstrating the current level of interest in this field and among the most aspirational approaches are those related to regenerative approaches. This thesis analyses the approach of regenerative design as applied to cities. Although the concept of regenerative cities was first formally presented in Girardet's (2010) pamphlet, earlier references to the concept of regenerative design as applied to human settlements date back to the late 1980s (Lyle 1996). These are discussed further in the literature review. However, the whole-of-city application of the concept can be attributed to Girardet's (2010) World Future Council pamphlet. In 2013, the UN-Habitat publication *The Future We Want, The City We Need* stated, "The city we need is a regenerative city" (UN-Habitat 2013). In 2015, Girardet published a book-length version of his 2010 pamphlet: *Creating Regenerative Cities* (Girardet 2015). In the same year, regenerative design in relation to urban environments was the topic of a special volume of the *Journal of Cleaner Production* (Zhang et al. 2015). Since then, academic publications on this topic have proliferated and the subject is beginning to permeate the mainstream. For example, the 2016 American Planning Association conference included a session titled *Regenerative Urbanism Rising: Next-Generation Practice*.

Despite the growth in interest, only a few research groups are focused on the practice of regenerative urbanism, notably the World Future Council (Hamburg, Germany), The Program for Regenerative Neighbourhoods (Vancouver, Canada) and the Thrive Hub (Melbourne, Australia). This thesis aims to contribute to the growing body of knowledge at both a global and local level.

1.3 Situating the researcher

1.3.1 Theoretical perspective

This research is consciously undertaken from a normative sustainability worldview (Graves 2015). This position is aligned with my own training, firstly in the Earth sciences and secondly in the theory and practice of urban planning and design.

Studies in the Earth sciences offered me a holistic view of the planetary processes of natural systems. I brought this thinking with me as I transitioned into urban planning practice. Urban planning is primarily concerned with, and discussed in terms of, the creation of local or city-scale human environments. However, the discipline, like all human systems, exists within a larger natural system; that is, it is a nested system with economic considerations existing within a larger social system, and the human social system sitting within a larger environmental system (see Figure 1 [A]). Conventional urban planning practice tends to focus almost exclusively on the economic and social factors of human systems. Because of this, it risks missing the larger connection to the broader environment (see Figure 1 [B]). The interface between the two disciplinary areas of planetary science (natural systems) and urban planning (within a human system context) – is the academic territory this thesis occupies (see Figure 1 [C]).

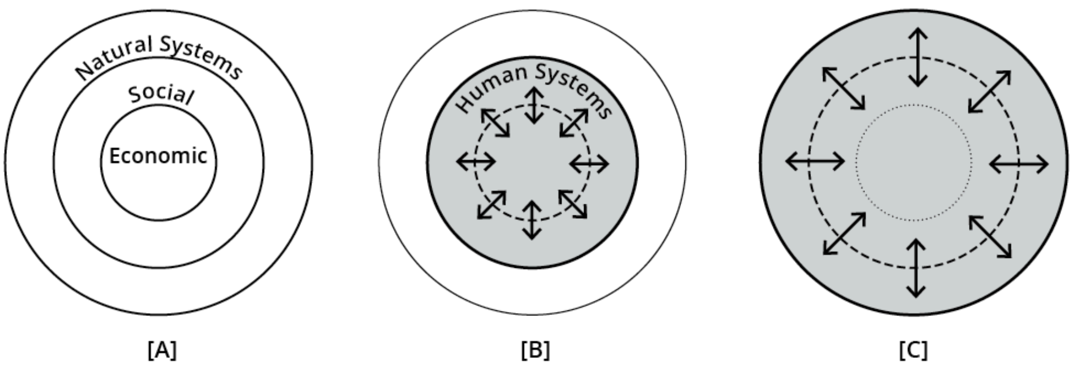


Figure 1: Integration between systems

To understand this link, it is necessary for there to be integration across spatial scales (see Figure 2). Cities, after all, exist within a broader natural landscape. They are artefacts of human culture, yet citizens are subject to the same natural laws that apply to all living beings. An ecological world view, such as that offered by regenerative design, is therefore the appropriate lens for viewing urban life, in which the limits on the natural systems that support urban life are now being threatened.

Integration across scales requires urban systems, such as cities, precincts and buildings, to be cognisant of their relative impact on the planetary system. This is essentially how the Paris Agreement is intended to work, with a nested model whereby each nation has its own emissions contribution, which, if not exceeded, is expected to keep aggregate emissions within the range that would limit the anthropogenic temperature anomaly to 1.5–2°C and reduce the risk of catastrophic climate change (United Nations 2015a; Walker & Swartz 2016; Schellnhuber et al. 2016; Schellnhuber & Martin 2014; Lenton et al. 2008).

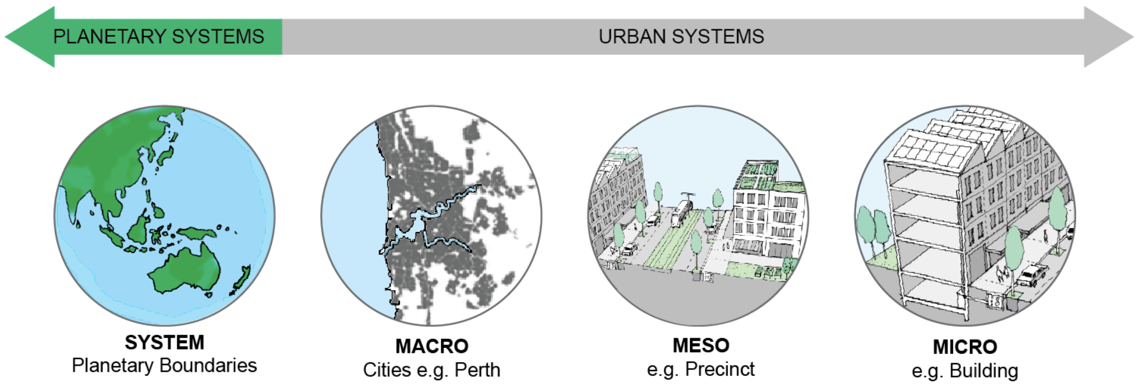


Figure 2: Integration across scale

Viewing city planning and design in an integrated manner across systems and between scales represents a holistic approach to a discipline that rarely looks beyond the more typical, but much narrower, real estate driven response for "highest and best use" within a legally defined site boundary.

1.3.2 Personal experience

My initial training in Earth science has shaped my own worldview and practice as an urban planner. I have been fortunate to work on several planning initiatives designed to demonstrate possible ways to reduce adverse impacts of urban development on natural systems. This thesis is therefore written from the perspective of a reflective practitioner.

Significant among the projects I worked on were the 2007 Peterborough Carbon Challenge, a UK government initiative to attract private sector investment in low carbon development (English Partnerships 2007), and the 2011 South Australian Government "zero carbon house challenge".

For the Peterborough carbon challenge I worked for a private consultancy in London (AECOM) and was assigned the role of lead urban designer for the preparation of the Peterborough Carbon

Challenge Development Brief. The brief invited developers to tender for the demonstration project within tight guidelines prescribed by the UK government and project stakeholders. When the winning scheme of 295 dwellings was completed in 2013 (marketed as “Vista”) it was the largest zero carbon development in the UK. This project, while useful to trial new technology and upskill the housing industry participants, was heavily subsidised by government and a flagship demonstration project rather than representing a shift towards mainstreaming sustainable urbanism (this is discussed further in Publication 7).

Upon returning to Australia, I was involved in the preparation of a similar, albeit smaller, project brief for the “zero carbon house challenge”. I was working for the South Australian Government and wrote the criteria for the state development authority’s competition design brief. The winning consortium delivered a house with exemplary operational performance. However, its location in low-density suburbs, its double garage and its poor public transport access (despite being only seven kilometres from the city centre) alerted me to the fact that while the zero (operational energy) carbon house was pushing engineering boundaries, a holistic approach to city level planning was missing. This search for greater integration and more holistic outcomes led me to the conclusion that there is a need for far better sustainability decision-making at the strategic planning level, particularly within the most car dependent cities found in Australia, New Zealand, the United States and Canada.

My academic training, personal perspective and professional experiences undoubtedly influence my position. However, I believe this arguably subjective quest for sustainable urban form and sustainable strategic planning is important, and justified, from a planetary sustainability perspective. This view is also becoming increasingly topical among researchers, governments and practitioners as previously explained in section 1.1 – the need for this research.

1.4 Research question and objectives

The overarching research question asks “How can the transition towards a regenerative urbanism be mainstreamed?”. Answering this primary question required an investigation into several interrelated subquestions, as outlined in Table 1 below.

Table 1: Research subquestions and objectives

Subquestions	Objective
1. What is regenerative urbanism and how can it help deliver sustainable cities and a sustainable planet?	The objective of this subquestion was to link theory to practice, i.e., to understand how regenerative design principles can help shape a new paradigm of urbanism and city planning. This included differentiating between sustainable urbanism (based on a sustainable development target) and regenerative urbanism (aiming for biosphere repair in a world where some planetary boundaries are local ecosystems are already compromised). This subquestion is addressed in Publication 1: "Geoengineering in the Anthropocene through Regenerative Urbanism".
2. How do cities work, and therefore be changed?	This subquestion focuses on processes for urban change, both physical change and changes in sustainability performance. The thesis addresses this by using urban metabolism to describe the relative sustainability of three types of urban fabrics. This subquestion is addressed in Publication 2: "Urban Fabrics and Urban Metabolism – From Sustainable to Regenerative Cities".
3. What is the best scale for achieving a transition to a regenerative urbanism?	The objective of this subquestion was to investigate the preferred scale of the urban unit for the delivery of regenerative urbanism (e.g. plot, block, precinct, corridor, city). Consideration was given to the ease of change, scale of impact, business models and governance. This subquestion is addressed in Publication 3: "Urban Regeneration and Urban Fabrics in Australian Cities".
4. How can regenerative design be integrated into urban development?	This subquestion addresses sustainability-focused urban renewal. This subquestion is the topic of Publication 4: "Sustainable Infill Development".
5. How can governance deliver and manage regenerative urban development?	This subquestion considers the role of governance and funding for regenerative urbanism. This subquestion is the topic of Publication 5: "Material Flows, Information Flows and Sustainable Urbanism"; Publication 6: "GRID: A new governance mechanism for financing eco-infrastructure at the district scale"; and, Publication 7: "A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia."

1.4.1 Scope

The complex nature of the questions addressed in this thesis warrants drawing boundaries around the potential scope. This is difficult because complex urban systems represent wicked problems and are a symptom of other problems (Rittel & Webber 1973). Sustainability and regenerative urbanism in planning – the subject area of this thesis – is comprised of multiple interrelated factors. Not only are cities embedded within natural systems, including topography and bioregion (e.g., climate, ecology), but they are also a function of human (sub)systems such as:

- culture (i.e., social values)
- technology (e.g., transport modes, construction techniques)
- governance (e.g, building codes, property law)
- markets (e.g., consumer patterns, real estate markets)
- demographics (e.g., resident composition, age) and so on.

When natural systems are put under stress due to human activity, as discussed in section 3.1.1, recalibrating city shaping human systems is very difficult, as each of these subsystems impacts the other with a shift in one having ramifications on other interrelated factors.

Therefore, to tighten the scope, this thesis focuses on the underlying physical infrastructure of cities and seeks to understand which urban fabrics (e.g., buildings, public realm, utilities and other urban elements) are more sustainable than others and why.

The thesis describes the regenerative city as an aspirational new norm. Cities are shaped through urban planning and design processes. Regenerative cities need a new planning paradigm to realise this aspiration. Therefore, the thesis focuses upon describing the processes that can deliver regenerative outcomes – through regenerative urbanism. The literature review and case studies describe best practice. The discussion and conclusions focus upon principles that can be used as a framework for transitioning to regenerative urbanism, in terms of both the physical "product", as well as the "processes" for its delivery.

Chapter 2 Research design and methods

2.1 Research design

This research applies the iterative qualitative research design approach described by Maxwell (2009) and illustrated in Figure 3. Maxwell's approach overcomes the limitations of many models of research design that present a series of simple linear steps for conducting an enquiry. Given the very dynamic nature of sustainability and urban planning, in both theory and practice, a linear sequential research design was simply not appropriate for inquiry into this wicked problem.

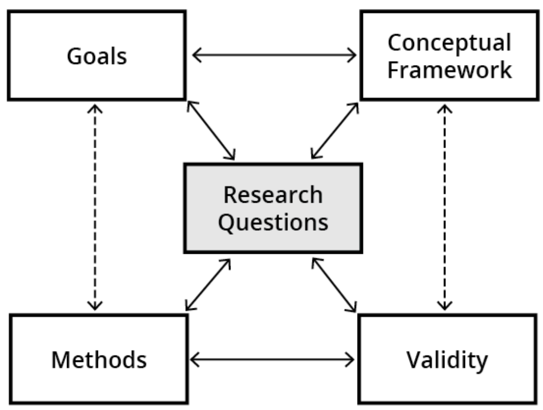


Figure 3: Maxwell's interactive model of research design (recreated from Maxwell 2009)

Maxwell's model has five components that may interact with one another as more information comes to light. The five components are:

1. **Goals** – Why is the study worth doing? What is the need for this research? (Discussed in section 1.1)
2. **Conceptual framework** – What theories, beliefs and prior research finding will guide the research? (Discussed in section 1.2 and 1.3)
3. **Research Questions** – What specifically do you hope to understand by doing this study, what do you not know about the things you are studying, and what question does the research hope to answer? (Discussed in section 1.4)
4. **Methods** – What will actually be done in this study? (Discussed in section 2.2)

5. **Validity** – How might the results and conclusions be wrong? How can the data support or challenge preconceptions about what is going on?

Maxwell's model illustrates that the research process of collecting and analysing information, developing a conceptual framework, defining the research questions and ensuring validity are processes that occur iteratively and concurrently (Maxwell 2009).

Utilising an interactive research model that permits iterative revision of the research project and between research components has allowed the incorporation of several major developments that have occurred in the lifetime of this study, notably:

1. September, 2015 – Adoption of the Sustainable Development Goals (United Nations General Assembly 2015)
2. December, 2015 – Entry into force of the Paris Agreement (United Nations 2015a)
3. August, 2016 – Announcement by the Anthropocene Working Group at the 35th International Geological Congress, that after seven years of consideration they conclude there is a conditional case for the formalisation of the Anthropocene as a potential new geologic epoch (University of Leicester 2016)
4. October, 2016 – The announcement of *the New Urban Agenda* at Habitat III (United Nations 2016).

2.2 Methods

This research began with a scoping study aimed at identifying global best practice in terms of low carbon sustainable precincts. The scoping study was provided to the Cooperative Research Centre for Low Carbon Living as part of a scholarship funding requirement for this PhD thesis.

A broad selection of case studies was reviewed and a "short list" of exemplars identified based on the following criteria for selection:

- frequency of occurrence – from a survey of the literature and peer networks
- urban unit – the site must not be an individual building, rather it must form part of a larger urban unit, ideally a "precinct", that is, it must incorporate shared infrastructure and a public realm
- sustainability performance – developments were addressed against six precinct sustainability criteria (embodied carbon in materials, construction processes, energy production and management, water management, waste management, transport) as defined by Bunning et al. (2013)
- development status ("constructed" or "underway") – a project was not considered if only "planned". It was noted in *The International Eco-Cities Initiative – A global survey 2* (2011)

that a large number of planned sustainable urban development projects had failed to eventuate or changed nature after the initial planning phase.

The resulting "short list" of 20 exemplary projects represents a diverse range of approaches to sustainable urbanism and an equally diverse range of strategies for delivery such as subsidised demonstration projects, integrated eco-services and innovative funding and governance models for delivering low carbon precincts.

The scoping study offered multiple exploratory case studies (Yin 1994) as a foundation for the definition of the problem and design of this thesis.[1]

Literature review

A systematic literature review was conducted to describe characteristics of sustainable urbanism projects, understand planetary boundaries and determine processes that have been used by various successful case studies to deliver sustainable outcomes. Secondary sources were drawn from academic literature for example, journal articles, academic books, research papers and conference papers; and relevant industry and government literature for example, international, national and local government reports, industry reports, press releases, statistical yearbooks, websites and personal correspondence. The literature review concerning the Earth sciences and sustainability drew almost exclusively upon academic sources with occasional reference to high level policies or intergovernmental reports; whereas, the literature review for the case studies and current practice in the industry-oriented planning and development sector drew upon a more eclectic range of sources.

This thesis applies a descriptive-comparative approach (Sarantakos 1998) to the case studies in an attempt to find commonalities among the case studies regarding work towards (or against) meeting a sustainability or regenerative goal to minimise adverse sustainability impacts resulting from human settlements.

Multiple case studies

Multiple case studies have been drawn upon to function as exploratory, descriptive and explanatory tools. Exploratory case studies help focus and frame the research area, descriptive case studies illustrate observed phenomenon, and explanatory case studies cross check and validate causal links through repeated examples (Yin 1994).

Yin (1994; 2006) explains that "how" and "why" questions are more explanatory and likely to lead to the use of case studies and experiments as preferred research strategies because such questions need to be traced over time rather than mere measurement of frequency or incidence.

1 Publication 3 is a conference paper developed from the key findings of the scoping study.

The cost, time and complexity of urban planning preclude experimentation, leaving case studies and possibly some historical analysis as the preferred strategy for exploring the research question.

Multiple case study analysis was appropriate to establish multiple sources of evidence that demonstrate trends which can be used to infer a causal link. This was achieved through the collection and analysis of patterns and trends observed (see Figure 4)

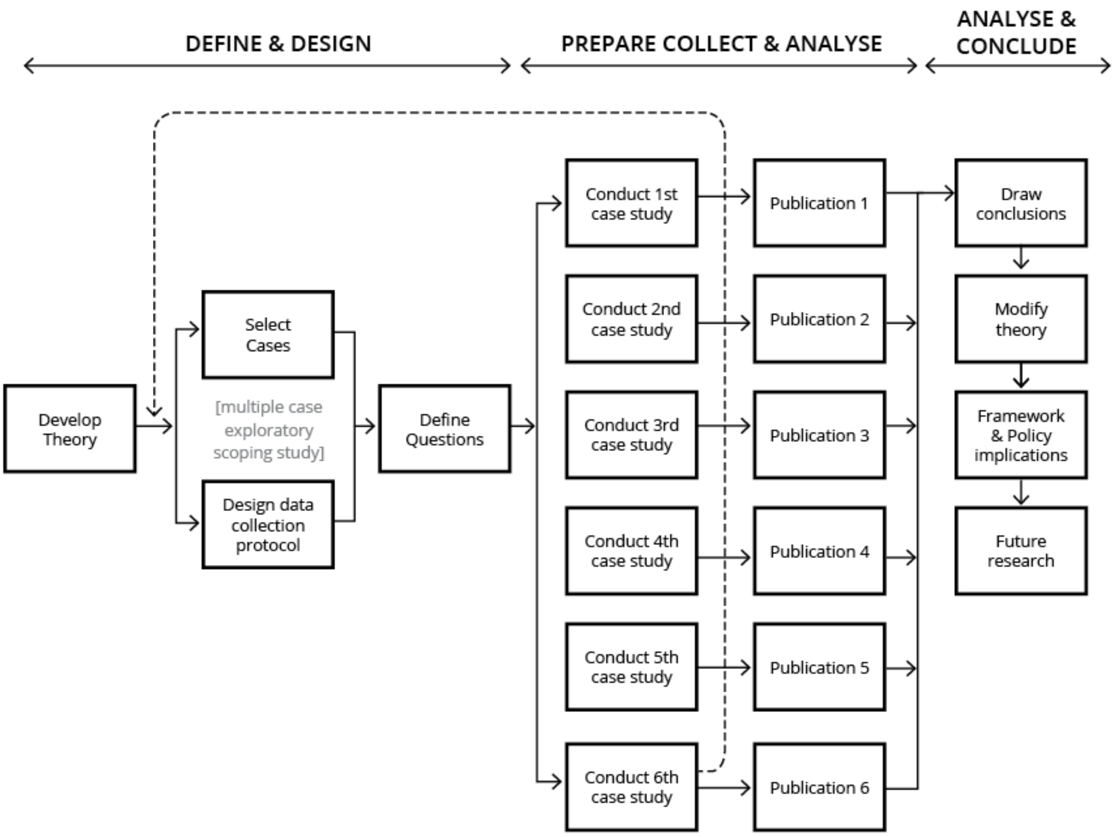


Figure 4: Case study method (adapted from Yin, 1994)

Urban planning is a discipline that has many local jurisdictions. Urban planning is typically a devolved power from a national to a local authority. This is an increasingly global trend as the United Nations states: “decentralization has quietly become a fashion of our time . . .” (UN-Habitat 2016, p.10). Decentralisation allows urban planning diversity to flourish. In Australia, for example, the federal government devolves power to the states and territories resulting in eight state planning strategies and 565 local councils to interpret the strategy and approve development applications (Thompson & Maginn 2012). At the global scale, with 193 nations usually with multiple planning systems, there exist a huge number of precedents developed under different conditions from which case studies may be selected. Exemplars found in this diversity can inform planning practice elsewhere.

Validity

This thesis looks to the outcomes of some of the best of these global exemplars to determine what factors enable some locations to deliver more sustainable outcomes than other locations. Whereas experimental analysis relies upon *statistical* generalisation of a large sample, case studies rely on *analytical* generalisation (Yin 1994). It is the observation of recurring trends in multiple case studies that builds the *replication logic,* just as repeat experiments build replication logic in laboratory based science (Yin 1994).

In this thesis, case studies, particularly at the precinct scale, are provided to offer hope and inspiration by demonstrating the application of key theoretical concepts. These case studies are analysed to provide insight into both the "product", in terms of site planning and design, and the "process", in terms of how the sustainable development was achieved. Case studies are referred to occasionally in the exegesis, and form a large component of the published papers.

Evaluation and comparative analysis

The focus of this thesis is upon the underlying structural elements of urban planning, which are capable of delivering improved sustainability outcomes and perhaps even regenerative outcomes. Case study analysis is largely focused upon pattern matching. Evidence is collected to draw conclusions, adapt theories, and apply research to make recommendations and outline policy implications (Yin 2006) (See Figure 4).

The multiple case studies in this thesis also have multiple "units of analysis"; this is what Yin refers to as an "embedded multiple case study" method (Yin 1994). The units of analysis for the urban planning and urban design examples include:

- urban sustainability performance (conventional, green, sustainable or regenerative – as described in Publication 1)
- urban morphology (physical attributes of the urban fabric – as described in Publication 2)
- design of urban systems (water, waste, electricity provision – as described in Publication 4)
- urban development delivery mechanisms (including governance, design and finance – as described in Publications 3,5,6,7).

This broad approach to case study analysis allowed for the consideration of the multiple factors influencing sustainable and regenerative urban planning. Patterns and trends were used to draw conclusions about why certain urban fabrics demonstrate far superior urban sustainability performance than others, and what processes help shape a more or less sustainable outcome.

Case studies are drawn from international best practice. However, the process of urban transformation described in Publications 2,3,4,5 places the greatest emphasis on practical considerations for the transformation of unsustainable low-density suburbs.

2.3 Knowledge domains

To assist in breaking down the complexity and interdependencies of the research questions, several knowledge domains were used to analyse the research questions. To structure these, this thesis applies the generic 5-level framework for planning in complex systems, as used in the framework for strategic sustainable development developed by Robèrt et al. (2002) (see Table 2).

The 5-level framework can be used to plan transitions in any complex system. The framework requires identification of the system. In this thesis, global sustainability is defined as the cumulative sum of human activities operating within safe planetary boundaries. By defining the system as the safe operating space within planetary boundaries (see: Rockström et al. 2009), it becomes possible to:

- define levels of success
- develop strategic guidelines for achieving success, and
- determine the actions and tools necessary to support the strategic guidelines (Robèrt et al. 2012).

Once success has been defined, it is possible to establish a goal. A sustainability transition can work backwards from this goal-oriented approach or target. A process that Robèrt et al. (2002) describes as "backcasting", which involves developing a future vision and defining goal-oriented steps to arrive there. In the discussion and conclusion sections of this thesis, the goal of mainstreaming regenerative cities is outlined (as regenerative urbanism) and steps are described for the delivery of this goal.

Level	Generic 5-level framework for planning in complex systems	Area of application within this thesis	Publications (see Figure 5)
1. System	The system relevant to the goal	• Planetary boundaries and (urban) human settlements	Publication 1
2. Success	The definition of success	• Changing the paradigm from conventional development to a regenerative paradigm • Transitioning from niche demonstrations projects to mainstream practice	Publication 1, 2
3. Strategic Guidelines	Guidelines or models used to move the system towards success	• Backcasting from the normative regenerative city • Development of a regenerative urbanism • Leverage points to catalyse change	Publications 2, 3
4. Actions	Actions that support the strategic guidelines	• Replicating good practice • Scaling up	Publications 2, 3, 4, 5, 7
5. Tools	Tools that support the process	• Urban Metabolism analysis • Indicators and ratings • Innovative finance • Supportive policy • New forms of local governance	Publications 4, 5, 6, 7

Table 2: The "5-level framework for planning in complex systems" applied to this thesis

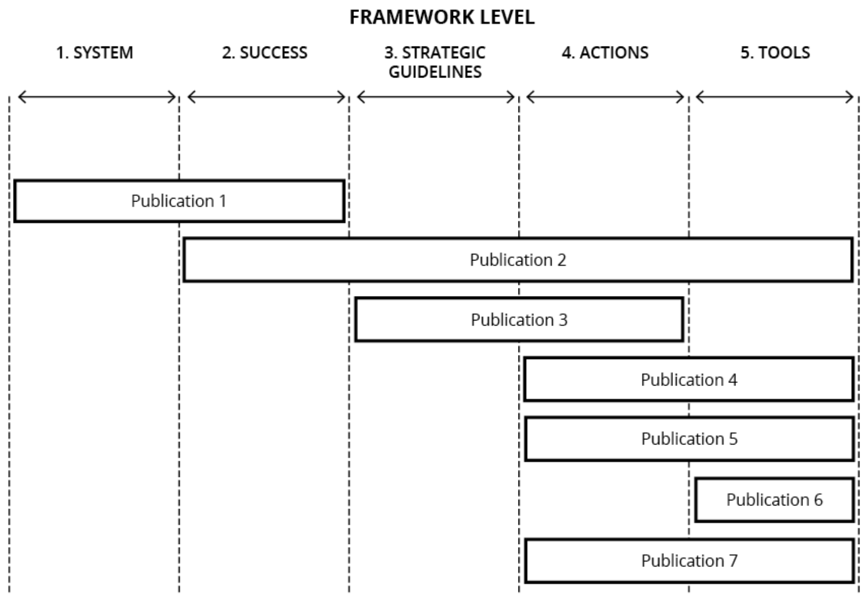


Figure 5: The relationship between the publications and the 5-level framework

Planetary boundaries

Planetary boundaries are already compromised and solutions are needed to mitigate adverse anthropogenic environmental impact (Kolbert 2010; Robèrt et al. 2013; Rockström et al. 2009; Seitzinger et al. 2012; Steffen et al. 2011; Steffen, Richardson, et al. 2015; Whitmee et al. 2015; Wackernagel & Rees 1998). This knowledge domain is treated in section 3.1.1 and in Publication 1.

Urban metabolism

Urban metabolism is a way of understanding the stocks and flows of material and substances through a city (Baccini & Brunner 2012; Baccini 1997; A Wolman 1965; Newman 1999; Kennedy et al. 2007; Broto et al. 2012). Urban Metabolism can be either linear or circular with linear metabolism extracting material inputs from the biosphere and expelling them as substantial wastes into the biosphere, often exceeding what can be absorbed by nature. Circular urban metabolisms are designed to use waste as a resource. This makes them more efficient and can greatly reduce their environmental impact because a circular metabolism requires less inputs from nature and produces fewer waste outputs (Girardet 2010; Girardet 2015; Ellen MacArthur Foundation 2015). This knowledge domain is treated in section 3.2.2 and in Publication 2.

Regenerative design

Regenerative design presents a positive alternative to conventional development. Regenerative approaches aim to go beyond net-zero impact to regenerate aspects of the biosphere such as greenhouse gas emissions, water, nutrient cycles, biodiversity. They achieve this by designing in efficiencies and designing out wastes through the application of a circular metabolism (Lyle 1996; Lyle 1999; Williams 2012; Cole 2012; Cooper 2012; Girardet 2015; Zhang et al. 2015; Mang & Reed 2012; Hes & du Plessis 2014). Regenerative design is explained in section 3.2 and Publications 1, 2 and 4.

This thesis explores how regenerative design may mitigate, or reverse, adverse anthropogenic environmental impact. To be effective, this would need to be done at scale, therefore the system success must involve a paradigm shift from conventional development to regenerative development.

Urban planning and design

The central disciplines of this thesis are urban planning and design: urban planning as it relates to the layout and systems of a settlement (Taylor 2007), and urban design as an intermediate scale between planning and architecture that emphasises the relationship between urban elements with a particular emphasis upon the qualities of "place" (Carmona et al. 2012).

The particular focus is on how it is possible to shift conventional urban planning and design practice, which typically deliver unsustainable development, to more sustainable practices. This is difficult because alternative futures are not systematically structured within existing regimes; rather, the dominant policy and industry actors tend to emphasise short- and mid-term outcomes due to political cycles, individual interests and public pressure (Loorbach 2010). The mismatch between planning timeframes is visualised clearly by Roggema and Van den Dobbelsteen (2008) (see Figure 6).

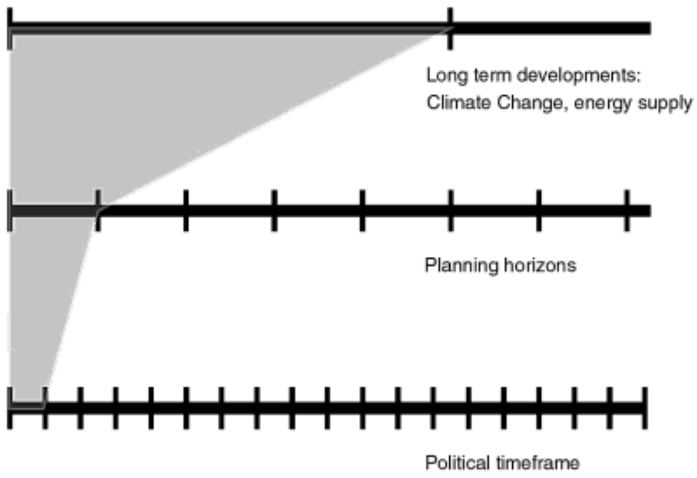


Figure 6: Planning timeframes (source: "Connection of long and short term" Roggema and Van den Dobbelsteen, (2008)) Reproduced with permission

Planning solutions exist for most sustainability problems. For example, the case studies demonstrate that it is possible to be regenerative in terms of energy, water, food and biodiversity within cities. However, examples of this are an exception rather than the rule. These are niche activities (Geels 2011) and, as Publication 7 describes, they are often subsidised by visionary actors willing to support emerging innovation and demonstrate what is possible. Loorbach (2007) outlines his description of transition management types and their focus (see Table 3). The typical short-termism of electoral and business cycles is a function of operational management types and under this model sustainability transitions can only hope to be incremental. The perils of incremental policy-making when dealing with potentially existential sustainability crises such as climate change, resource depletion and exponential consumption patterns are well documented (e.g., Coglianese & D'Ambrosio 2008; Thackara 2005; Blood & Partner 2012).

Hajer (2011), a researcher and former director of the Netherlands Environmental Assessment agency, is a proponent of an urban metabolism evidence base to help drive urban sustainability transitions. To shape change is beyond the role of government alone. Instead, his influential essay "the Energetic Society" calls for a "radical incrementalism". This approach would keep the large objectives in mind, but, rather than traditional, hierarchical, government-led "analysis and instruction", he argues policies should emphasise "releasing energy" to effectively facilitate partnerships between government, industry and community. This is more likely to result in many relatively small steps towards the sustainability transition and lead to sizeable results (Hajer 2011, p.43).

Sustainability transitions in most societies are challenged by what Loorbach (2007) refers to as "strategic transition management" (see **Table 3**). The problem is that *cultural* change is not keeping pace with the speed required to meet the urgent demand for sustainability transitions to mitigate current and projected anthropogenic planetary boundary transgressions (as outlined in the literature review, Chapter 3).

Table 3: Transition management types and their focus (source: reproduced from Loorbach (2007))

Transition management types	**Focus**	**Problem scope**	**Time scale**	**Levels of activities**
Strategic	Culture	Abstract / societal system	Long term (30 years)	System
Tactical	Structures	Institution / regime	Mid term (5–15 years)	Subsystem
Operational	Practices	Concrete / project	Short term (0–5 years)	Concrete

The primary impediment is a cultural one (Lowe 2015). To become mainstream, an urban sustainability transition requires a strategic transition shift, a shift that changes culture: a long term proposition according to Loorbach (2007). The narrative for sustainability transitions has a long history; it is around 30 years since the publication of *Our Common Future* (United Nations 1987) but the recent 2015 announcement of both the SDGs and the Paris Agreement may mark the tipping point for a societal reframing of sustainability.

Big business is not only shifting because of the potential legal implications of non-compliance with the Paris Agreement (Ferguson 2016; Kitney 2016), but also because of the potential financial benefits for innovative companies through the "first mover advantage" (Hargroves & Smith 2005). A cultural reframing or paradigm shift may be necessary to overcome the relative indifference that society has placed upon scientific evidence to date, where sustainability policy has failed to impact heavily upon societal values. A number of writers are calling for the narrative to shift through longer-term strategic management that incorporates the big picture knowledge of scientists over short term politics or business decisions (McPhearson et al. 2016).

2.3.1 Research significance

This thesis develops new knowledge that demonstrates how, and why, sustainability transitions may occur. It demonstrates a causal link between urban fabrics and urban metabolism, which had not previously been discussed in the academic literature. It also takes the theory of urban fabrics and overlays regenerative design to add practical depth to the emergent area of regenerative urbanism, which, to date, has largely been framed as a concept that draws upon ad hoc case studies of discrete projects or districts that demonstrate some regenerative principles. This thesis offers a replicable framework of principles that allow the systemic implementation of regenerative urbanism. Thus, the thesis provides a framework for transitioning to regenerative urbanism allowing the concept to move from niche idea to mainstream movement. If this can be achieved in practice, then the research has not only academic significance but practical significance for the future of cities, and indeed human activity on the planet.

2.3.2 Research assumptions and limitations

The “export” of urban patterns from the west

The thesis assumes that city planning thought leadership will continue to be generated in the west and exported globally. This has been the pattern historically. Developing nations have imported, or had imposed upon them, urban planning patterns and technological solutions from wealthier and more industrially advanced nations. Many of the structures that created this relationship have changed or are changing. For example, colonial ties were largely severed during the mid- to late-20th Century, and economic wealth is increasingly shifting from the west to the east. So this assumption may become outmoded.

However, where rapid growth has occurred in an ordered manner (as distinct to informal and slum development) in developing nations, the process of planning has typically followed western city practice. Examples include many of China’s “instant cites”, cities in the Arab nations and Latin American cities. The Modern city is truly an international style. There is still a heavy reliance upon large multinational consulting practices to provide planning and infrastructure advice to both developed and developing nations. As most of these organisations are based in western nations, urban patterns recommended by consultants tend to reflect western knowledge and fashion. The assumption is that this centre–periphery consulting model will continue for some time as developing nations import knowledge from developed nations, and the best urban planners from developing countries tend to be trained in the West. The significance of changing the urban paradigm in western cities is therefore of global significance.

System understanding – urban metabolism

The use of urban metabolism as a way of understanding material flows and stocks through a city, and more specifically the regenerative city, is limiting for two main reasons:

1. The language of urban metabolism varies between disciplines. During my PhD candidacy I was fortunate to take part in a small gathering of 20 researchers in the Netherlands to work "towards an interdisciplinary approach to urban metabolism" (TIPUM) at the Lorenz Institute at Leiden University. Here it became apparent that there were still multiple perspectives in the field. Several of these perspectives as they relate to planning are discussed in an historic overview offered by Kennedy in his (2011) paper on the application of urban metabolism to planning and design. Kennedy considers the discourse from a planning perspective, however, different disciplines may emphasise different aspects such as energy or chemical substance flows may use different approaches with a focus upon different units of measurement. This paper considers urban metabolism from the practical material input-output approach outlined by Kennedy et al. (2011) for use in urban planning. Kennedy and colleagues describe this as "the mainstream school of urban metabolism", that "essentially just uses the units that local government officers would use, recognize and understand, for example, in water works departments, solid waste management, or utilities etc." (Kennedy et al. 2011, p.1967).

2. The available data on material stocks and flows is limited, often incomplete, and where available may have inconsistent data quality as there are no established conventions to standardise data collection. The World Council of City Data (WCCD) and the 2016 release of the international standard ISO37120 for sustainable development in communities (ISO 2016), may begin to change this. However, often where data is absent, interpolation or assumptions may be used (Global Footprint Network 2016). In this thesis, urban metabolism is treated as the conceptual understanding of the urban system without detailed analysis of system stocks and flows, although several examples are used throughout the text, particularly the detailed case study of three urban fabrics in Perth, Australia (see Publication 2).

Strategic direction – regenerative design

Regenerative design (and regenerative cities) is an emergent field. As such, the discourse is still developing and will continue to develop beyond the completion of this thesis. Use of the term is based upon a broad literature review, but questions still remain. A relatively recent critique of the theory, by a practitioner, questioned how easily the theory could be translated into practice, particularly the urban realm (see: Clegg 2012). This thesis offers a framework to assist application of regenerative urbanism, but given the depth of the field it can only provide a partial answer. The framework is limited to my own area of practice, urban planning and design. Key areas requiring further research are outlined in 6.1.

Transitions

This thesis emphasises “structural transitions”. However, creating structural transition also requires “cultural transition”. In practice, these two aspects of a sustainability (or any) transition cannot be separated. This thesis assumes a cultural willingness for a sustainability transition, so only lightly treats the notion of sociocultural paradigm shifts to describe the steps required for a structural transition towards sustainable and regenerative city building.

Pathways for success

There is no single way to deliver a sustainable city. This thesis tackles some of the major themes related to pathways for success. The pathways and principles are examples based on evidence drawn from the literature and case studies. Each urban area will have a host of locally dependant factors that make it unique. This thesis can only hope to provide a generalised view of how regenerative urbanism might be delivered, but there will be many other ways, and circumstance will differ across locations, cultures and time. There can be no universal principles. Indeed, the one size fits all, normative approach to urbanism is one of the major failings of Modernist planning. Successful pathways will vary between sites and many permutations will be appropriate for each site. Variations from the normative assumptions presented in this thesis may be required due to a specific location’s physical and cultural context. Multiple other pathways may also yield regenerative outcomes.

Chapter 3 Literature review

3.1.1 The Anthropocene

We live in the Anthropocene, the geologic era defined by the ubiquitous impact of *homo sapiens* upon the physical and chemical composition of the Earth, particularly those impacts found within the litho- and biospheres (Whitmee et al. 2015; Zalasiewicz et al. 2010; Baccini & Brunner 2012; Ruddiman et al. 2015; Crutzen & Stoermer 2000; Steffen et al. 2007; Steffen et al. 2011; Steffen, Broadgate, et al. 2015; Crutzen 2002).

In August 2016, The Anthropocene Working Group, after seven years of assessing evidence, voted to support the formalisation of the Anthropocene. This represents the first step towards formal designation of the Anthropocene as the current epoch by the geological science community (University of Leicester 2016). Early writings by Steffen et al. (2007) suggested that the Anthropocene commenced around 1800 with the onset of the industrial revolution. However, a subsequent review led to a revised start date, around 1950, being described as the great acceleration, coinciding with rapid post-WWII population and economic growth (Steffen, Broadgate, et al. 2015):

> . . . of all the candidates for a start date for the Anthropocene, the beginning of the Great Acceleration is by far the most convincing from an Earth System science perspective. (Steffen, Broadgate, et al. 2015, p.81)

Numerous indicators were analysed by Steffen, W. Broadgate, W., et al. (2015). Collectively, they clearly demonstrate the exponential growth that characterises the period (Figures 7).

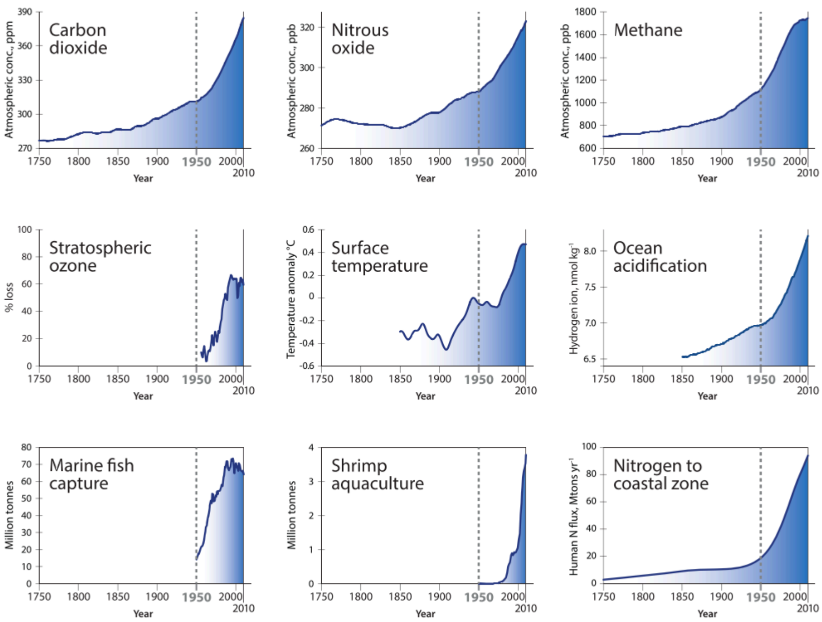


Figure 7: Several indicators of the "great acceleration" (source: Steffen, W., Broadgate, W., et al., 2015) Reproduced with permission.

The anthropogenic markers that provide evidence for the functional and stratigraphic distinction of the Anthropocene are outlined in a 2016 *Science* article describing stratigraphic markers such as concrete, plastic, fuel ash particles, carbon dioxide concentration and plutonium fallout (Waters et al. 2016). At the IGC, it was plutonium fallout that was voted the primary anthropogenic marker and 1950 the year of origin (University of Leicester 2016).

The great acceleration and the Anthropocene are the overarching narratives that define the accelerating impact of humanity on this finite planet. These notions are detailed below in terms of (un)sustainability and the thesis explores how this knowledge enables creative solutions to provide continuous learning, measurement and adjustment to patterns of human life on the planet.

Over the first 50 years of the great acceleration, between 1950 to 2000, the global population increased from three to six billion. While the population doubled in this short period, the global economy increased 15-fold, and with this explosion of trade came a corresponding increase in resource consumption and waste outputs (Steffen et al. 2007):

> The dominant socio-economic trend is that the economic activity of the human enterprise continues to grow at a rapid rate (Steffen, Broadgate, et al. 2015).

In 1972, relatively early in the great acceleration, Meadows et al. prepared the Club of Rome Report *Limits to Growth* (Meadows et al. 1972). This report recognised early warning signs of a stressed biosphere and provided scenarios based on a systemic analysis of global population, industrialisation, pollution, food and resource systems. The report was the first major publication to question the carrying capacity of the planet, as a closed system, to support limitless human economic expansion based on linear metabolism; failure to recognise these limits in the modelling suggested risk of ecological "overshoot and collapse" (Meadows et al. 1972).

By the mid-1990s, this debate had expanded and various attempts were made not only to model future human impact, but to measure current impact upon the biosphere. The concept of "ecological footprinting", proposed by Wackernagel and Rees (1997; 1998), emerged as a popular tool for measuring the ecological impact of nations. Part of its popularity stemmed from the apparent simplicity of the metric as an easily understood account balance measuring "natural capital" and "natural income" (Rees & Wackernagel 2008). By measuring national inputs and outputs, ecological footprinting attempts to measure the human carrying capacity of the planet. This approach can equally be applied to individuals to measure a personal ecological footprint. However, the ecological footprint notion was only a crude indicator of the extent of global impact.

In 2009, Rockström et al. introduced the notion of planetary boundaries, nine thematic areas that define the safe operating space for humanity (Rockström et al. 2009; Rockström 2009). Of the nine boundaries, three (climate change, biosphere integrity and biochemical flows) were highlighted as having been crossed (i.e. "ecological overshoot" cf. Meadows et al. (1972) and Wackernagel and Rees (1998)). The planetary boundary researchers note that scientific uncertainty related to the complexity of Earth processes, and the interrelated, but unknown, impacts of systems interactions and feedback makes the impact of boundary transgressions uncertain (Rockström 2009). Nevertheless, their research provides the strong evidence that these three planetary boundaries are at risk of transgression. The crossing of thresholds risks system failure. A 2015 update (Steffen, Richardson, et al. 2015) reiterates these findings (see Figure 9).

More sophisticated indicators from each of the planetary boundaries will need to be developed to enable these issues to be mainstreamed. However, the science of the need to reduce impact and even begin regenerating previous impact is now firmly on the agenda.

The need for a shift in worldview towards the biosphere as a site of extraction to a finite resource in need of stewardship has now been called for by numerous scientists and scholars (Steffen et al. 2011; Williams 2012; Browning et al. 2014; Schepelmann et al. 2010; Whitmee et al. 2015; UN DESA 2011; Pickett et al. 2011; Fink 2013; Zhang et al. 2015). Such a shift would elevate the importance of attending to the global limitations as defined by planetary boundaries. To do this effectively requires a reconsideration of the conventional economic systems and the supporting infrastructure (including cities) that underlie it. The content of this thesis relates to three of the most threatened planetary boundaries: climate change, biosphere integrity and land-system change (a planetary boundary inherently connected to the spatial organisation of human habitation and production systems) (Steffen, Richardson, et al. 2015)).

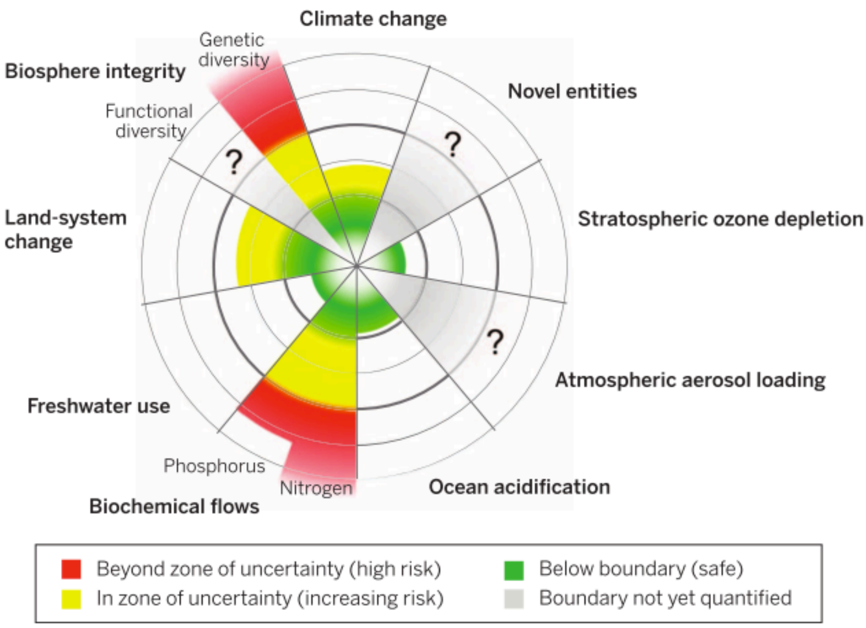


Figure 8: Planetary boundaries (source: Steffen, W., Richardson, K., et al., 2015). Reproduced with permission.

The key variables of each of these planetary boundaries is described in Steffen et al. (2015), and a brief summary is provided below:

- Climate change: Control variable = global atmospheric concentrations of CO_2. This variable enters a zone of uncertainty between 350 – 450 ppm. The current value of the control variable is 398.5ppm so the boundary has been transgressed.

- Biosphere integrity: Control variables = extinction rate and biodiversity intactness index (BII). The extinction rate zone of uncertainty is <10 Extinctions per million species-year (E/MSY) with a range between 10–100 E/MSY however, this current value of the control variable greatly exceeds this boundary at 100–1000 E/MSY, the boundary has been considerably transgressed. BII aims to maintain intactness at >90% as assessed geographically by biomes/large regional areas (e.g., southern Africa). The current value of the control variable is 84% (applied to southern Africa only).

- Land-system change: Control variable = Global area or forested land as a percentage of original forest cover (as a weighted average between the three biomes, tropical, temperate and boreal forest). The zone of uncertainty begins at less than 75%. The current value of the control variable is 62% so the boundary has been transgressed.

The extractive nature of human economies has largely been externalised by failing to capture the true costs related to the impact of these planetary boundary transgressions (Wackernagel & Rees 1997). Mitigation measures have the potential to control CO_2 emissions and restore forest cover (Rockström 2009); however, damage to biosphere integrity is very hard, if not impossible, to reverse as extinction is forever, at least with current technology.

The rapid acceleration of global ecological problems is a function of human consumption patterns and population growth (Lovins et al. 1999). But the population explosion of the great acceleration also coincides with mass flows of human movement (Forman & Wu 2016). Human movement is largely driven by economic migration as people seek better livelihoods for themselves and their families. People flow not only between countries, but also from rural areas to cities. Cities, as centres of culture and exchange, attract people because of the quality of life they promise (UN Habitat 2016). This phenomenon of migration began with the industrial revolution, but accelerated after World War II as people moved to cities in ever larger numbers and a period of mass urbanisation began (UNFPA 2007; Rees & Wackernagel 2008).

3.1.2 Urbanisation

In 1850, around 200 million lived in urban areas. By 2000 that figure was 3 billion, or roughly 50% of the global population (Steffen et al. 2007). This trend is set to continue well into the 21st Century. The 2014 revision of the UN *World Urbanization Prospects* noted that 54% of the current world population was urbanised and their 2050 projections were for between 65 – 75% of the global population to live in cities by 2050 (comprising 85.9% in developed nations and 64.1% in developing nations) (United Nations 2014). Indeed, we live in the "Age of Cities" (Burdett & Sudjic 2010). Most of the population growth since 1950 has been in the non-OECD world, but the world's economy (GDP), and hence consumption, is still strongly dominated by the OECD world (Steffen, Broadgate, et al. 2015, p.81).

Land is a limited resource. The Earth's surface area is about 30% land and 70% water. Satellite night light mapping through the Global Rural Urban Mapping Project (GRUMP) indicates that around 3% of the Earth's land surface is urban (CIESIN 2005). Although this sounds like a small percentage, the relationship between urban and non-urban areas is important for understanding the true impact of urban habitats on the global landmass. Cities are highly dependent upon their regional, and increasingly global, hinterland to extract resources for construction and operation. In 2002, a comprehensive study of the City of London indicated that the ecological footprint of Londoners was 49 million global hectares (Gha), which was 42 times its biocapacity and 293 times its geographical area (Chambers et al. 2002).

Currently not all cities have a footprint like London. There exists a disparity between rich and poor nations, with wealthy nations typically consuming more per capita than their poorer neighbours. This can be measured as an ecological footprint, which is represented as global hectares per capita (Gha[1]) (Wackernagel & Rees 1998). The not-for-profit organisation, Global Footprint Network, monitors the ecological footprint of nations. Their analysis, some of which is cited below, showed that in 2012 ecological footprints varied considerably between nations. Generally, this measure was proportional to national wealth, with the richer nations having higher ecological footprints than poorer nations. For example, at the higher end of the scale were wealthy nations such as Luxembourg (15.8 Gha), Australia (9.3 Gha) and the USA (Gha 8.2) compared to poorer nations such as Eritrea (0.4 Gha), Haiti (0.6 Gha) and Bangladesh (0.7 Gha). In 2012, the average available global hectares per capita was 1.7 Gha (Global Footprint Network 2016). If every person on the planet lived like a citizen of Australia or the USA, the human population would exceed the biosphere capacity by around five times.

Consumption rates in these developed nations are highly unsustainable unless significant decoupling of wealth and ecological footprint can begin; early signs of these patterns changing are now appearing as outlined by the UN (2013; 2011) and by scholars such as von Weisacker, Hargroves et al. (2009) and Newman and Kenworthy (2015).

Cities are at the centre of the planetary boundary phenomenon as well as the opportunities now being shown by decoupling (Newman and Kenworthy, 2015; UNEP, 2013). Their recent past during the great acceleration is highlighted in urban ecological footprinting:

> Cities are amongst the brightest stars in the constellation of human achievement. At the same time ecological footprint analysis shows that they act as entropic black holes, sweeping up the output of whole regions of the ecosphere vastly larger than themselves (Rees & Wackernagel 2008).

The relationship of the city to its hinterland is conceptualised in the "urban funnel model", which is based on ecological footprinting of cities (Luck et al. 2001), see Figure 9.

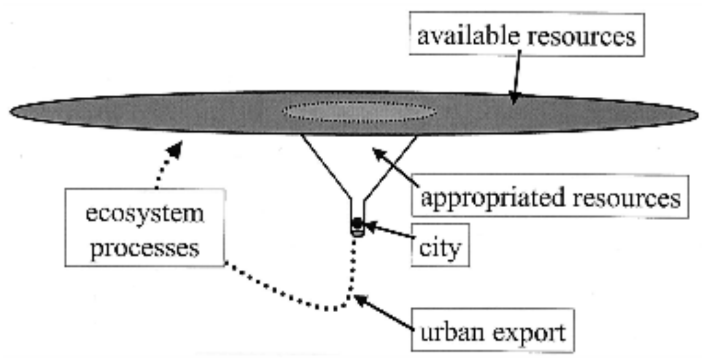


Figure 9: The urban funnel schematic showing the relationship between urban areas and the surrounding hinterland (source: Luck et al. 2001)

[1] Defined as: the area of biologically productive land and water a nation uses divided by the population of the nation (Wackernagel & Rees 1998).

Referring to the urban funnel diagram, the goal would be to reduce the amount of "appropriated resources", and the amount of waste ("urban export") discharged into the ecosystem to be absorbed by the "available resources".

However, it is more complicated than simply reducing the resource demand and impact of existing cities. Modelling by Seto et al. (2012) indicates that if current trends in population and urbanisation continue, then urban land cover will increase dramatically. Their study suggests that there is a 75% probability that global urban land area will increase by 185% by 2030 from a 2000 baseline. This is even faster than population growth. Over the last 30 years, the global trend has been for urban areas to be developed at lower densities than was historically the case – on average urban areas are expanding twice as quickly as their populations. More than 55% of this growth is forecast to occur in China and India, but the greatest increase in urban land cover is predicted for Africa, with 590% growth from 2000. The study even suggests developed nations such as the US may experience a 50% increase in urban cover over the same period, despite the current population already being 78% urban (Seto et al. 2012). The main problem with this is that as urban land cover increases it encroaches upon adjoining biodiverse habitats, carbon pools and agricultural land (Seto et al. 2012; Bringezu et al. 2014).

UNEP (2013) and Newman and Kenworthy (2015) have a more positive perspective on the potential for cities to reduce their footprint and new data shows cities contracting faster than expanding, hence creating opportunities to reduce their land take and their metabolism.

Understanding how we use the Earth's land resources is necessary for moving towards planetary stewardship. Planetary stewardship is a concept described by Seitzinger et al.,

> the active shaping of trajectories of change on the planet, that integrates across scales from local to global, to enhance the combined sustainability of human wellbeing and the planet's ecosystems and non-living resources (Seitzinger et al. 2012, p.787).

To achieve this requires a global system of cities that develop sustainable processes and policies in concert with non-urban areas (Seitzinger et al. 2012) (Figure 10).

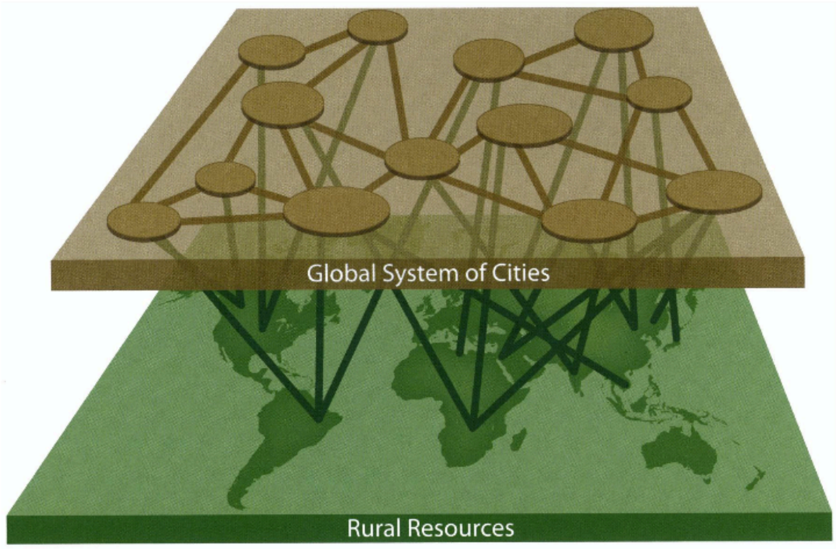


Figure 10: A global network of cities (source: Seitzinger et al. 2012) Reproduced with permission.

Monitoring and communicating the relationship between the city and its hinterland may reveal opportunities for system adjustment. A transparent, evidence-based approach to policy and urban development is key to reducing ecological footprint. In the past, the expansion of economic activity, as described in Section 3.1.1, at a rate far greater than population growth indicated that the per capita ecological footprint was growing rapidly, extending the extractive tentacles of city dwellers further and deeper into the bio- and geospheres.

However, there are two ways that these ecological footprinting analyses are overly simplistic and misleading. First, urban citizens typically have lower per capita energy and resource consumption than their rural or peri-urban counterparts (Droege 2008; Rauland & Newman 2015). Second, wealth and footprint can be decoupled if cities utilise new technologies and this is in fact now beginning to be evident as outlined above. Thus, cities, although they may be presented as the problem, also present the greatest opportunity. The work of Seto et al. (2012) suggests that there is a need for new urban forms that are more compact and designed to reduce resource demand. This is echoed in the 2013 report by UN-Habitat which suggests "the battle for a more sustainable future will be won or lost in cities" (UN-Habitat 2013).

Currently, the relationship between cities and their hinterlands is not apparent due to the remote and dispersed impacts of economic expansion (e.g., resource depletion, pollution). As a result these impacts are externalised (Wackernagel & Rees 1997). If urbanisation continued on the former trajectory, it would result in increased pollution, rising emissions, congestion and rising input costs as resources became more scarce and in greater demand (Hajer & Dassen 2014). However, it may also be possible to turn the more recent trends into mainstream behaviours and create a whole new future for humanity.

Cities are becoming the primary human environment and also the driver of human activities. To achieve planetary stewardship will require a continuing shift in the relationship between urban and natural systems. The historic approach to cities, whereby they function as an extractive engine taking materials from, and ejecting wastes into, the surrounding hinterland, cannot continue without existential risk to humanity. Cities need to be redesigned and rebuilt to function in a sustainable and regenerative manner that reduces their reliance on the ability of non-urban areas to supply resources and absorb wastes.

None of the planetary boundaries are currently directly linked to urban areas. However, it is this relationship between urban and non-urban resource pools and waste sinks that makes cities a big driver of, and potential solution to, planetary boundary transgressions. The way we design and deliver cities to remain within a safe operating space are critical (Robèrt et al. 2013).

3.1.1 The historical origin and function of cities

City design and delivery is a function of culture. Therefore, in order to understand city design it is necessary to have some understanding of the social history and cultural function of cities, as these are major determinants of city design.

The causal factors leading to the origin of cities remains a subject of academic debate (Kostof & Tobias 2004; Mumford 1961; Geddes 1949). Zvelebil (2009) suggests that cities can be linked to the advent of agriculture, as humans transitioned from hunter-gathering economies into neolithic farming settlements. Mumford (1961), in *The City in History,* is more cautious and hypothesises early origins in small settlements that housed palaeolithic people as nomads and hunters began to settle more permanently in preferred camps. Jacobs (1969), however, in her book *The Economy of Cities,* suggests that cities developed at the cross roads of trade, around which intensified agriculture then followed; a position Kostof & Tobias (2004) refutes as too simplistic. They argue instead that a range of drivers including agriculture, commerce, defence and in particular political transformations led to the emergence of urban societies. He calls this the role of social power as a generating force for cities: “at some level, city-making always entails an act of will on the part of a leader or collectivity” (Kostof & Tobias 2004, p.33).

Although the precise origins of cities may still be debated, two key points are relevant to this thesis. First, that cities are a focus of trade with important, but often neglected, implications regarding the urban–hinterland relationship and hence their urban metabolism. Second, if the concentration of people within urban geographies is based around a political social power then this can be shifted to create more regenerative outcomes.

Urban trade

Regardless of whether trade was a driving force behind the origin of cities, all cities now function as centres of trade. The earliest settlements would have been small and supported by what could be grown or gathered locally (Mumford 1961). However, as cities grow in size and population, so too does the demand for goods and the scale of the hinterland required to support urban life with more goods sourced from distant lands along trade routes. This transition marked a shift from living within an ecosystem to extracting from an external ecosystem to support human life in an urban centre, often with negative impacts upon the surrounding hinterland (Martinez-alier 2007). Cities attract populations through the agglomeration benefits they offer for culture and trade. These opportunities generally increase with the population and size of the settlement (Florida 2002; Glaeser 2011; Rawnsley & Spiller 2012). There has therefore been a trend towards increasingly large cities with increasingly large ecological footprints.

Social power

The agglomeration benefits of cities also lead to administrative efficiencies as concentrations of people enable greater consolidation of political power (Kostof & Tobias 2004). As such, cities represent a disproportionate consolidation of power relative to their landmass, though many cities protect a bioregion for their water and food and in some cases still have political control over that area, for example, city states. This centralised governance may be used to influence political, social and environmental agendas through policy (Smith 2002). Hall (1998) describes how great cities are central to civilisation because of their size and complexity, which makes them the home of the "innovative milieu". Through the creativity of these innovators, cities may overcome cultural inertia to generate new paradigms and transform society.

3.1.2 Urbanism: the process of making cities

Urbanism is the process of city making. Cities are in a constant state of flux (Kostof et al. 1999), so an understanding of the grand narratives, movements and processes that shape the dominant global urban typology[2] is essential for making apparent the assumptions that underlie conventional unsustainable city-making practices.

The industrial revolution marked the beginning of modern city form. The centralisation of jobs, and therefore labour forces, to cities began the movement of people from poorer rural communities to the urban environment in search of economic opportunity (Jacobs 1969). By the late 1800s, working class areas in major industrial cities saw overcrowding, poor sanitation and squalor adversely impact urban communities leading to outbreaks of disease (Hajer & Dassen

[2] Assumed here to be the Western Modernist planning model as outlined in section 2.3.2 Research assumptions and limitations

2014). This represented a significant negative environmental impact of urbanisation, and it led to calls for the reform of the cities in the world's largely European and American industrial centres.

The first major interventions involved the creation of infrastructure: city-wide railways and city-wide sewers that spread the city out along corridors. Both forms of modern infrastructure were massive and costly undertakings, and were not, at first, widely supported. But the overcrowding and under-provision of clean sanitation, which triggered tuberculosis and cholera outbreaks in major metropolises such as Paris and London, soon led to acceptance. All major cities in history have had extensive sewers to separate water and waste but it took the epidemiological work in London to scientifically link poor quality drinking water to disease outbreaks, before there was government intervention to improve sanitation infrastructure (Hajer & Dassen 2014).

In the early decades of the twentieth century, thought leaders in planning still made adverse assessments of dense and overcrowded cities, despite significant improvements in health and mobility. Proposals by leading Modernists such as Le Corbusier called for cities to be opened up through the introduction of wide areas of open space with either houses or high rise apartments linked by roadways to accommodate the recently invented automobile (Carmona et al. 2012; Taylor 2007). The idea was supported by many influential people, and Modernist city planning was born and the high density, tight-knit grain of historic walking cities and corridors of transit fell out of fashion. This model of planning was all but erased in the Anglosphere cities after the Second World War as the car-based suburb was created as the way of creating low-density, healthy and accessible (by car) cities.

The ills of car-based planning started to become apparent in the 1960s following draconian top-down planning approaches based on highways that crossed the city no matter what forms of urban fabric lay in their path. This led to new areas that were totally dependent on car mobility with significantly more land consumption and lack of walkable urban environments. It also led to the destruction of traditional high-density neighbourhoods in the old parts of the city composed of walking and transit urban fabric. Nowhere was this more apparent than in New York City, where the chief city planner Robert Moses oversaw the demolition of tenements, introduced highways and massive homogenous housing "projects" all based upon Modernist planning principles. It was a journalist, Jane Jacobs, who first built popular support for the advantages of the old, high density, neighbourhood structure of the inner city (Jacobs 1989). Her work championed the emerging discipline of urban design, which emphasised the relationship between the urban form and its impact on the quality of life of citizens. The links identified by Jacobs were largely social and economic, but increasingly the environmental links to compact city form were becoming apparent as well (Calthorpe 2010; Newman et al. 2009).

The "study or appreciation of the processes of change in towns and cities" is known as urbanism

(Cowan 2005). As previously mentioned, the past decade has delivered several types of urbanisms related to the environmental impact of urban form; the most ambitious and holistic of these is regenerative urbanism (Girardet 2010; Woo 2014).

3.2 Components of a regenerative urbanism

3.2.1 Reinventing urbanism

In a globalised economy consumption-related decisions may have material impacts around the world. Conventional cities draw on a regional, and increasingly global, hinterland (Rees & Wackernagel 2008; Girardet 2010; Girardet 2015; Baccini & Brunner 2012). The reach of the global hinterland has been made possible by hydrocarbon-based transport that permits the cheap movement of goods across the globe. This phase of unsustainable petroleum fuelled growth is referred to by Girardet (2010) as “Petropolis” .

The preface to Mumford’s magnum opus, *The City in History,* states

> . . . the city will have an even more significant part to play in the future than it has played in the past, if once the original disabilities that have accompanied it through history are sloughed off. (Mumford 1961, p.ix)

What if cities could reinvent the dominant form of urbanism to develop a new model based upon urban sustainability performance; a model that would allow city dwellers to (re)localise many of their activities to build a low impact green economy that still met their needs but with a greatly reduced ecological impact?

Different cities, and different parts of cities, have different urban sustainability performances. Through an analysis of different urban fabrics, Newman and Kenworthy (2015) have shown that compact walkable and transit oriented cities with higher dwelling density have a considerably lower footprint than auto-dependent urban fabric. This is a function of both the influence of this infrastructure on human behaviour and the greater operational and embodied energy and material demands of lower density development. Linking urban sustainability performance to urban design can reveal opportunities for improvement within urban system.

Achieving this will require the development of standardised urban performance metrics. Through an understanding of urban performance metrics, cities can be optimised to minimise adverse environmental impact and maximise liveability.

3.2.2 Urban metabolism and urban performance

Urban Metabolism is a bio-physical approach to studying and quantifying urban material and energy flows, drawing on the field of industrial ecology as it is applied to city processes (Gandy

2004; Broto et al. 2012). It can offer a helpful means of understanding how cities perform..

This process of resource flows has led to some researchers likening cities to an organism (Newman & Kenworthy 1999; Girardet 2010; Kennedy et al. 2007). Just as organisms have metabolism, cities have a metabolism to maintain their structure, grow and respond to their environment. A city's resource flows can impact heavily up the local, regional and global environment. Monitoring and responding to these flows is the key to transitioning from ecologically extractive to sustainable cities (Baccini & Brunner 2012)

One of the earliest comprehensive urban metabolism studies depicted the metabolic flows of Brussels, representing the stocks and flows of the system. The diagram combined a graphic representation of various urban elements with proportional line widths to represent material flow volumes derived from these elements, Figure 13 More recent work such as the Dutch publication *Smart About Cities* (Hajer & Dassen 2014) uses the proportional line widths of a Sankey diagram populated with data from PBL, The Netherlands' environmental assessment agency, to represent relative volumes of material inputs and outputs.

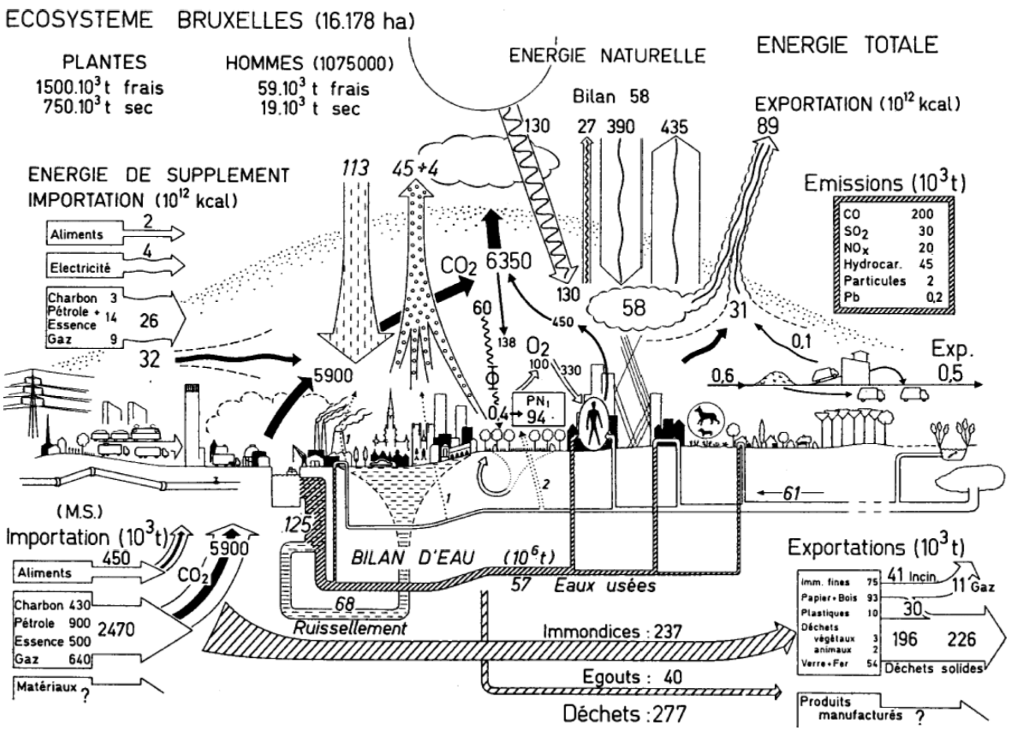


Figure 11: The urban metabolism of Brussels (source: Duvigneaud and Denaeyer-DeSmet 1977)

3.2.3 Regenerative design and cities

Given rapid population growth projections and increasing consumption trends, urban redesign based on low impact urban fabrics is essential to limiting adverse environmental impact.

Regenerative design relates to "the reconnection of human aspirations and activities with the evolution of natural systems" (Mang & Reed 2012, p.26). As applied to cities, regenerative approaches focus on designing "with and for nature to create regions, cities and buildings that function as ecosystems" (du Plessis 2012).

Achieving this goal may involve biomimicry in urban systems, particularly the energy, water, waste and food nexus, in order to help optimise resource efficiency. It may also require urban governance and management practices to shift from "silo" planning (i.e., each sectoral management or department planning in isolation) to:

> an integrated planning that seeks to optimise synergies between sectors and manage trade-offs through innovative integrated and cost-effective planning, as well as collaborative decision making and implementation. (GIZ and ICLEI 2014).

The relatively recent call for regenerative cities is quite different from the notion of urban regeneration, which is used extensively to describe the process of urban renewal in areas of decline (Carmona et al. 2012). Regenerative cities are grounded within a restorative ecological world view (Girardet 2010) so they can result from urban renewal and urban design but require an integrated approach that recognises cities as complex systems within a bioregion. As explained at the "Future of Cities" forum for regenerative urban development:

> The road to regenerative urban development begins with a switch in our thinking so that by-products conventionally considered "waste" can be reframed and reused as resource inputs. Regenerative cities are productive centres that help to regenerate the materials and resources they use and foster a mutually beneficial relationship between urban areas and their surrounding territories (Woo 2014).

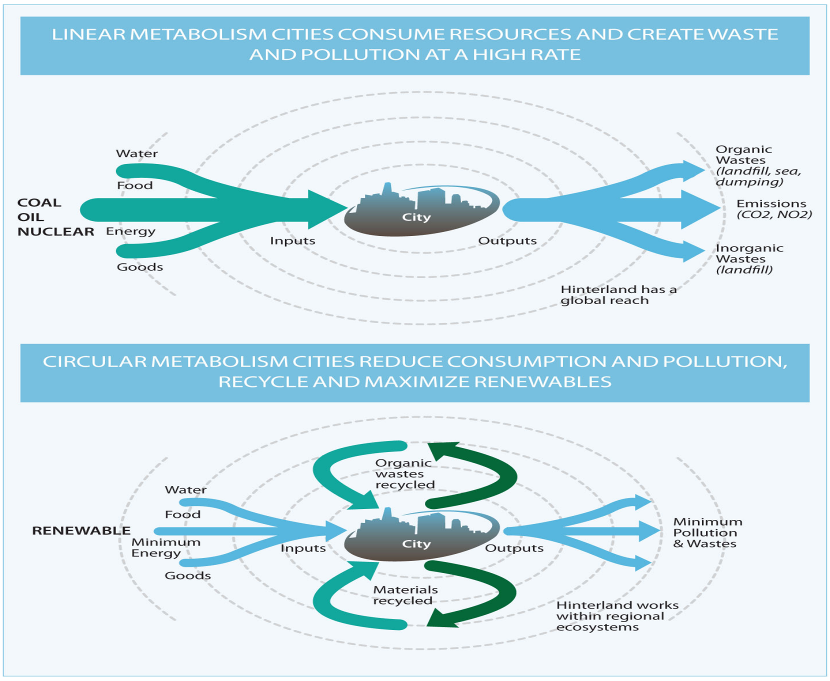
3.2.4 Regenerative urbanism and regenerative cities

Cities are the dynamic centres of commerce and trade, so the sheer scale and volume of goods and material resource flows that they process make them the world's most complex "nexus" of social, political, economic and environmental systems (GIZ and ICLEI 2014). The material needs of cities are supplied by a vast national hinterland and, increasingly, by a global supply chain. The volume of consumption in most cities exceeds the rate at which the local bioregion and global biosphere can regenerate. Thus, the management of cities is no longer merely about maintaining a healthy economy to finance material purchases, but rather it must expand to include management of material resource flows and other environmental impacts, local and global. Mumford's (1961) premonition about the significant future role of cities foretold of the need for a regenerative urbanism.

Many factors influence urban metabolism, including the structure of "front end" inputs such as energy, food, goods and water, and "back end" processes such as the treatment of pollution and waste (Baccini & Brunner 2012; Broto et al. 2012; Gandy 2004; Girardet 2010). Through targeted improvements it is possible for some elements of the city to become regenerative so that they restore parts of the degraded urban environment thus reversing damage to the biosphere. For example, an "energy plus" building can produce more energy than it consumes, thereby reducing inputs and outputs from the system while still providing the same level of service to the end user.

Delivering the regenerative city requires a paradigm shift from current conventional practice in which cities have generally been designed as extractive engines drawing resources from natural systems, processing these resources to generate value, and producing waste with impacts that are externalised. A new paradigm is required to plan urban systems that more closely resemble the cyclical resource flows observed in balanced natural systems whereby wastes are treated as resources for use in other parts of the system (see Figure 12) (Lyle 1999; Lyle 1996).

Governance, as much as planning and design, will need to be reformed. The reductive thinking that has led to the modern city is largely driven by siloed decision-making and budgeting (GIZ and ICLEI 2014). An integrated approach that considers the interrelated components of a complex urban system is necessary to shift the way our cities are designed.



Credit: Herbert Girardet.

Figure 12: The circular metabolism of a regenerative city (source: Girardet (2010) Reproduced with permission.

Component parts

- **Energy**. Energy can become regenerative if the fuel used to build and operate buildings and build and run transport is renewable and is greater than is actually being consumed by the city and thus can be used to help power and fuel the surrounding bioregion. This is likely to occur through renewably-powered electric systems in buildings and transport as well as renewable-gas (e.g., bio gas from waste) (Newman & Kenworthy 2015).

- **Water**. Water can become regenerative if it is collected at source within a city, and grey water and black water are recycled and used to help regenerate aquifers and water bodies in the bioregion (Gandy 2004; Nair et al. 2014). This can be done with current technologies (BioRegional 2009, pp.22–33).

- **Waste**. Waste can be reduced to very small amounts but not regenerated unless very large amounts of energy are used due to thermodynamic limitations. However, the return of carbon, phosphorus, nitrogen and other trace elements to surrounding soils in the bioregion can be achieved, for example, through compost systems (Newman & Jennings 2008).

- **Biodiversity and open space.** Biodiversity can become regenerative if it is built into every part of the urban fabric, including the new technologies of green roofs and green walls. Bioregional needs for biodiversity can be assisted by the city with its different structural habitats and intensive human power (e.g. through gardening, urban agriculture and urban biodiversity conservation); see Beatley (2011), Newman and Jennings (2008); Newman and Matan (2013), Newman (2014).

- **Sequestration**. Increasingly, the potential of sequestration mechanisms capable of actively "scrubbing" CO_2 from the atmosphere is being explored. Mechanisms could include increasing biomass (cf. biodiversity above); building or otherwise incorporating third way materials for example, bio-char or carbon sequestering rocks in urban infrastructure (see Flannery 2015); the large-scale incorporation of biogenic materials, for example, cross laminated timber, into building design (see Thompson & Waugh 2009); the redesign of cities for low carbon and carbon sequestering activity (see Fink 2013). This last point is also the subject of Publication 1 of this thesis.

Integrated circular metabolism is common in industrial ecology. In an urban environment this approach is best illustrated at Hammarby Sjöstad in Stockholm, Sweden. Here, a comprehensive masterplan of an old naval yard was overseen by the city and national governments. Part of the process was to manage various service provision agencies to work in a coordinated manner to develop a circular metabolism of urban systems. Figure 16 illustrates the "Hammarby Model", which integrates urban energy, water and waste systems (GlashusEtt 2007). This integration of services has enabled the precinct of 10,000 homes and businesses to halve their energy, water and waste outputs compared to the average Stockholm resident (Svane 2007).

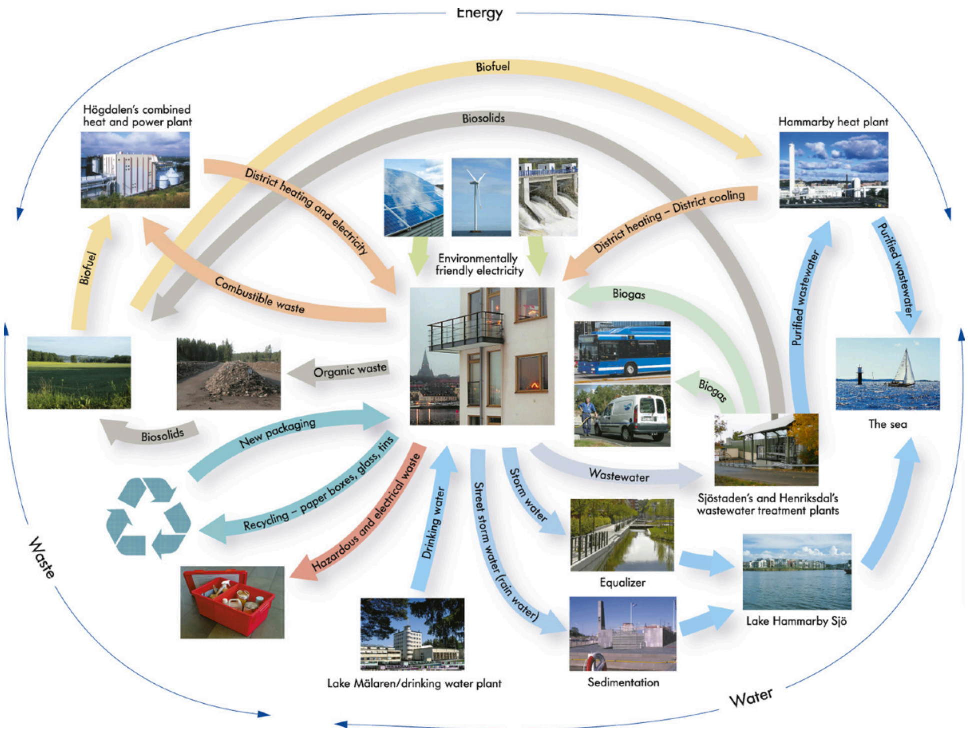


Figure 13: The Hammarby Model integrating energy, water, waste (source: GlashusEtt (2007)) Reproduced with permission

3.3 Transitioning to regenerative urbanism

To effectively address the diverse urban challenges requires a concerted approach integrating local, national, and international efforts, and mobilising all sectors and actors (Bai et al. 2016).

A number of major economic studies do already argue the benefits of increased integration. For example, the *Stern Review* (Stern 2006) in the UK, the *Garnaut Review* (Garnaut 2011) in Australia, and *The Cost of Delaying Action to Stem Climate Change* (The Council of Economic Advisers 2014) in the United States, each makes the economic case for sustainable, particularly low carbon, economies. The common thread is an ethical argument based upon intergenerational equity. This message echoes calls put out by *Our Common Future* (United Nations 1987) two decades earlier, that failure to address the issue now will place a social, environmental and economic burden upon future generations.

These, and similar, reports have been used to inform high level policy, but do not offer a clear process describing how they could achieve these goals. There is a need for translation into local policies, particularly those that shape city form, which shapes urban sustainability. This objective is one of the key goals of the New Urban Agenda launched at the United Nations Habitat III conference in October 2016 (Norman & Reid 2016). However, the exclusion of scientists in shaping city policy and in the shaping of the Habitat III remains a contentious issue with an article in *Nature* calling for greater involvement of scientists in shaping the urban agenda; specifically, the formation of a global urban scientific body (Fink 2011), global knowledge sharing, increased funding for urban research, more transdisciplinary research, and improved access for researchers to the science-policy arena (McPhearson et al. 2016). There are already early links to this with a 60,000 strong community of natural scientists belonging to the Future Earth program and particularly the recent Future Earth Sustainable Urbanism initiative, and stronger science-policy links through the United Nations SDGs (United Nations 2013; McPhearson et al. 2016).

In developed nations most cities rate highly on comparative international liveability and quality of life indices, but as Newton (2012) points out this is “a result of having inputs of high, and now unsustainable, levels of resource consumption”. The gradual decline of the biosphere’s potential, combined with growing global societal needs (trends towards both population and consumption increases), is described metaphorically as a “funnel” moving from greater abundance to narrower resource availability where more people are competing for increasingly limited resources (Robèrt et al. 2013).

Despite the urgent sustainability challenge, there is little incentive for an average citizen to adjust to a potentially more restrictive lifestyle. The call by academics such as Jackson (2009) and Trainer (2008) for the “simpler way”, whereby wealthy nations with high quality of life use less (and potentially sacrifice some of their own life quality) to benefit unknown other global citizens, has not found widespread acceptance. The dilemma was eloquently put forward in Hardin’s 1968 paper *Tragedy of the Commons* (Hardin 1968) where he outlined the mathematical and biological limitations to continued population and consumption growth in a limited world.

Hardin’s call for “the abandonment of the freedom to breed” (Hardin 1968, p.1248) is unlikely to be met. Therefore, if future generations wish to maintain the quality of life experienced in developed nations in recent years, it will be necessary to find ways to completely decouple the generation of wealth from the expansion of the ecological footprint through new technologies, new systems of urban management and new behaviour patterns that still meet human need by creating economic and social opportunities. This is *the* challenge of the 21st century. There is already considerable literature in this area, see for example discussions relating to environmental economics by Lovins (1999), Pauli (2010), Vollan and Ostrom (2010), Ostrom (2010), Costanza (2008).

The origin of much environmentally unsustainable production stems from the supply chains that feed urban populations and the lifestyle of urban populations themselves. These are embedded into the very fabric of our cities, that is, low-density sprawl, waste disposal, and hydrocarbon intense energy, transport and food production (Newman & Kenworthy 1989; Newman & Jennings 2008; Girardet 2004; Fink 2011; Calthorpe 2010).

These embedded structures require more than incremental policy that tinkers with the edges of the system. Instead, there have been calls for a radical reconsideration that looks at the underlying performance, barriers and opportunities of our living environment and behaviour (Thackara 2005; UN System Task Team on the Post-2015 UN Development Agenda 2012).

There are signs of a step change, with research into and application of renewable energy, which is rapidly displacing conventional hydrocarbon fuelled energy (Droege 2008; World Future Council et al. 2013; Keirstead et al. 2012). There is a need to understand what other eco-infrastructure may support high quality of life, and, possibly more importantly, how can this be made into a desirable and affordable life choice. Successful redesign of urban areas must seek to improve performance, improve desirability and ideally reduce (societal) costs by factoring in externalities.

More recently, a hopeful message around sustainability has been building a positive narrative and gaining traction among some thinkers. Since 2013, the following titles have been released espousing a new mindset relating to design that can unleash the bountiful nature of sustainability: *Thrivability* (Russell & Gurevich 2013), *Abundance* (Diamandis & Kotler 2014), *The Upcycle: Designing for Abundance* (McDonough et al. 2013), *Atmosphere of Hope* (Flannery 2015), and *Designing for Hope* (Hes & du Plessis 2014). It is upon this growing and engaging message of hope that this thesis aims to build.

The emerging concept of the regenerative city (see Girardet 2010; Newman, Mason and Gardner, 2013) provides a theoretical framework to help direct long term urban planning to move beyond sustainability towards performing a restorative role.

Girardet (2010) states that the creation of regenerative cities will require comprehensive political, financial and technological strategies in order to create an environmentally enhancing, restorative relationship between cities and the ecosystems from which they draw resources. A systems approach to urban development performance and management is needed to achieve this, but integrated approaches are not currently how most siloed government agencies and business structures are organised or funded (GIZ and ICLEI 2014; Brugmann 2011). No single agency is responsible for the urban agenda to coordinate development and sustainability (Fink 2011). However, this is happening and a number of highly efficient integrated exemplars do exist. There are examples that demonstrate that industry has the technological capability to deliver sustainable or regenerative development (e.g. Europacity (Germany), BedZED (UK), Hammarby Sjöstad (Sweden)). However, the reality is that uptake of sustainable urbanism is slow. Genuinely regenerative projects are rare and the rate of global urbanisation is in the range of tens of millions of dwellings every year. United Nations projections indicate a global population of 9.7 billion by 2050 (United Nations 2015b). If this projection is correct, it will be necessary to build approximately the equivalent of a city for one million every five days (Norman & Reid 2016).

3.3.1 Scales of influence

Meadows (1999) describes leverage points that may drive urban transformations within complex social-ecological-technical systems. In the case of the human ecological impact upon the planet, as described in sections 3.1.2 and 3.2.1, cities warrant the majority of attention, despite forming only 3% of the global land mass. The argument for focusing on cities is outlined in Publication 1.

This thesis identifies cities as the global landmass on which major sustainability transitions should be focused. Human activity is concentrated in these locations and indeed this is where most population, economic and infrastructual growth is happening. Different parts of the city present more effective leverage points for maximising impact when considering sustainability transition potential. These shifts may be described in terms of macro, meso and micro scales.

Macro scale

The macro scale takes in the whole urban area or large parts of a city region.

Historical patterns for car-based sprawl that emerged in the second half of the 20th century can no longer be sustained, not simply from a sustainability perspective, but also from economic and social perspectives (Newman & Kenworthy 2015).

As cities grow and the mean exposure time to travel extends beyond a 30 minute commute (an hour a day) known as the Marchetti constant (Marchetti 1994), the urban system tends to become dysfunctional. The dysfunctional nature of cities tends to have the greatest negative impact in terms of lost productivity, stress and cost (related to fuel) on the citizens with the longest commute, who also tend to be from lower socioeconomic demographics (Dodson & Sipe 2006).

Urban infrastructure can affect this by improving travel times. In larger cities, the most efficient mode for travelling longer[3] distances is rail, which is beginning to improve on private vehicle travel times in larger cities (Newman et al. 2013).

[3] e.g. distances greater than around one hour total per day – see Publication 2 “Marchetti Constant”.

In response, some larger cities are introducing planning policies that encourage the integration of land use planning and transport. This involves a shift from monocentric "hub-and-spoke" cities, with a central business district surrounded by dormitory suburbs, to polycentric cities with multiple activity centres (Moir et al. 2014). To improve transport speeds and efficiency, polycentric city activity centres are often built around transit hubs such as heavy or light rail stations. Urban development that integrates transit with activity centres is known as transit oriented development (TOD) (Scheurer & Curtis 2008; Curtis & Scheurer 2010; Newman & Kenworthy 2011).

Transformative approaches such as the entrepreneur rail model (Newman et al. 2016) provide a mechanism for large-scale transformative change to urban fabric, enabling the replacement of less sustainable automobile urban fabric across the city region. The model uses private capital to finance urban transformation along corridors selected by strategic planners for their redevelopment potential. The model permits low density areas to be transformed into high density public transport corridors, with "value capture" from the redeveloped sites to fund the adjacent rail infrastructure. The corridor results in automobile fabric being displaced for more sustainable transit urban fabric punctuated by a collection of higher density mixed use cellular communities – "precinct", "districts" and "neighbourhoods".

Although desirable, holistic approaches to sustainability in the context of whole cities or city regions are rare. This is largely because of complexities related to scale, in which in cities quickly becomes too broad and complicated. Implementation of urban sustainability transition becomes far more realistic at the neighbourhood, precinct or corridor scale.

Meso scale

Meso scale development includes precinct (neighbourhood or district) level development, which may involve housing and public infrastructure (e.g., roads, open space, utilities).

Neighbourhoods and precincts form the scale of community and as such are the building blocks of cities (Rohe 2009). Perhaps more importantly, in terms of delivery, the precinct is the scale at which land development takes place. Precinct scale development permits comprehensive planning of buildings, open space and infrastructure, and as such is the ideal scale for shaping the quality of the built environment in terms of sustainability performance (Sharifi & Murayama 2013) and liveability (Carmona et al. 2012).

Precincts, neighbourhoods and corridors are small enough to invite innovation and big enough to leverage meaningful investment and public policy (EcoDistricts 2016). Greater efficiencies can be achieved at the precinct scale than at the individual household scale due to the complex network of interaction between urban systems such as energy, water, food and transport that in combination provide opportunities for a more holistic integrated approach to urban environments (be they greenfield, brownfield or greyfield sites) (Newton 2014; Newton, Murray, et al. 2012). The smaller scale of the (regenerative) precinct versus the (regenerative) city allows for greater control through more focused governance and management to oversee development outcomes and to prototype new models and replicate those that are most successful.

Precincts may function as transitional, decentralised, semi-autonomous, cellular components that incrementally work towards the aspirational end state of the regenerative city. The precinct permits eco-infrastructure at a scale of efficiency not achievable at the individual building level, and may provide the best opportunity for radical urban sustainability transitions. Interestingly, several rating tools for the assessment of building sustainability have expanded to address precinct or neighbourhood sustainability assessment in recent years, for example:

- BREEAM (Building Research Establishment Environmental Assessment Method) was the first environmental certification tool for buildings, developed in the UK in 1990 and now the most widely used sustainability rating tool in the world; BREEAM communities was introduced in 2008
- LEED (Leadership in Energy and Environmental Design), which was developed in the USA, piloted LEED-ND (Neighbo(u)rhood Development) in 2007, and officially launched in 2009
- The Green Building Council of Australia launched Green Star in 2003 and piloted Green Star Communities in 2012.

The precinct has a number of advantages over the individual building scale. For example, the precinct:

- is the scale of community and can allow comprehensive planning with a mix of uses within walkable distance and a distinct sense of place (Newton et al. 2011)
- allows for the integration of social infrastructure (schools, parks, shops), enabling greater liveability and a more community-based way of life (Newton et al. 2011; Rauland & Newman 2015)
- assists the economic feasibility of eco-infrastructure – localisation solutions versus centralised solutions are a major issue in future planning as many sustainability solutions, particularly infrastructure (e.g. distributed energy, sustainable transport, water sensitive urban design) are local in scale (Newton et al. 2011; Rauland & Newman 2015; Bunning et al. 2013).

Precincts effectively offer a microcosm of the city and can be planned as such with consideration for transport, buildings, energy, water, food, waste, biodiversity and open space.

Micro scale

Micro scale, in the context of cities, relates to the piecemeal transformation of individual plots. Although important, this is the least effective means of transformation. However, if small transformations occur en masse, it may be possible to achieve massive small change (Campbell 2011). Campbell, one of the most celebrated urban designers in the UK, leads the massive small movement out of the UK. The massive small declaration[4] is presented "as an antidote to bigness" – and "that governments alone cannot effectively tackle the increasingly complex problems of rapid urbanisation" (Campbell 2016). Effectively it is a call to mobilise people's creativity to collectively harness the power of many small ideas using a consistent set of simple urban design rules. The distributed and decentralised nature of the internet can help such models flourish, be shared and replicated.

Discussion of scales

Each scale has its relative advantages and disadvantages. At the micro scale it is possible to have the greatest control over the product as it is in single ownership. It may be easier to deliver a regenerative building and there are examples, and models (e.g., the Living Building Challenge (2014)) that demonstrate how this can be done. Such approaches may become policy but this is less likely than comprehensive development at the precinct scale.

Precinct scale development has advantages that have been discussed earlier. It is at the precinct, the scale of community allowing for the co-ordination of services, schools, open space and other social infrastructure. Comprehensive, staged, neighbourhood based development not only allows for the co-ordinated deliver of social infrastructure but also distributed infrastructures to deal with energy, water or waste.

A distributed system will ideally display the following characteristics, it will be:

- Localised – positioned close to resource supply and demand,
- Modular – the capacity to operate independently and combine with other networks,
- Open – ownership of the system is (more) democratic, is transparent and may involve or encourage local stakeholders to have a greater understanding and role in the supply chain (Biggs et al. 2010).

Comprehensive planning, at the precinct, neighbourhood and district, meso scale of development lends itself to the co-ordination and integration of local systems. Regenerative urbanism applied at the precinct scale can deliver decentralised, semi-autonomous, cellular

[4] available here: http://www.massivesmall.com/declaration/

urban development that radically transitions a part of the city as part of an overall sustainability transition. Sustainability performance can be measured through the use of sustainability assessment tools (e.g., LEED, BREAM, GreenStar Communities) or regulations that apply standardised metrics that monitor resource inputs and waste outputs of the development (i.e., an urban metabolism analysis).

Finally, while the macro scale presents the greatest opportunity for rapid change, changes of this scale are also the most contentious because they have the largest impact not just in terms of performance but also urban disruption. For this reason it is critical that affected communities (including future residents where possible) are involved in the decision making process. Deliberative democracy approaches directly involve the community in the decision making process so that change is not just done *to* the community, but rather is driven *by* the community (Gollagher & Hartz-Karp 2013; Hartz-karp 2007). Models for macro scale urban transformation such as the entrepreneur rail model (Newman et al. 2016) need to be build community support. In Portland, Oregon the transformation of the Pearl District through an infrastructure led redevelopment program was funded through value capture (TriMet 2015). Supporting this strategy was strong leadership by the City of Portland, which had the mandate from the community through the city vision, which included a compact city enforced by maintaining a long standing urban growth boundary, integrated land use planning laws for high density development and an expanded network of transit (VisionPDX 2007).

Chapter 4 Publication summaries

The following section provides a summary of each publication submitted as part of this thesis, the full publications are provided later. Each publication answers a subquestion of this thesis as outlined in Table 4.

Table 4: Publication titles and status

Paper title	Publication and status	Subquestions
Publication 1 "Geoengineering in the Anthropocene through Regenerative Urbanism".	*Geoscience* MDPI, SI Geosciences and the Built Environment Published October 2016	**Subquestion 1.** What is regenerative urbanism and how can it help deliver sustainable cities and a sustainable planet?
Publication 2 "Urban Fabrics and Urban Metabolism – from Sustainable to Regenerative Cities".	*Resources Conservation and Recycling,* Elsevier, SI: Urban Metabolism. Published January 2017	**Subquestion 2.** How do cities work, and therefore how can they be changed?
Publication 3 "Urban Regeneration and Urban Fabrics in Australian Cities".	*Journal of Urban Regeneration and Renewal,* Henry Stewart Publications. Published December 2016	**Subquestion 3.** What is the best scale for transitioning to a regenerative urbanism?
Publication 4 "Sustainable infill development"	In *WA Infill Housing Futures*. Rowley, S., Ong.R., Duncan, A. (eds). Accepted in press.	**Subquestion 4.** How do cities and precincts regenerate?
Publication 5 Material flows, Information flows and sustainable urbanism	*9^{th} International Urban Design Conference proceedings.* Peer reviewed conference paper. Published November 2016	**Subquestion 5.** How can governance deliver and manage regenerative urban development?
Publication 6 "GRID: A new governance mechanism for financing eco-infrastructure at the district scale".	*7^{th} International Urban Design Conference proceedings.* Peer reviewed conference paper. Published September 2014	
Publication 7 "A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia".	*State of Australian Cities Conference Proceedings 2013.* Peer reviewed conference paper Published August 2013	

4.1 Publication 1: Geoengineering in the Anthropocene through Regenerative Urbanism

Published paper

Thomson, G., Newman, P. (2016) Geoengineering in the Anthropocene through Regenerative Urbanism. *Geosciences* **2016,** *6,* 46; doi:10.3390/geosciences6040046

Paper abstract

Human consumption patterns exceed planetary boundaries and stress on the biosphere can be expected to worsen. The recent "Paris Agreement" (COP21) represents a major international attempt to address risk associated with climate change through rapid decarbonisation. The mechanisms for implementation are yet to be determined and, while various large-scale geoengineering projects have been proposed, we argue a better solution may lie in cities. Large-scale green urbanism in cities and their bioregions would offer benefits commensurate to alternative geoengineering proposals, but this integrated approach carries less risk and has additional, multiple, social and economic benefits in addition to a reduction of urban ecological footprint. However, the key to success will require policy writers and city makers to deliver at scale and to meet high urban sustainability performance benchmarks. To better define urban sustainability performance, we describe three horizons of green urbanism: green design, whcih seeks to improve upon conventional development; sustainable development, which is the first step towards a net-zero impact; and the emerging concept of regenerative urbanism, which enables biosphere repair. Examples of green urbanism exist that utilise technology and design to optimise urban metabolism and deliver net positive sustainability performance. If mainstreamed, regenerative approaches can make urban development a major urban geoengineering force, while simultaneously introducing life-affirming co-benefits to burgeoning cities.

Subquestion and approach

This paper addresses the questions "What is regenerative urbanism and how can it help deliver sustainable cities and a sustainable planet?"

The idea for this paper was triggered by the success of the world's first universal unilateral global climate deal – the Paris Agreement (United Nations 2015a). The Paris Agreement requires nations to decarbonise but does not suggest *how* they decarbonise. The paper describes how cities may be part of the answer.

A broad ranging literature review discusses, in general terms, the global environmental policy agenda to decarbonise, the wider environmental crisis, and the potential for reimagining cities as an arena to offer solution to address global environmental issues.

Publication conclusions

Cities, if designed to meet high urban sustainability performance measures (defined in this paper by three horizons of green urbanism: *green design*, *sustainable development* and *regenerative urbanism*) can help with climate change mitigation. Cities may be designed to be low carbon, or through the incorporation of "third way" technologies to sequester carbon. If this process can be replicated at scale, then cities may present a possible alternative to ethically contentious geoengineering as a means of rapid decarbonisation. Cities could perform *urban geoengineering* function of removing carbon. Cities that are designed as regenerative, consider not only reduction of carbon emissions but also a range of ancillary benefits for example improved liveability, improved waste and water performance and increased urban biodiversity.

The use of simple categorisations such as the "three horizons" of this article can help make notions of urban sustainability performance easier to understand, assisting policy makers to ensure that urban performance measures genuinely contribute to larger policy objectives such as the Paris Agreement.

The paper concludes with the suggestion that the large-scale regenerative potential of cities could reframe the Anthropocene as a period of rapid negative environmental impact to a period of biosphere repair.

4.2 Publication 2: Urban Fabrics and Urban Metabolism

Accepted paper

Thomson, G., and Newman, P. (2016) Urban Fabrics and Urban Metabolism – From Sustainable to Regenerative Cities. *Resources, Conservation and Recycling*

Paper abstract

This paper uses urban metabolism as a way to understand the sustainability of cities. It suggests that the city organism can reduce its metabolic footprint (resource inputs and waste outputs) while improving its liveability. Like organisms, different cities have different metabolisms. This paper demonstrates that different parts of a city (walking, transit and automobile urban fabrics) also have different urban metabolisms. A detailed case study from the city of Perth, Australia, is presented.

The paper responds to the question "How do cities work and therefore how can they be changed?" *used to demonstrate metabolic variations in different parts of the city. Understanding urban metabolism and the processes that drive it is the key to transitioning from ecologically extractive to sustainable cities. Through targeted improvements it is even possible for some elements of the city to become regenerative so that they restore parts of the degraded urban environment thus reversing damage to the biosphere.*

Subquestion and approach

Understanding the physical attributes and limitations of the regenerative capacity of a city will help focus interventions in the built environment. The focus of this paper is the potential of the physical infrastructure of cities to be regenerative.

A literature review of sustainable and regenerative cities is supplemented by the interpretation of new data in a case study of the urban metabolism of three urban fabrics in Perth, Australia.

Publication conclusions

Different parts of the city (walking fabric, transit fabric and automobile fabric) are demonstrated to have different metabolisms. The least sustainable is automobile fabric, not simply because of the greater vehicle kilometres travelled as a result of sprawling built form; but, more significantly, because of the multiple inefficiencies resulting from lower density. In particular, increased land consumption and extent of infrastructure are observed to result in considerably greater volumes of basic raw materials embedded in construction materials.

In addition to the sustainability efficiencies observed in the higher density walking and transit urban fabrics, the paper describes additional benefits derived from Technical and Construction Innovation (TCI). TCI includes processes such as building information systems (BIM) and prefabricated construction; both processes greatly improve construction efficiency in terms of materials but also construction time and cost.

Under business as usual (BAU) scenarios, efficiencies of around 50% are observed in walking fabric over automobile fabric. But following the introduction of TCI efficiencies in walking fabrics basic raw material efficiencies increase to almost 20 times that observed in a BAU automobile fabric. The greatest improvements were possible in the reduction of basic raw materials, however, other aspects such as solid waste, (hydrocarbon based) transport energy and raw materials have limits.

The paper demonstrates that transport infrastructure has a strong influence upon urban planning, which in turn has a strong influence on urban sustainability performance. Planning for automobiles results in low-density, sprawling cities, while planning for transit with walkable urban centres results in compact and vibrant cities. That transport influences urban form is well documented. That there is such a strong relationship between urban sustainability performance (as measured by the urban metabolism analysis of Perth), is a new finding of this paper.

4.3 Publication 3: Urban Regeneration and Urban Fabrics in Australian Cities

Published paper

Thomson, G., Newton, P., Newman, P., 2016. Urban Regeneration and Urban Fabrics in Australian Cities. *Urban Regeneration and Renewal*. 10.2. pp.1–21

Paper abstract

This paper describes Australian urban regeneration in terms of urban fabric – walking, transit or automobile and geography – brownfield and greyfield arenas. Case studies are used to highlight the importance of understanding urban fabric when considering development and regeneration across any geography. Urban regeneration in Australian cities, which has been occurring in brownfields locations for the past three decades driven initially by government intervention, but is now a strong market force. The "peak car" phenomenon is now associated with an even stronger demand for urban regeneration stretching beyond the inner city into the middle suburbs or greyfields. This paper provides a brief history of major regeneration influences followed by an overview of the processes, policies and practices that can enable the next phase of urban regeneration in all three urban fabrics particularly the greyfields.

Subquestion and approach

This paper responds to the question, "What is the best scale for transitioning to a regenerative urbanism?" It achieves this through a case study analysis of urban regeneration areas over the last 30 years in Australia's major cities with a focus on Melbourne and Perth.

Publication conclusions

Large-scale land assembly in Australian cities follows a similar pattern to that observed in international cities in developed nations where well-located post-industrial "brownfield" sites, lent themselves to regeneration following the shift from manufacturing to service economies.

In Australian cities, stocks of brownfield sites are running low following several decades of rapid urban population growth. This has led to a shift away from brownfield sites to greyfield[1] sites as a focus for urban regeneration. However, the incremental policy driven densification of greyfield locations tends to deliver suboptimal piecemeal redevelopment. Case studies indicate that the optimal scale of urban regeneration is the precinct scale. What is needed are new

1 Greyfields are the ageing but occupied tracts of inner and middle ring suburbia that are physically, technologically and environmentally failing and which represent under capitalised real estate assets (Newton 2010)

planning tools (e.g., digital GIS analytical and scenario testing tools), and governance mechanisms to facilitate coordinated land assembly and comprehensive redevelopment at the precinct scale to permit the delivery of superior integrated planning outcomes.

Currently no such governance structure exists and the paper concludes that to do so requires a new form of urban renewal authority with the mandate to coordinate land assembly and deliver sustainable regeneration projects. Without such a structure it is unlikely that the full potential of the greyfields will be unlocked to lead an urban sustainability transition.

4.4 Publication 4: Sustainable Infill Development

Forthcoming book chapter

Thomson, G. and Newman, P. (2017) Sustainable Infill Development. In: *WA Infill Housing Futures*. Rowley, S., Ong, R., Duncan, A. (Eds)

Chapter abstract

This chapter shows how infill[1] *development can be sustainable in a global and local sense. It does so by discussing sustainable urban systems in terms of energy, water, biodiversity and waste; and how an integrated approach to the design of these systems can drive efficiencies even further. Infill opportunities, especially at the larger precinct scale, present an excellent opportunity for enhancing city sustainability, so this chapter concludes by considering a range of sustainability elements in light of a recent Perth case study "WGV".*

Subquestion and approach

This paper asks, "How can regenerative design be integrated into urban development?". The emphasis is upon the redesign of existing urban areas in Perth, Australia. A number of existing problems facing this rapidly growing city are discussed.

Chapter conclusions

In Australian cities high liveability comes at the expense of sustainability. Amongst other factors this is a function of low density spawl. Attempts to reverse these patterns have been made by encouraging infill over greenfield development. However, where this has been poorly designed different problems occur. For example, significant amounts of canopy cover loss have occurred where trees are removed to allow for infill development. However, better planning processes and technological advances have permitted some innovative new developments that demonstrate much higher urban sustainability performance.

Through the use of case studies the chapter suggests that several elements will accelerate the mainstreaming of sustainable urbanism including:

- leadership to establish and drive a clear vision
- accreditation and auditing to ensure the outcomes planned are the outcomes delivered
- digital tools and evidence-based design to optimising production processes and operational performance
- a planning framework that supports and facilitates integrated development outcomes and maximises community input and buy-in

[1] Redevelopment of existing urban areas cf. urban regeneration.

- unlocking previously developed, low-density land (brownfields and greyfields) for redevelopment.

4.5 Publication 4: Material Flows, Information Flows and Sustainable Urbanism

Published peer reviewed conference paper

Material Flows, Information Flows and Sustainable Urbanism. *9th International Urban Design Conference Proceedings*, Canberra, Australia

Chapter abstract

Urban metabolism is a holistic way to understand the physical sustainability of cities. A genuinely "smart" urbanism is sustainable when it links development decisions to ecological impact. Urban metabolism can be used as a tool to monitor material flows and optimise metabolic footprint (resource inputs and waste outputs) to reduce ecological impact, while improving liveability. Like organisms, different cities have different metabolisms. Analysis from a detailed case study in Perth shows that different parts of a city (walking, transit and automobile urban fabrics) also have different urban metabolisms. Urban metabolism analysis is essential for identifying urban design leverage points that will enable the transformation of Australian cities from some of the world's most resource intensive to sustainable cities. A smart city, therefore, is one that measures material flows, and makes this data widely available as information flows to those people who are able to influence urban outcomes. Urban metabolism can inform evidence-based policies to optimise sustainable urban designs.

Subquestion and approach

This paper asked, "How can governance deliver and manage regenerative urban development?" This is achieved through the use of case studies related to the measurement of metrics and creation of policy in Australian cities.

Chapter conclusions

The paper refers to a recent case study to demonstrate the disconnect between performance metric aspirations from high level policy makers, and what is actually being measured. The federal government in Australia in 2010 released a set of 81 aspirational performance metrics to measure urban liveability, sustainability and productivity. An attempt to apply these metrics by a state government agency with the assistance of the Australian Bureau of Statistics was unsuccessful due to poor data. The results showed that only 28% of the indicators were deemed suitable for use. Data availability, or data quality, was insufficient or absent for many indicators, particularly those measuring sustainability or social outcomes of communities. Policy was let down by a lack of available research and data.

In another instance research into the metabolism of cities (see Publication 2) showed that different urban fabrics have different sustainability performance. Walking and transit urban fabrics having far less negative environmental impact than automobile fabric. Having this data available allows policy makers to make informed decisions about the future of the city. But again, this is only useful if the right information gets into the hands of the right decision maker at the right time to influence change. The case studies show how the processes of choosing the right metrics, or having the right research are not enough in themselves to bring about change. The paper therefore concludes that the alignment of the following measures can assist in bringing about meaningful, and widespread, urban sustainability transitions:

- active monitoring of the city and its parts using metrics such as material flow analysis to reveal the urban sustainability performance of an area
- systems to enable information flows that make urban research available in a useful form and timely manner as an evidence base for decision makers
- iterative feedback loops to continually drive transformative change to deliver genuinely sustainable urbanism.

Where any one of these elements is missing fully informed decision-making will be hindered, the status quo will prevail, and urban form and urban sustainability will likely suffer.

4.6 Publication 6: GRID: A new governance mechanism for financing eco-infrastructure at the district scale

<u>Published peer reviewed conference paper</u>

Thomson, G. and Rauland, V. (2014) GRID: A new governance mechanism for financing eco-infrastructure at the district scale. *7th International Urban Design Conference Proceedings*, Adelaide, Australia

Paper abstract

The combined challenges of climate change, finite resources, population growth and ageing infrastructure demand a shift towards more resource-efficient, low carbon sustainable cities. This may be achieved through new forms of eco-infrastructure delivered at the district scale. Despite considerable success in numerous demonstration projects globally, such development has not yet become mainstream. Finance remains a key obstacle preventing wide-spread implementation.

This paper suggests that new funding models are needed that can help spread the costs of the infrastructure over a longer time period and across different land titles. It highlights a range of possible funding options and introduces the concept of Green Regenerative Improvement Districts, or "GRIDs", as a possible new governance mechanism that could assist with financing and managing precinct scale eco-infrastructure.

Subquestion and approach

This paper asked, "How can governance deliver and manage regenerative urban development?"

It involved a multiple case studies looking for processes that enabled successful implementation of sustainability initiatives. The resulting industry-oriented paper provides a short survey of policies, programs and innovative financing options that could be used as tools to enable sustainability transitions.

Publication conclusions

Based upon observations in the various case studies reviewed to inform the paper, the conclusion was that new governance models (e.g., GRIDs) could greatly assist with the coordination, planning, financing, monitoring and management of various precinct scale eco-infrastructure. It is possible that the same authority that might be involved in land assembly (see section 4.2) might transform into a GRID following site development.

4.7 Publication 7: A Review of International Low Carbon Precincts

<u>Published peer reviewed conference paper</u>

Thomson, G., Newman, P., and Matan, A. (2013) A Review of International Low Carbon Precincts. *State of Australian Cities 2013 Conference Proceedings.* Sydney, Australia

Paper abstract

Urban environments, once built, are slow to change, therefore the neighbourhoods we build today, will ideally be designed to meet our future needs. The combined challenges of climate change, population growth and finite resources demand we rapidly decarbonise our cities. Failing to provide the necessary infrastructure to decarbonise Australian cities today will place a social, environmental and economic burden upon future generations of Australian society.

At a high strategic level this imperative is acknowledged but in practice government planning agencies have typically placed greater emphasis upon maintaining land supply and housing affordability over effectively fostering a culture of sustainable urbanism. The absence of a strong sustainability culture within the built environment sector, has seen barriers, such as the "sustainability cost premium" and the political "short termism" of a three year electoral cycle, impede more rapid transition to a widespread culture of sustainable urbanism practice.

This paper describes six international "low carbon precinct" case studies to show how they were able to overcome some of these barriers. The case studies employ a diverse range of strategies including demonstration project trials, integrated eco-services and innovative funding models to deliver low carbon precincts. It shows how political, skill and market barriers can be overcome through the use of different delivery models, and how these models may provide useful lessons to help develop pathways to decarbonise urban development in Australian cities.

Subquestion and approach

This paper investigates "How can governance deliver and manage regenerative urban development?"

The paper was refined from a multiple case study analysis of 78 sustainable precincts as part of a scoping study prepared for the Cooperative Research Centre for Low Carbon Living. Six of the most insightful case studies were chosen to demonstrate how each was able to overcome certain barriers to delivery.

Publication conclusions

The paper was able to demonstrate that some of the most globally renowned sustainability demonstration projects are heavily subsidised, typically by governments driving a political agenda (usually to promote sustainability). However, there are an emerging number of demonstration projects, typically delivered by the private sector, that are not subsidised and are able to compete with conventional real estate products. The paper discussed BedZED (UK), the Peterborough Carbon Challenge Site (Vista development, the largest zero carbon development in the UK in 2012) and Hammarby Sjöstad (Sweden) as examples of precinct scale developments that were subsidised to varying degrees. It then describes two further exemplars that were able to deliver highly sustainable products that could compete with conventional developments. "One Brighton" in the UK, was driven by the private sector and the other Vauban, Freiburg in Germany by the community owner developers.

In the case of One Brighton the developer looked for ways to maximise financial return to absorb the additional build cost of the sustainable product. They achieved this by applying the "planning gain mechanism". This involved finding opportunities to increase site yield (and therefore saleable area) through planning mechanisms. The developers, planning application presented a green transport plan in lieu of the car parking required by the local planning policy. The council approved this conditionally due to the site's proximity to a train station and services. The additional floor area allowed the developer to make a respectable profit margin from the additional site yield, while delivering higher quality sustainable product despite the financial crisis of 2008.

In the case of Vauban, building owners were able to cut out the developer by participating in a *baugruppen* – or housing collective. This process is common in Germany and Denmark. In Vauban, the local council actively encouraged this development model and assisted the community members wanting to develop collectively. The outcome is higher quality houses (because of the vested interests of the owner occupier) and less expensive product with around 5–15% saved from the developer's profit margin; this money can be saved or reinvested into sustainability measures or other personalised benefit.

To mainstream sustainable development, financial mechanisms (see Publication 6) are necessary to allow sustainable products to compete with conventional products. Even though long term savings may make a business case for an occupant to spend more on building a house, the split incentive discourages most developers from investing high performance building specifications.

Chapter 5 Results and discussion

The results and discussion is split into two sections:

- Section 5.1 *Regenerative Urbanism – the Product,* describes the physical attributes of a regenerative urbanism in a scalar context from planet to urban fabric
- Section 5.2 *Regenerative Urbanism – the Process,* describes a range of techniques based upon replicable case studies that may be introduced into urban development areas as tools that will help meet the strategic goal of delivering a regenerative urbanism.

5.1 Regenerative urbanism: the product

The redesign of cities has the potential to provide numerous benefits ecologically, socially and even economically (du Plessis 2012; Girardet 2015; Seitzinger et al. 2012; Pickett et al. 2011); failure to do so risks an existential crisis for humanity (Droege 2012; Bostrom 2002).

At the core of regenerative urbanism is land use planning. Therefore, before attempting to describe what regenerative urbanism might look like it is useful to first reiterate the position of cities in a global land use context. Figure 14 conceptually illustrates cities in a global land use context.

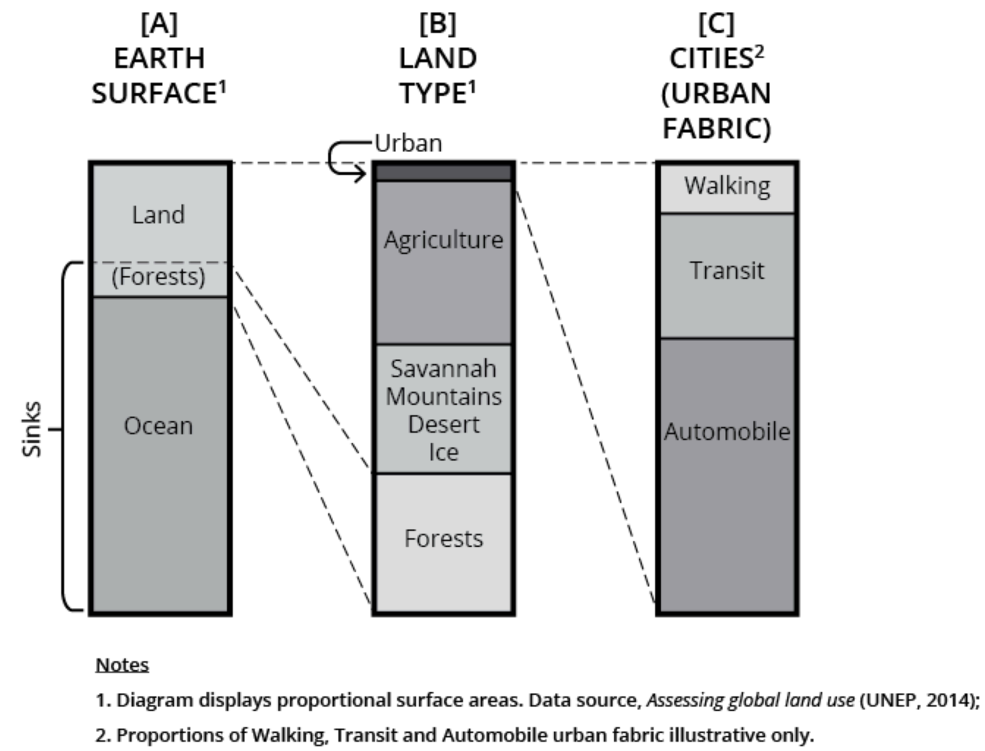


Figure 14: Diagram of global land use categories

The following text relates to Figure 14, with the letters preceding the text corresponding to the labels in the diagram.

A. **Planet.** The Earth's surface is 70% water and 30% land. The ocean and land resources function as sinks that absorb pollution resulting from human activity (Pincetl et al. 2012; Luck et al. 2001; Crutzen & Stoermer 2000).
B. **Land.** The 30% of the planet that is land may be loosely categorised into forest; deserts, glaciers, mountains; grassland (savannah), agriculture (pasture and arable land); and cities (Bringezu et al. 2014). Of this only around 3% is urban (CIESIN 2005). However, the metabolic processes generated by human consumption patterns in cities have an ecological footprint that extends into the other land use categories (Wackernagel & Rees 1998; Newman 1999; Abel Wolman 1965).
C. **Cities.** The underlying infrastructure of all cities can be described in terms of three urban fabrics – walking, transit and automobile. Each fabric has a different metabolism with automobile urban fabric the least efficient and walking fabric the most efficient and therefore the most sustainable (for full treatment of this topic see Publication 2). This knowledge allows design of the underlying infrastructure to optimise urban metabolism (Newman & Kenworthy 2015; GIZ and ICLEI 2014; UNEP 2013; Hajer & Dassen 2014). The detailed material flow analysis findings from the Perth case study (Publication 2) reinforces more general studies into the efficiency of cities based upon their density and dominant transport modes (Kenworthy & Laube 2001; Kenworthy 2014; Newman & Kenworthy 1989). By all accounts low-density automobile fabric delivers suboptimal outcomes for liveability and sustainability.

This integration of systems (natural and human), and integration across land use scales is an essential component of creating a new urban paradigm. Thinking in planetary boundaries is quite abstract to most people, whereas the majority of the global population experience interaction with cities daily, making land use decisions about city planning and design a very tangible concept. Decision-making in most cities occurs in isolation at this smaller scale, yet the aggregate impact of many small decisions is huge. It is out of balance with the planetary boundaries, and not managed by any one jurisdiction. A regenerative urbanism needs to consider the design of cities at this smaller more manageable size, but these fine-grain elements must be considered and managed in a manner cognizant of their cumulative impact.

Regenerative urbanism therefore requires urban design proposals to align with the aspirational goals of a "preferred future" vision, that is, a regenerative vision. This will require the radical redesign of the small proportion of the Earth's surface that is urban. While this fraction is small, the relationship between urban and non-urban areas is typically one way, with cities extracting vast resources from a global hinterland to feed consumption patterns. This unsustainable relationship can stop if cities are reimagined from conventional extractive engines that consume and create wastes oblivious of impact; to regenerative settlements that consciously monitor and manage sustainability impact within a global spatial context. While urban form is important, it is possible for urban systems to retrofit with minimal physical impact to existing city form, while delivering major urban sustainability performance improvements (see Publications 2 and 3).

The cumulative ecological footprint of all humans (including the majority that live in cities) is not sustainable and a safe operating space for human consumption needs to be found (Steffen et al. 2011). Cities, while being geographic concentrations of material consumption and waste generation, also display efficiencies that make their per capita ecological impact less than their rural or peri-urban counterparts (Newman & Kenworthy 1999; Rees & Wackernagel 2008). If this per capita component can be reduced to become sustainable or even regenerative, then cities may be reframed as a focus for hope and planetary stewardship (Benne & Mang 2015; Newman et al. 2012; du Plessis 2012; Cole 2012; Woo 2014; Girardet 2010; Lyle 1996; Hes & du Plessis 2014). A global network of regenerative cities would not only greatly reduce the human ecological footprint and demand for resources from other land categories (Seitzinger et al. 2012) but as set out in the publications, the network would begin to reverse the impact of centuries of extractive human activity.

As described in earlier sections, wasteful linear urban metabolisms can and need to be replaced by efficient circular metabolisms that utilise wastes as resources (Girardet 2015; Lyle 1996). This would allow human consumption patterns to be reduced to a level at which nature can absorb waste and generate new resources. In other words, humanity could begin to operate within the biocapacity of the planet (Global Footprint Network 2016).

Figure 15 shows the speed and magnitude by which the problem has grown over the last 60 years (the great acceleration), and the problem faced if this trajectory continues unabated. In 1950, the global population was three billion people (United Nations 2015b), about 30% of whom were urban dwellers (United Nations 2014) and the global ecological footprint was around 60% or less (Global Footprint Network 2016).

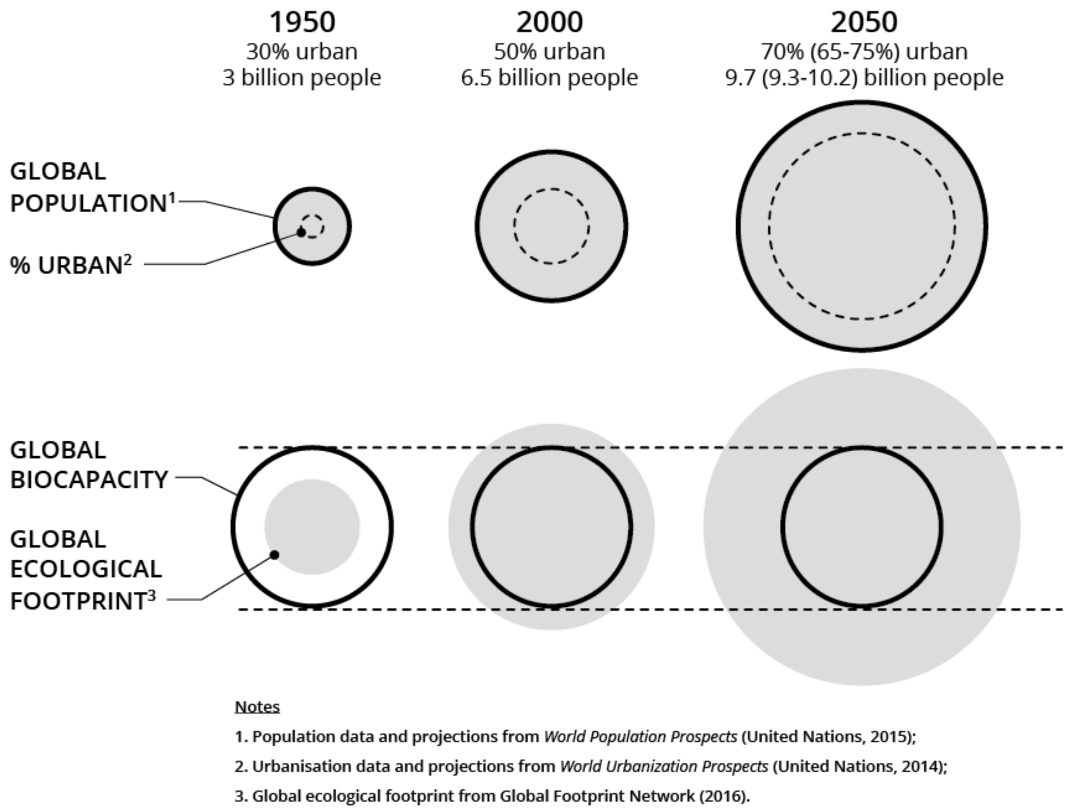


Figure 15: Global population, percentage global urban population and ecological footprint 1950–2050

This builds a compelling story for reducing the ecological footprint of cities, which will house the majority of the global population. Cities are also centres of industry and governance. Therefore they have the greatest power to change; and, as population centres they generate a large demand for resource extraction from their (local, regional and global) hinterlands. Reduction in ecological footprint could slow or even reverse habitat destruction, pollution and associated threats to biodiversity in the city's ecological catchment. A reduction in ecological footprint would allow ecological areas in the hinterlands, such as forests that function as waste sinks, to regenerate (Seto et al. 2012). Achieved at scale, through a global network of regenerative cities, it will become possible to reduce the global ecological footprint and even go into reverse. Just how much will depend upon the success of a sustainability transition from conventional to regenerative cities (see Figure 16).

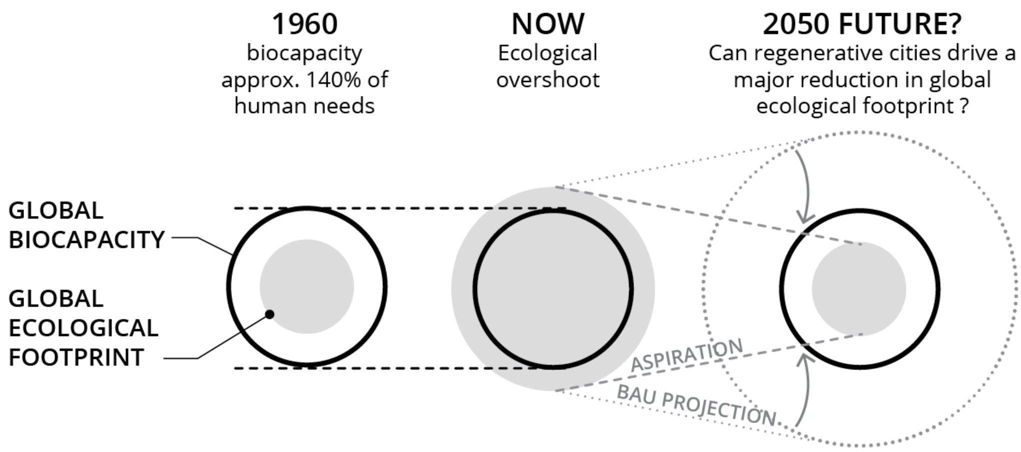


Figure 16: A global network of regenerative cities would reduce global ecological footprint

An urban sustainability transition will take time. The transition from the dominant conventional Modernist planning paradigm is showing evidence of being on the wane (as described in Publications 1, 2 and 3). There are only a few examples of sustainable and regenerative urbanism but momentum and interest in the area, catalysed by exemplars offer case studies to assist developers and policy makers with models for replication facilitating a planning paradigm shift (see Figure 17). Such a shift to a regenerative urbanism paradigm could bring about widespread structural change to cities catalysing urban sustainability transitions.

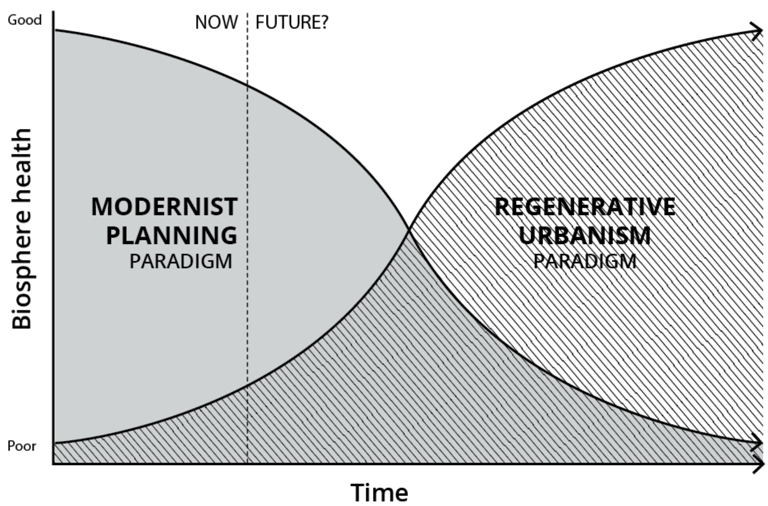


Figure 17: Shifting urban paradigms

Delivering a regenerative city requires two primary conditions to be met:

1. Maximising the higher density sustainable walking and transit urban fabrics
2. Maximising urban sustainability performance through regenerative design, particularly through a circular metabolism.

Meeting both these conditions are the fundamental goals of regenerative urbanism.

Figure 18 illustrates this and the notes below relate to the corresponding letter in the diagram:

A. Expand walking and transit fabrics into existing automobile fabric through urban regeneration aimed at increasing density and fabric optimisation. New urban development should be designed around walking and transit modes minimising automobile fabric.
B. Expand regenerative urban sustainability performance into conventional low performance suburbs and into the "less bad" but still unsustainable green design areas.
C. Introduce regenerative design to walking and transit urban fabrics.
D. Where automobile urban fabric cannot or will not be transformed into a higher order (e.g., transit or walking based development), introduce regenerative design elements to maximise urban sustainability performance.

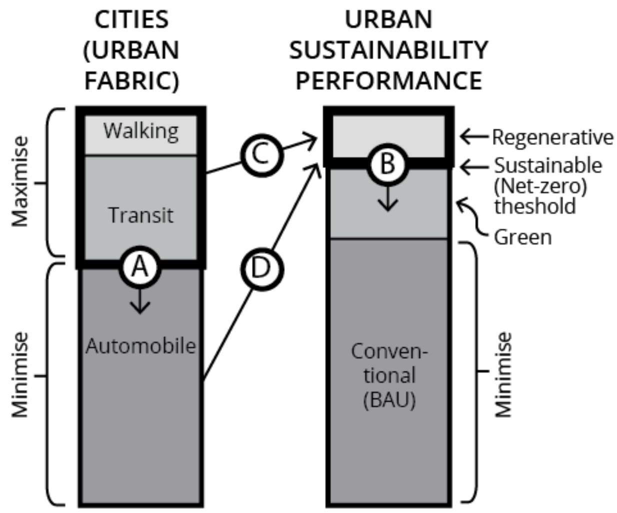


Figure 18: Regenerative urbanism will require an efficient urban fabric with a regenerative design overlay

As Figure 18 illustrates, regardless of urban fabric, opportunities should be sought to incorporate regenerative design.

It is possible to greatly improve the urban sustainability performance of automobile urban fabric through the introduction of regenerative design principles. Certain urban systems may even become regenerative, for example, photovoltaic renewable energy, water, biodiversity and urban agriculture. This is because each of these elements benefits from the extra space in low density areas that is, photovoltaics have more roof area per resident than in high density areas; additional garden space can be used for wildlife habitat or local food production. However, at scale the impact of low density has negative sustainability impacts on transport energy, water consumption and waste production as well as economic factors like infrastructure lengths, economic thresholds for services and distributed infrastructure as well as social factors such as health impacts from lack of active transport. Figure 19 indicates the regenerative potential of several planning considerations by urban fabric.

	Biodiversity	Urban Agriculture (Private)	Urban Agriculture (Public)	Photovoltaic Energy	Trigeneration	Water	Land Efficiency	Public transit
AUTO	H	H	L	H[3]	L[5]	L[6]	L	L
TRANSIT	M	M	M	M	H	M	M	H
WALKING	M[1]	L[2]	H	M[4]	H	H	H	H

Notes

H / M / L = High/Medium/Low regenerative potential

1. Biophilic practices (e.g., green roofs/walls) increase biodiversity potential in high density areas. e.g., Singapore.
2. lower public urban agriculture participation tends to occur where people have access to private gardens.
3. High roof area/resident maximises PV potential. PV uptake has been rapid in Australia's low density urban areas (Newman & Newton, 2013)
4. Current PV efficiency limitations make it difficult to power for dwellings by rooftop PV in buildings over 5 storeys high.
5. Low density thresholds, efficiency losses and additional cost due to greater distances make trigeneration infrastructure unviable at densities much lower than 50dw/ha.
6. Dependant upon the bioregion. Larger garden areas planted with exotic species most regions outside the tropics usually need irrigation at some point.

Figure 19: Regenerative potential by urban fabric

As a means of transition, regenerative urbanism can result in precincts, neighbourhoods and corridors that can deliver decentralised, semi-autonomous, cellular components that cumulatively work towards the aspirational end state – the regenerative city – while simultaneously achieving a range of other urban development goals.

5.2 Regenerative urbanism: the process

The previous section outlines the case for optimising urban fabric and urban sustainability performance through regenerative design; this section introduces some ways in which these aspirational planning directions could be achieved. The processes involved in bringing about urban transformation are planning, delivering (finance and construction) and operating (including monitoring and maintaining).

Knowledge of the different sustainability performance of the various urban fabrics of a city identifies key leverage points to identify the most efficient locations in which to focus on structural change. This knowledge may be absorbed into top-down planning approaches. However, to maximise effectiveness it should be coupled with governance environments that encourage "massive small-scale change" that fosters top-down and bottom-up approaches (Campbell 2011). This involves enabling leadership within government administration (not just from the most senior levels) and empowering the self-organising capabilities of the community (e.g., community housing, community energy, urban agriculture, distributed utilities, local green economies) (see Figure 20).

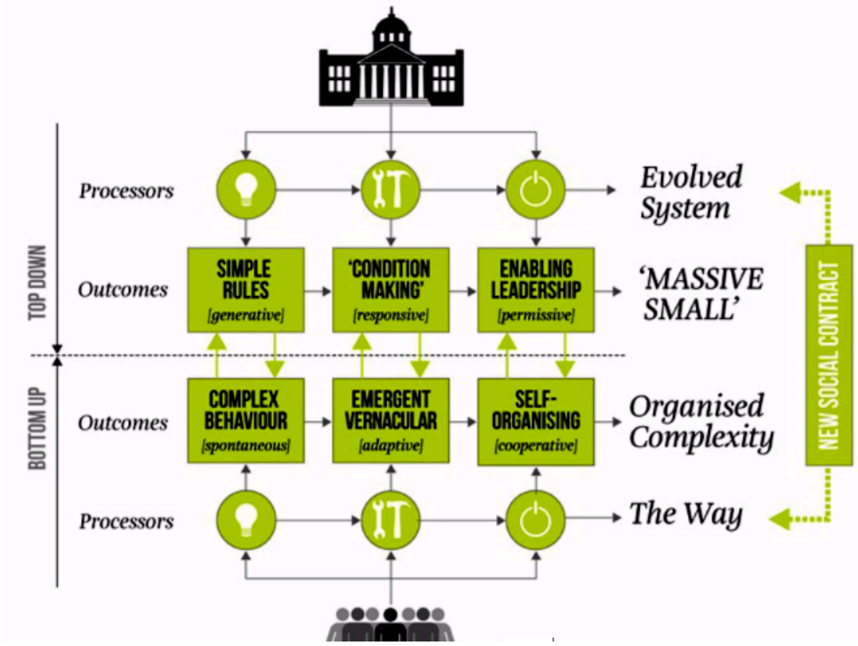


Figure 20: Smart Urbanism (Massive small), fostering top-down and bottom-up approaches (source: Campbell 2011) Reproduced with permission

Bringing it all together

At any stage in a city's history the patterns of land use can be changed and opportunities can be taken to transform the urban fabric.

Cities that fail to respond to the grand challenges such as climate change, resource scarcity or economic advantage expose themselves to greater risks (Landry & Burke 2014). A core principle of such a response should be to address the underlying urban fabric. This is because as cities become increasingly large and increasingly automobile oriented the resultant sprawl increases the required area of land (including city-fringe farms and ecologically rich land), volumes of materials, distances travelled and costs of infrastructure required to function. Addressing this one variable has the potential to have a profound impact upon many other aspects of complex urban systems. Urban fabric represents a powerful leverage point in the sustainability transition. Simply substituting electric vehicles for hydrocarbon fuelled vehicles is not enough. This thesis demonstrates that there are many structural considerations embedded in the infrastructure of a city's urban fabric; transport fuel is important, but not enough to address planetary sustainability.

The discussion on the following pages describes the steps required for an urban sustainability transition that can maximise liveability and the possibility for regenerative outcomes.

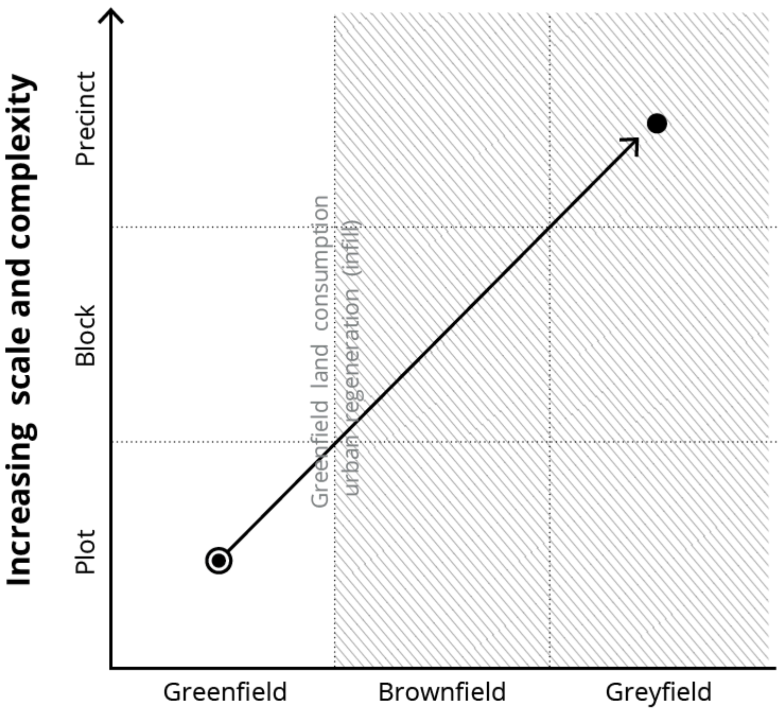


Figure 21: Urban arenas and scale

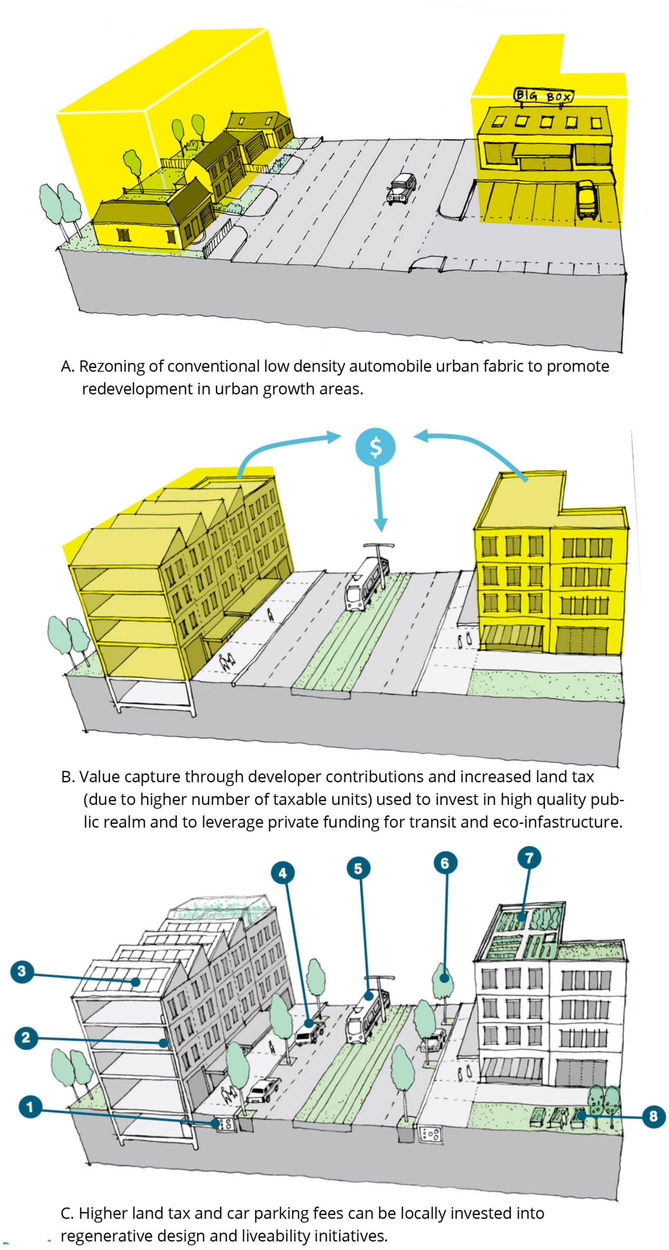
Figure 21 is based upon Publication 3 as it relates to the regeneration of Australian cities. The principles are the same for any automobile dependent city. Land consumption at the edge of the city occurs when urban fringe land is released to accommodate development demand. Cities grow in concentric waves with new housing sprawling across relatively cheap, former agricultural or ecologically important land. But as Publication 3 describes, as cities get larger this pattern of growth delivered through conventional Modernist planning principles, results in suboptimal urban form. Not only is liveability reduced for urban dwellers as a result of low density and poor proximity to services, but also food producing agricultural land and ecologically valuable land is displaced by inefficient urban development. Greenfield subdivisions developed plot by plot are the norm in many parts of the western world. But as Publication 3 outlines urban regeneration resulting from infill, particularly high density development, can accommodate growth within a city's existing footprint. Concentrating urban growth in urban regeneration areas (the hatched areas in Figure 21) means fringe land is not required for urban development.

Larger scales of development (i.e. plot<block<precinct) allow for greater opportunity to coordinate physical and social infrastructure and even incorporate new local distributed infrastructure such as solar energy, water sensitive design and waste recycling systems. A conventional low-density city, therefore, should aim to focus upon the regeneration of brownfield and greyfield development sites at the precinct scale to maximise the coordination of shared infrastructure to enhance liveability, sustainability and reduced long term operating costs.

But how can this occur?

The following discussion describes a hypothetical transition strategy for the transformation through urban regeneration of a typical low-density automobile urban fabric to a regenerative walking or transit urban fabric.

Steps in the transition of existing automobile urban fabric to regenerative transit or walking fabric are illustrated in Figure 22.



A. Rezoning of conventional low density automobile urban fabric to promote redevelopment in urban growth areas.

B. Value capture through developer contributions and increased land tax (due to higher number of taxable units) used to invest in high quality public realm and to leverage private funding for transit and eco-infastructure.

C. Higher land tax and car parking fees can be locally invested into regenerative design and liveability initiatives.

Figure 22: Steps in transitioning from conventional to regenerative urbanism

In Figure 22 A. the first step is the identification of areas of redevelopment potential by finding well-located low-density urban areas where there is a high ratio of land value to total property value (Newton, Newman, et al. 2012). Rezoning these areas where there is capacity for growth will promote redevelopment.

In Figure 22 B. the redevelopment of the area can provide revenue to development authorities provided the right policies are in place. Value capture is one such policy that has been tried and tested and has been successful in the delivery of infrastructure such as rail or district energy in many locations (McIntosh et al. 2014; Mittal 2014). As land values increase due to favorable proximity to improved services, the additional land tax revenue can be used to repay the infrastructure investment. Similarly, direct sales of government owned land for example, in Vauban (see Publication 7), can be invested directly into infrastructure or used to repay loans for local eco-infrastructure investment.

In Figure 22 C. a range of smaller scale interventions and policies can be overlain to facilitate regenerative design outcomes. For example:

1. combined services corridor (water, trigeneration, waste vacuum, broadband, electricity etc.) (Seto et al. 2014; Beatley 2009)

2. demand management (e.g., highly efficient thermal envelopes) combined with distributed infrastructure (e.g., trigeneration) to reduce energy emissions. Such initiatives if retrofitted can be funded through Property Assisted Clean Energy or Environmental Upgrade Agreements (EUA) – loans provided by a council or bank and tied to the property (not the loan applicant) and offset by utility bill savings (Sanders et al. 2013; New South Wales Government 2013)

3. community solar or energy service company (ESCo) providing photovoltaic renewable energy projects on solar optimised roofs (Seyfang et al. 2014; UK GBCA & Zero Carbon Hub 2010). ESCos can also implement energy efficiency upgrades to buildings or precincts and manage trigeneration ideally distributed through combined service corridors (Rauland & Newman 2015)

4. "parking district" revenue – funds from local car parking reinvested locally into public realm improvements for example water sensitive urban design (City of Sydney 2013) or local public transit

5. value capture from density uplift to finance rail or other eco-infrastructure (e.g., combined services corridor and high quality public realm) (McIntosh et al. 2014; Newman et al. 2016)

6. urban agriculture policies and urban forest policies to reduce travel distance for food, increase ecosystem services including biodiversity, urban heat island mitigation and psychological benefits of nature immersion (Beatley 2009; City of Sydney 2013;

Davison & Kirkpatrick 2013; City of Melbourne 2012)

7. green roofs and walls to insulate buildings, reduce peak water runoff, and offer biodiversity benefits as small patch habitats (Soderlund & Newman 2015; Forman & Godron 1986; Dramstad et al. 1996).

For a lengthier description of enabling finance mechanisms, policies and tools see Publication 6.

Operating

It is not enough to successfully deliver the infrastructure. Management needs to be ongoing, which has the potential to build a local green economy (Truffer & Coenen 2012; UNEP 2013). Regular monitoring of urban sustainability performance through the use of urban metabolism as an analytical tool will help ensure iterative design approaches that highlight the points in the urban system that are suboptimal thus helping find leverage points for improvement. The narrative in the previous section describes the sustainability benefits of transforming inefficient low-density urban fabric into high performance high density urban fabric with a regenerative overlay – a regenerative urbanism.

A regenerative urbanism requires integrated policy bundling similar to those illustrated in Figure 22 and ideally supportive entrepreneurial models for precinct governance such as value capture and similar local funding mechanisms to manage, monitor and maintain supporting eco-infrastructure and green enterprise initiatives.

Currently consistent measurements are not commonly used but they are required to provide a common lexicon for urban sustainability performance comparison and coordination (Fink 2011; Rauland & Newman 2015). However, this may change following the development of consistent urban sustainability measurements proposed by the International Standards Organization – *Sustainable Development in Communities* (ISO 2016) that will enable comparison and rolling up of metrics, between jurisdictions and through the tiers of government. A standardised reporting structure will be essential for intercity and international knowledge sharing exercises such as those that now occur between cities involved in C40 and ICLEI, though mostly on climate issues rather than the full planetary boundaries.

Cities are always changing. Change may be slow in some cases, particularly when considering the underlying infrastructure of roads, rail and underground services. However, rapid urbanisation, especially in developing nations and developed nations with high immigration policies, is putting pressure on some cities to redevelop. It is important that the right kind of development occurs particularly over the next half century as forecasting would indicate the "great acceleration" is not over, but rather that we are in the middle of it. The new evidence of decoupling may indicate that a major change in global footprint could now be underway; but to ensure this has any hope of becoming a powerful new mainstream trend will require the world's cities to operate under a new urban paradigm. To recast the trajectory of cities will require a major change in education, governance processes, planning practice and political leadership. Once underway it will require constant vigilance and system evaluation to ensure the required outcomes are happening as set out in Figure 26.

Delivering a good development is helpful but it is not the complete answer, it is just a point in a process that must be ongoing. Figure 23 illustrates such a model (for full discussion see Publication 5) where urban research into urban metabolism, to support existing research into economics and quality of life performance, also flows into the policy-making arena. Research can and should inform evidence-based policies that in turn shape the form of the city. For much of the past century Modernist planning paradigms have influenced planning policy based upon fashion and market preference but research indicates that as cities grow ever larger this is to the detriment, not only of sustainability performance, but also liveability. Increasingly sophisticated flows of information including "big data" may help with the dissemination of information to the right people in a timely manner to influence outcomes that can help deliver sustainability transitions and maintain or improve quality of life (Arup 1999; Hajer & Dassen 2014; Keltanen 2013).

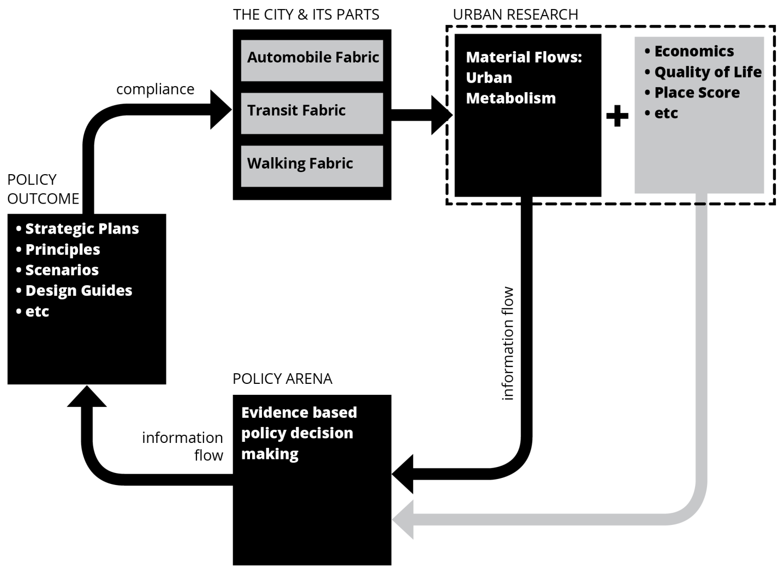


Figure 23: An iterative model of urban policy, development and research

Chapter 6 Conclusions & recommendations for future research

This thesis has described regenerative urbanism by linking physical delivery of *regenerative design* to the *theory of urban fabrics* (Newman & Kenworthy 2015) and the processes of regenerative design through *transition theory* (Geels 2002) including *leverage points* (Meadows 1999) for catalysing change. These factors combined are capable of driving urban transformation within the complex social-ecological-technical systems that shape cities (Ramaswami et al. 2012). To distinguish *regenerative urbanism* from the more generic concept of green urbanism, this thesis has demonstrated how *urban metabolism* may be used as a tool for measuring and monitoring *urban sustainability performance* (see Publications 2 and 5).

Critical to the successful delivery of a regenerative urbanism is greater integration between systems and across planning scales. There is an ethical dimension to regenerative urbanism that is grounded in global stewardship. This represents a paradigm change from conventional market-driven urban development practice, which externalises environmental impacts. A regenerative urbanism is more holistic in that it takes responsibility for these externalities and factors them into development decisions. Assessment of ecosystems services represents a shift toward more integrated ways of thinking about the benefits provide by natural systems to urban environments (Gómez-Baggethun & Barton 2012; Luck et al. 2001).

This ethical dimension is beginning to permeate broader culture, and as a result is increasingly enshrined in policy, especially at the international level (e.g., the Paris Agreement, SDGs, the New Urban Agenda). There are lessons that can be learnt by studying the many planning and development models that exist globally; this is the approach this thesis has taken. Although excellent examples exist as niche developments in many parts of the world, the challenge is to scale these up; to *mainstream* these processes. The growing body of international policies may provide the necessary catalyst to shift conventional practice using policy directions that trickle down from international agreements into national, state and local level governance.

The combination of a policy agenda and cultural shift can put in place a supportive societal framework for a built environment sustainability transition. But these alone are not sufficient to deliver a regenerative urbanism. Specific planning, development, construction and management processes are also necessary to deliver the infrastructure, services and jobs required to make the physical transition happen.

Local development decisions need to feed into larger regenerative city plans and a global network of regenerative cities if urbanisation is to be harnessed as a potential solution to reduce and then reverse an excessive ecological footprint that exceeds planetary boundaries. The most degraded planetary boundaries (climate change, biosphere integrity and biochemical flows) can be addressed if truly regenerative cities can be delivered. Compact, higher density regenerative cities can also minimise and reverse damage to land-systems in their bioregions.

In response to the original research question "*How can regenerative urbanism be mainstreamed*?" the evidence analysed in the preceding sections and in the publications that form the basis of this thesis, suggest numerous mechanisms for mainstreaming regenerative urbanism. These can be summarised from the thesis publications as the following set of 11 principles for mainstreaming regenerative urbanism:

1. **Create cultural change for regenerative urbanism.** For a regenerative cities agenda to take hold at scale requires a paradigm shift away from the current dominant unsustainable Modernist automobile-oriented planning paradigm to a regenerative urbanism mindset. The latter aspiration aligns with the United Nations call for a new paradigm for cities as outlined in the *New Urban Agenda* (United Nations 2016). It is possible that the cumulative messaging of the Paris Agreement, the Sustainable Development Goals and the New Urban Agenda may herald a global shift in culture (for more on the implementation of cultural shifts, see Publications 1 and 6).

2. **Enable an aspirational vision through urban leadership.** There must be a clear vision to drive regenerative urbanism at the local level. The implementation of locally regenerative development needs a shared, and ideally co-designed, vision that is based on strong leadership and broad community support – in this sense leadership may be from the bottom up as well as the top down. Co-ordination though a shared vision is necessary to ensure the alignment of key actors, institutions and business models around this vision, particularly with regard to how the statutory planning system can include low metabolism urban fabric in its system. (For an expanded description, see Publication 5).

3. **Monitor urban sustainability performance through urban metabolism**. Urban metabolism must be monitored to ensure inputs and outputs are optimised through circular metabolism, seeking, where possible, to design genuinely *regenerative* urban systems. Monitoring also reveals the greatest opportunities for system optimisation, and can reveal the extent of the extractive nature of urban economic inputs on the surrounding regional and global hinterland, as described in section 3.3.1. (For an expanded description of urban metabolism, see Publications 1 and 2).

4. **Optimise regenerative outcomes through integrated systems.** Optimisation of urban

systems can result in some systems delivering genuinely regenerative outcomes. Other systems can be designed for minimal impact but will never be regenerative. Energy, water and biodiversity can be regenerative; however, we can only hope to minimise the environmental impact of waste and basic raw materials; these can never be completely regenerative. (For an expanded description of optimising urban fabrics, see Publication 2; and for regenerative overlays, see Publication 4).

5. **Create strong spatial planning processes to deliver regenerative outcomes.** Hall (2013) refers to the "lost art of urbanism" as being at the heart of many urban problems. Strong planning does not imply that it should be dictated in a non-democratic way, it means having clear objectives that inform every step of the planning process. The opportunity presented by strong planning is to enable the fundamentals of sustainability and regenerative urbanism to inform the whole planning system. This is not unlike the way that Modernism and car-based planning infiltrated every area of planning to create the city forms of that helped drive the "great acceleration". Precinct scale development can deliver optimal outcomes because it permits a comprehensive approach to planning that allows for the integration of urban elements. However, not all precincts are equal in their ability to demonstrate regenerative urbanism, even if they superficially appear so (e.g., have a similar density, look and feel). The use of urban metabolism can reveal sustainability performance indicators that can be used to determine where to focus most attention and create the best exemplars. Performance is strongly influenced by physical design including urban fabric, site layout and urban systems (e.g., energy, water, waste, biodiversity) integration. (For an expanded description of the advantage of precinct scale development, see Publication 3; and for a discussion on the design of various regenerative urban elements, see Publication 4).

6. **Design ecologically sustainable and liveable urban fabric.** The quantitative analysis in Paper 2 demonstrates how walking urban fabric and transit urban fabric have considerably smaller ecological footprints than automobile fabric. These higher density fabrics can also offer greater liveability and vibrancy because they concentrate urban life and can therefore support more services and greater opportunities for social interaction. When opportunities for new urban development arise, as they do in growing cities, consciously designing walking and transit urban fabric will deliver outcomes that are more sustainable and liveable. Similarly, when opportunities for the urban renewal of automobile fabric are presented, redesign should aim to transform these locations into transit and walking urban fabric. at least by establishing some transit oriented centres and corridors within previously automobile-dominated suburbs. As a general principle, low-density automobile fabric should be minimised in any new urban development because of the non-sustainable consequences of fossil-fuel driven

transportation, excessive land take, encroachment on agricultural land and low densities that do not enable much of the regenerative urbanism agenda such as meeting thresholds to support distributed infrastructure, transit or services. (For an expanded description relating to the transition of urban fabric, see Publications 2 and 3).

7. **Minimise new low-density automobile urban fabric, and, where it is part of a city, design or retrofit it to maximise its regenerative potential.** There may be a role for lower density developments in certain locations, particularly pre-existing developments. The larger lot sizes can more easily incorporate biodiversity, gardens and urban agriculture or larger roof areas that enable greater photovoltaic uptake per dwelling. Therefore, these regenerative aspects should be maximised through policy incentives in low-density areas (For a discussion on the limitations of low-density automobile urban fabric, see Publication 3; and for the benefits of different densities, see Publication 4).

8. **Identify strategic leverage points.** To optimise urban sustainability performance, some parts of the urban geography are better suited to transformation than other locations. Integrated transport and land use planning promotes higher densities around activity centres and transit stations (TODs). These strategic locations form the key elements of a well-connected polycentric city. Where underdeveloped brownfield sites or low value greyfield sites exist, the introduction of transit and rezoning of adjacent land can put in place value capture potential to transform urban corridors. Such an approach has been successfully used in Portland's Pearl District, and in Hong Kong, China and Japan. It has been proposed for Australian cities as the Entrepreneur Rail Model (Newman et al. 2016). Both existing transit infrastructure and low-density potential transit corridors lend themselves to "strategic uplift" – effectively a transition in urban fabric. (For an expanded description, see Publication 3).

9. **Provide new governance models such as Greening Regenerative Improvement Districts (GRIDS) or Sustainability Management Associations (SMAs) to coordinate and manage district scale eco-infrastructure.** Geographically ring-fenced precincts or districts are incentivised to invest in eco-efficiency measures for their cost saving potential. These can become demonstrations that quickly mainstream or can become a rolling process that enables a whole city to eventually be greened. Such organisations have the mandate and motivation to find efficient, integrated approaches to distributed infrastructure provision, allow for the optimisation of urban system sustainability and maximise circular metabolism opportunities. Local utility provision drives a local green economy and excess energy, water or other "product" can be on sold as a revenue stream. A GRID model can assist with mainstreaming regenerative urbanism through sourcing capital for financing eco-infrastructure, for managing the

operation of infrastructure and urban services, for monitoring performance and shaping the strategic direction of a district or neighbourhood. (For an expanded description, see Publication 6).

10. **Make sure the transition to regenerative cities is through a corresponding socioeconomic desirability.** The technology for sustainable and regenerative transitions already exists but widespread implementation will only occur if the product maintains liveability and offers a desirable way of life. My review of sustainability precincts found that the most successful of these were not marketed on their environmental credentials, but rather on their enhanced liveability (For an expanded description, see Publication 7). This can be continued as a way forward in achieving regenerative urbanism outcomes.

11. **Ensure constant improvement in regenerative outcomes through flexible and adaptive feedback to emerging social, environmental and economic needs and new science and technology.** Constant feedback allows a GRID, SMA or local authority to continually enhance and seek improvements in the system by responding to changing needs and new technology. The creation of an evidence base linking science to policy will be necessary to enable a transition to a regenerative urbanism (For an expanded description, see Publication 5). City shaping processes for both policy and infrastructure delivery will need to be open to continuous learning, analysis, inspiration and modification.

6.1 Recommendations for future research

The findings from this research demonstrate there are many structural barriers, knowledge gaps and governance issues that need to be overcome in order to mainstream regenerative urbanism. The following recommendations identify areas of potential future research, which may assist cities in the transition towards mainstreaming regenerative urbanism.

Addressing structural barriers

- **Further research into, and possible development of, standardised metrics**. This would enable consistent sustainability accounting in much the same way that standardised financial accounting underlies Gross Domestic Product (GDP) analysis for monetary flows through a country. A Wuppertal Institute analysis of the various nationally determined contributions for GHG emission reductions presented by nations at COP21 (the Paris Agreement negotiations) highlighted the need for standardised carbon accounting practices (Kreibich & Obergassel 2016). However, it is important to develop new indicators that relate to each of the planetary boundaries and then apply them to cities and to each fabric of cities.

Standardised accounting systems across the various urban metabolism flows will help establish consistent measurement, which in turn will assist with benchmark comparisons, measurement of improvements and transfer of knowledge. The launch of ISO 37120 for sustainable development in communities and the forthcoming ISO 37122 and ISO 37123 for “smart” and “resilient” cities respectively represent movement in this direction.

- **Research into the development of an urban metabolism reporting framework using standardised metrics**. This could assist by building an evidence base and making apparent leverage points for improving urban systems and local communities. It is important that this is done in many different cities, including in the developing world.

Knowledge and education

- **Research that advances knowledge of sustainable construction and infrastructure**. Sustainable construction techniques and infrastructure typically require higher build quality or additional skill sets, so there is a need to advance technical skills in sustainability construction through training and education. Research can focus on the areas of greatest need and the best approaches to education. A number of industry reports from Europe, the US and Australia have identified the need for industry retraining and up-skilling to prepare for a transition to built environment sustainability and regenerative urbanism (European Union 2011b; European Union 2011a; Zero Carbon Hub 2009; The U.S. Green Building Council 2013).
- **Transdisciplinary research**. There is a pressing need for the establishment of more transdisciplinary research centres to investigate and develop regenerative practices. Globally, only a few centres exist that focus on integrated regenerative studies. An observation based on an international survey of sustainable built environment schools[1], is that the majority are engineering-based and these schools tend to focus on the technological aspects of sustainability efficiency, not the larger questions of systems change, paradigm shifts and non-urban impacts of urbanisation. Transdisciplinary research on regenerative urbanism will require many more university centres forming partnerships with city governments, business and community groups. Urban science and urban policy can be integrated in such centres.
- **Research that builds capacity and skills for large scale planning**. There is a need to build capacity and skills for larger scale regions-based sustainability planning. The United Nations Draft Quito Implementation plan for the New Urban Agenda, released in October 2016, states, under section 117, the need to support development of necessary knowledge and capacity to implement and enforce national and local plans for sustainability (United Nations 2016). There have been suggestions of a UN Cities unit to accumulate and

1 I co-authored this paper separately to this thesis at the request of my scholarship provider the Cooperative Research Centre for Low Carbon Living. The paper is available on their website at http://www.lowcarbonlivingcrc.com.au

disseminate knowledge on regenerative city infrastructure and processes (Scruggs 2016). More research is needed into how to prepare and implement such national and local sustainability plans in ways that gain traction with the wider community. A paradigm shift, as part of a broader cultural transition, has the greatest potential to drive a regenerative urbanism agenda. Regional planning skills need to be coupled with research into cultural change and engagement to support sustainability transitions.

Governance

- **Research into building community capacity and educational approaches to support collaborative participatory governance processes** (Weymouth & Hartz-Karp 2015; Hartz-karp 2007). Investigations are needed into appropriate governing arrangements that are capable of taking into account diverse views within society while providing an evidence base (e.g., an urban metabolism reporting framework) to inform decision-making. Such deliberative processes remain rare but are the basis of real political leadership for urban change (Newman 2016). Education and processes that linking evidence to outcomes is needed within both the community to create, a more engaged citizenry, and governments as government are the only body capable of co-ordinating the large scale urban changes that are needed.
- **Research into streamlining information flows, such that data is made available in a timely and cost-effective manner to decision makers and city builders**. Digital planning schemes based on GIS-based modelling of decisions can begin to enable regenerative outcomes to be quantified in every new urban development (Newton, Newman, et al. 2012).
- **Research into "big data" and "citizen science" to build cost-efficient monitoring of urban metabolism**. Community-based sensors and processes can begin to provide new ways of monitoring urban outcomes and there is a need to set up demonstrations that can be researched. Just as improved data flows to government and treasury can improve top-down decision making, access to open source data can empower communities to play a greater role in monitoring, analysing and co-designing the environments in which they live.
- **Research into land assembly for regenerative precincts**. There are many organisational structures capable of coordinating the necessary land assembly of previously developed land in multiple ownership in strategic locations to enable comprehensive planning of larger development parcels and enable more integrated infrastructure outcomes.
- **Research into organisational structures that can manage and monitor green enterprise at the local level, for example, Sustainability Management Associations** (Selzter et al. 2010) or Greening Regenerative Improvement Districts (GRIDs) (Rauland 2013). These demonstrations need to not only monitor the outcomes of such work, but also tell the internal story of how communities, business and government have been able to work in partnership to achieve regenerative outcomes. Research could focus on the extent to which

people are motivated by the need to contribute to the global agenda for reversing the "great acceleration" or to just improving their own local environment or both.

6.2 Concluding comments

Transitioning to a sustainable or regenerative city is an immensely complicated task, not least because of the interconnected nature of the multiple urban systems. This, coupled with unpredictable behaviour from multiple actors, makes it a truly "wicked problem" (Australian Public Service Commission 2007; Rittel & Webber 1973). When attempting to untangle performance metrics and urban elements from disparate actors, there is a need to have a simple set of defining principles to help keep a sharp focus upon key elements essential for the urban sustainability transition. The 11 principles outlined above provide direction for this task. This thesis covers considerable ground, but no matter how comprehensive any research in this area is, it will have gaps. To tackle the uncertainty resulting from inevitably incomplete information when attempting to transition from conventional to regenerative urbanism, this thesis suggests recognising the broad patterns. In this thesis, these patterns and themes have been identified and used to form the basis of a framework, expressed in the 11 principles above, that can be used to structure multiple possible pathways towards a regenerative urbanism. It is essential that a regenerative urbanism is ***monitored*** using urban metabolism to measure urban sustainability performance. To achieve optimal performance will also require regenerative urbanism to be ***aspirational***, ***managed, desirable*** and ***constantly improved***. With performance measurement and these tenets in mind, it may be hoped that countless regenerative urbanism exemplars will emerge, each offering new lessons for replication or improvement. In combination, a diverse array of regenerative cities could slow resource consumption and mark the beginning of a great deceleration, and a period of planetary stewardship to usher in a new hope for the Anthropocene.

Exegesis reference list

Arup, 1999. *Smart cities*, Available at: http://publications.arup.com/Publications/S/Smart_Cities.aspx.

Australian Public Service Commission, 2007. *Tackling wicked problems: A public policy perspective*, Canberra, Australia: Commonwealth of Australia.

Baccini, P., 1997. A city's metabolism: Towards the sustainable development of urban systems. *Journal of Urban Technology*, 4(2), pp.27–39.

Baccini, P. & Brunner, P.H., 2012. *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*, London, UK: MIT Press.

Bai, X., Norman, B. & Edwards, P., 2016. Navigating through the Urban Age : Principles Navigating through the Urban Age : Principles and Innovations. *Solutions*, 7(May), pp.55–62.

Beatley, T., 2011. *Biophilic Cities: Integrating Nature Into Urban Design and Planning*, Washington, D.C.: Island Press.

Beatley, T., 2009. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into our Lives. *William & Mary Environmental Law & Policy Review*, 34(1), pp.209–238.

Beatley, T., 2012. *Green Urbanism: Learning From European Cities*, Washington, D.C.: Island Press.

Beatley, T. & Newman, P., 2012. *Green Urbanism Down Under: Learning from Sustainable Communities in Australia*, Washington, D.C.: Island Press.

Benne, B. & Mang, P., 2015. Working regeneratively across scales—insights from nature applied to the built environment. *Journal of Cleaner Production*, (109), pp.42–52. Available at: http://linkinghub.elsevier.com/retrieve/pii/S095965261500150X.

Biggs, C., Ryan, C. & Wiseman, J., 2010. *Distributed Systems: A design model for sustainable and resilient infrastructure*, Available at: http://www.ecoinnovationlab.com/uploads/attachments/305_VEIL.Resilient Systems Briefing Paper.pdf.

Bina, O. et al., 2016. The future imagined: Exploring fiction as a means of reflecting on today's Grand Societal Challenges and tomorrow's options. *Futures*. Available at: http://dx.doi.org/10.1016/j.futures.2016.05.009.

BioRegional, 2009. *BedZED : Toolkit Part II A practical guide to producing affordable carbon neutral developments*, London, UK.

Blood, D. & Partner, S., 2012. *Sustainable Capitalism*, London, UK. Available at: www.generationim.com.

Bostrom, N., 2002. Existential Risks: Analyzing Human Extinction Scenarios and Related Hazards. *Journal of Evolution and Technology*, 9(March).

Bringezu, S. et al., 2014. *Assessing Global Land Use : Balancing Consumption with Sustainable Supply. A Report of the Working Group on Land and Soils of the Interantional Resource Panel*, United Nations Environment Program. Available at: http://www.unep.org/resourcepanel/Portals/50244/publications/Full_Report-Assessing_Global_Land_UseEnglish_(PDF).pdf.

Broto, V.C., Allen, A. & Rapoport, E., 2012. Interdisciplinary Perspectives on Urban Metabolism. *Journal of Industrial Ecology*, 16(6), pp.851–861.

Browning, W., Ryan, C. & Clancy, J., 2014. 14 Patterns of Biophilic Design. *Terrapin Bright Green,LLC*, pp.1–60.

Brugmann, J., 2011. *Financing the resilient city: A demand driven approach to development, disaster risk reduction, and climate adaptation*, Bonn, Germany.

Bunning, J. et al., 2013. Low-Carbon Sustainable Precincts: An Australian Perspective.

Sustainability, 5(6), pp.2305–2326. Available at: http://www.mdpi.com/2071-1050/5/6/2305/.
Burdett, R. & Sudjic, D., 2010. *The Endless City: The Urban Age Project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society*, Phaidon Press.
Calthorpe, P., 2010. *Urbanism in the Age of Climate Change*, Washington, D.C.: Island Press.
Campbell, 2016. Massive Small declaration. *Massive small*. Available at: http://www.massivesmall.com/declaration/ [Accessed November 25, 2016].
Campbell, K., 2011. *Massive Small: The Operating Programme for Smart Urbanism*, London, UK: Urban Exchange.
Carmona, M. et al., 2012. *Public Places - Urban Spaces*, London, UK: Taylor & Francis.
Chambers, N. et al., 2002. *City Limits: A resource flow and ecological footprint analysis of Greater London*, Oxford, UK. Available at: http://www.citylimitslondon.com/downloads/Complete report.pdf.
CIESIN, 2005. The Growing Urbanization of the World. GRUMP mapping project finds urban areas increasing in surprising ways. *Columbia University Earth Institute website*.
City of Melbourne, 2012. Urban Forest Strategy: Making a great city greener 2012-2032. , p.68. Available at: https://www.melbourne.vic.gov.au/Sustainability/UrbanForest/Documents/Urban_Forest_Strategy.pdf.
City of Sydney, 2013. City of Sydney Urban Forest Strategy 2013. , pp.1–80.
Clegg, P., 2012. A practitioner's view of the "Regenerative Paradigm." *Building Research & Information*, 40(3), pp.365–368. Available at: http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.663557.
Coglianese, C. & D'Ambrosio, J., 2008. Policymaking under Pressure: The Perils of Incremental Responses to Climate Change. *Connecticut Law Review*, 40(2007), p.1411.
Cole, R.J., 2012. Transitioning from green to regenerative design. *Building Research & Information*, 40(1), pp.39–53.
Cooper, I., 2012. Winning hearts and minds or evidence-driven: which trajectory for regenerative design? *Building Research & Information*, 40(3), pp.357–360. Available at: http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.662388.
Costanza, R., 2008. Stewardship for a "full" world. *Current History*, 107(705), pp.30–35.
Cowan, R., 2005. *Dictionary of Urbanism*, London, UK: Streetwise Press.
Crutzen, P.J., 2002. Geology of mankind. *Nature*, 415(January), p.23.
Crutzen, P.J. & Stoermer, E.F., 2000. The Anthropocene. *Global Change Newsletter*, (41), pp.17–18.
Curtis, C. & Scheurer, J., 2010. Planning for sustainable accessibility: Developing tools to aid discussion and decision-making. *Progress in Planning*, 74(2), pp.53–106.
Davison, A. & Kirkpatrick, J., 2013. Re-inventing the Urban Forest: The Rise of Arboriculture in Australia. *Urban Policy and Research*, 32(2), pp.145–162. Available at: http://www.tandfonline.com/doi/abs/10.1080/08111146.2013.832669.
Diamandis, P.H. & Kotler, S., 2014. *Abundance: The Future Is Better Than You Think*, Free Press.
Dodson, J. & Sipe, N., 2006. Suburban shocks : Assessing locational vulnerability to rising household fuel and mortgage interest costs. In *29th Australasian*

Transportation Research Forum. Gold Coast, Queensland.
Dramstad, W., Olson, J. & Forman, R., 1996. *Landscape Ecology Principles in Landscape Architecture*, Washington, D.C.: Harvard University Graduate School of Design, Island Press, American Institute of Landscape Architects.
Droege, P., 2012. *100% Renewable: Energy Autonomy in Action*, Routledge.
Droege, P., 2010. *100% Renewable Energy - and Beyond - for Cities*, Hamburg, Germany.
Droege, P., 2008. *Urban Energy Transition : An Introduction*, Elsevier Science.
EcoDistricts, 2016. *EcoDistricts Protocol Version 1.1*, Portland, Oregon. Available at: www. ecodistricts.org.
Ellen MacArthur Foundation, 2015. Open Source Circular Economy. In Perth: Creative Commons.
English Partnerships, 2007. *Carbon Challenge Standard Brief*, London, UK.
European Union, 2011a. *Greening of the building sector is held back by skill shortages. Skills-led strategies can drive green building forward*, Geneva, Switzerland.
European Union, 2011b. *Skills and Occupational Needs in Renewable Energy*, Geneva, Switzerland: International Labour Office.
Farr, D., 2012. *Sustainable Urbanism: Urban Design With Nature*, Wiley.
Ferguson, A., 2016. Law to Compel Low-Carbon Future. *Australian Financial Review*. Available at: http://afr.com.
Fink, J., 2011. The Case for an Urban Genome Project: A Shortcut to Global Sustainability. *The Bridge, Linking Engineering and Society*, 41(1).
Fink, J.H., 2013. Geoengineering cities to stabilise climate. *Proceedings of the ICE - Engineering Sustainability*, 166(5), pp.242–248. Available at: http://www.icevirtuallibrary.com/content/article/10.1680/ensu.13.00002.
Flannery, T., 2015. *Atmosphere of Hope: Solutions to the Climate Crisis*, Penguin Books Limited.
Florida, R.L., 2002. *The Rise of the Creative Class: And how It's Transforming Work, Leisure, Community and Everyday Life*, Basic Books.
Forman, R.T.T. & Godron, M., 1986. *Landscape Ecology*, Wiley.
Forman, R.T.T. & Wu, J., 2016. Where to put the next billion people. *Nature*.
Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. *City*, 8(3), pp.363–379.
Garnaut, R., 2011. *The Garnaut Review 2011*, Available at: http://www.cambridge.edu.au/academic/marketing/files/2011/August/August_Kit_sm.pdf.
Geddes, P., 1949. *Cities in Evolution*, Williams & Norgate.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), pp.1257–1274. Available at: http://www.sciencedirect.com/science/article/pii/S0048733302000628.
Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, 1(1), pp.24–40. Available at: http://dx.doi.org/10.1016/j.eist.2011.02.002.
Geels, F.W. & Schot, J., 2007. Typology of sociotechnical transition pathways. *Research Policy*, 36(3), pp.399–417.
Girardet, H., 2000. Cities, People Planet. In *Schumacher Lectures April 2000*. Liverpool, UK: Schumacher Society.
Girardet, H., 2004. *Cities people planet: liveable cities for a sustainable world*, Wiley-Academy.
Girardet, H., 2015. *Creating Regenerative Cities*, Routledge.
Girardet, H., 2010. *Regenerative cities*, Hamburg, Germany. Available at:

www.worldfuturecouncil.org.
Girardet, H., 1996. *The Gaia Atlas of Cities: New Directions for Sustainable Urban Living*, Gaia.
GIZ and ICLEI, 2014. *Operationalizing the Urban NEXUS: towards resource efficient and integrated cities and metripolitan regions*, Eschborn, Germany.
Glaeser, E., 2011. *Triumph of the City*, Pan Macmillan UK.
GlashusEtt, 2007. *Hammarby Sjöstad – a unique environmental project in Stockholm.*, Stockholm, Sweden.
Global Footprint Network, 2016. Global Footprint Network. Available at: http://www.footprintnetwork.org/ [Accessed October 1, 2016].
Gollagher, M. & Hartz-Karp, J., 2013. The role of deliberative collaborative governance in achieving sustainable cities. *Sustainability (Switzerland)*, 5(6), pp.2343–2366.
Gómez-Baggethun, E. & Barton, D.N., 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, pp.235–245. Available at: http://dx.doi.org/10.1016/j.ecolecon.2012.08.019.
Graves, T., 2015. From Problem-space to Solution-space: Causal layered analysis and context-space mapping. In S. Inayatullah & I. Milojević, eds. *CLA 2.0 - Transformative Theory in Research and Practice*. Taipai, Taiwan: Tamkang University Press.
Hajer, M., 2011. *The energetic society*, The Hague, The Netherlands.
Hajer, M. & Dassen, T., 2014. *Smart about Cities*, Rotterdam, The Netherlands: Nai010 Publishers.
Hall, P., 1998. *Cities in Civilization: Culture, Innovation, and Urban Order*, London, UK: Pantheon.
Hall, P., 2013. *Good Cities, Better Lives: How Europe Discovered the Lost Art of Urbanism*, New York, NY: Routledge.
Hardin, G., 1968. The Tragedy of the Commons. *Science*, 162(3859), pp.1243–1248.
Hargroves, K. & Smith, M.H., 2005. *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, London, UK: Earthscan.
Hartz-karp, J., 2007. How and Why Deliberative Democracy Enables Co-Intelligence and Brings Wisdom to Governance How and Why Deliberative Democracy Enables Co-Intelligence and. *Journal of Public Deliberation*, 3(1). Available at: http://www.publicdeliberation.net/jpd/vol3/iss1/art6.
Hes, D. & du Plessis, C., 2014. *Designing for Hope: Pathways to Regenerative Sustainability*, New York, NY: Taylor & Francis.
Inayatullah, S., 2015. *What Works: Case Studies in the Practice of Foresight*, Tamsui, Taiwan: Tamkang University Press.
Inayatullah, S. & Milojević, I., 2015. *CLA 2.0 Transformative Research in Theory and Practice* S. Inayatullah & I. Milojević, eds., Taipai, Taiwan: Tamkang University Press.
ISO, 2016. *INTERNATIONAL STANDARD Sustainable development in communities — Management system for sustainable development*, Switzerland.
Jackson, T., 2009. *Prosperity without Growth. Economics for a Finite Planet*, New York, NY: Earthscan.
Jacobs, J., 1989. *The Death and Life of Great American Cities*, New York, NY: Vintage.
Jacobs, J., 1969. *The economy of cities*, New York, NY: Random House.
de Jong, M. et al., 2015. Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, pp.1–14. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652615001080.

Keirstead, J., Jennings, M. & Sivakumar, A., 2012. A review of urban energy system models: Approaches, challenges and opportunities. *Renewable and Sustainable Energy Reviews*, 16(6), pp.3847–3866. Available at: http://dx.doi.org/10.1016/j.rser.2012.02.047.
Keltanen, M., 2013. Why "lean data" beats big data. *The Guardian*.
Kennedy, C., Cuddihy, J. & Engel-yan, J., 2007. The Changing Metabolism of Cities. *Journal of Industrial Ecology*, 11(2).
Kennedy, C., Pincetl, S. & Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*, 159(8–9), pp.1965–1973. Available at: http://dx.doi.org/10.1016/j.envpol.2010.10.022.
Kenworthy, J., 2014. Total daily mobility patterns and their implications for forty-three global cities in 1995 and 2005. *World Transport Policy and Practice*, 20(1), pp.41–55.
Kenworthy, J. & Laube, F., 2001. *Millenium Cities Database for Sustainable Transport*,
Kitney, D., 2016. Leaders Heed Warning on Climate Risks. *The Australian Business Review*. Available at: http://www.theaustralian.com.au/business.
Kolbert, E., 2010. The Anthropocene Depate: Marking Humanity's Impact. *Yale Environment 360*.
Kostof, S., Castillo, G. & Tobias, R., 1999. *The City Assembled: The Elements of Urban Form Through History*, London, UK: Thames and Hudson.
Kostof, S. & Tobias, R., 2004. *The City Shaped: Urban Patterns and Meanings Through History*, London, UK: Thames and Hudson.
Kreibich, N. & Obergassel, W., 2016. *Carbon Markets After Paris How to Account for the Transfer of Mitigation Results?*, Wuppertal, Germany.
Landry, C. & Burke, T., 2014. *The Fragile City and the Risk Nexus*, Stroud, UK: Comedia Publications Limited.
Lehmann, S., 2010. *The Principles of Green Urbanism: Transforming the City for Sustainability*, Earthscan.
Lenton, T.M. et al., 2008. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, 105(6).
Living Building Challenge, 2014. LIVING BUILDING A Visionary Path to a Regenerative Future. *Living Building Challenge 3.0. A Visionary Path to a Regenerative Future*. Available at: http://living-future.org/sites/default/files/reports/FINAL LBC 3_0_WebOptimized_low.pdf.
Loorbach, D., 2007. *Transition Management: NewMode of Governance for Sustainable Development*, Utrecht: International Books.
Loorbach, D.A., 2010. Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. *Governance, An International Journal of Policy, Administration, and Institutions.*, 23(1), pp.161–183. Available at: 10.1111/j.1468-0491.2009.01471.x.
Lovins, L.H., Lovins, A. & Hawken, P., 1999. *Natural Capitalism: The next industrial revolution*, Earthscan.
Lowe, I., 2015. Causal Layered Analysis, Climate Change and Limits to Growth. In S. Inayatullah & I. Milojević, eds. *CLA 2.0 - Transformative Theory in Research and Practice*. Taipei, Taiwan: Tamkang University Press, pp. 109–122.
Luck, M.A. et al., 2001. The Urban Funnel Model and the Spatially Heterogeneous Ecological Footprint. *Ecosystems*, 4(8), pp.782–796.
Lyle, J., 1999. *Design for Human Ecosystems: Landscape, Land Use, and Natural Resources*, Washington, D.C.: Island Press.
Lyle, J.T., 1996. *Regenerative Design for Sustainable Development*, New York, NY: Wiley.
Mang, P. & Reed, B., 2012. Designing from place: a regenerative framework and

methodology. *Building Research & Information*, 40(1), pp.23–38.
Marchetti, C., 1994. Anthropological Invariants in Travel Behavior. *Technological Forecasting and Social Change*, 47, pp.75–88.
Martinez-alier, J., 2007. Marxism, Social Metabolism, and Ecologically Unequal Exchange. In A. Hornborg, J. McNeill, & J. Martinez-alier, eds. *Rethinking Environmental History*. Plymouth, UK: AltaMira Press, pp. 19–22.
Maxwell, J. a, 2009. Designing a Qualitative Study. *The SAGE Handbook of Applied Social Research Methods*, pp.214–253. Available at: http://www.corwin.com/upm-data/23772_Ch7.pdf.
McDonough, W., Braungart, M. & Clinton, B., 2013. *The Upcycle: Beyond Sustainability--Designing for Abundance*, Farrar, Straus and Giroux.
McIntosh, J., Trubka, R. & Newman, P., 2014. Can value capture work in a car dependent city? Willingness to pay for transit access in Perth, Western Australia. *Transportation Research Part A: Policy and Practice*, 67, pp.320–339. Available at: http://www.sciencedirect.com/science/article/pii/S0965856414001736.
McPhearson, T. et al., 2016. Scientists must have a say in the future of cities. *Nature*, 538(7624), pp.165–166. Available at: http://www.nature.com/doifinder/10.1038/538165a.
Meadows, D.H., 1999. *Places to Intervene in a System*, Hartland, Vermont.
Meadows, D.H. et al., 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*, New York, NY: Universe Books.
Mittal, J., 2014. Self-financing land and urban development via land readjustment and value capture. *Habitat International*, 44, pp.314–323. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0197397514001155.
Moir, E., Moonen, T. & Clark, G., 2014. *The future of cities: what is the global agenda?*, London, UK.
Mostafavi, M., Doherty, G. & Design, H.U.G.S., 2016. *Ecological Urbanism*, Lars Muller Publishers.
Mumford, L., 1961. *The City in History: Its Origins, Its Transformations, and Its Prospects*, Harcourt, Brace & World.
Nair, S. et al., 2014. Water-energy-greenhouse gas nexus of urban water systems: Review of concepts, state-of-art and methods. *Resources, Conservation and Recycling*, 89, pp.1–10. Available at: http://dx.doi.org/10.1016/j.resconrec.2014.05.007.
New South Wales Government, 2013. *Factsheet Overcoming Split Incentives, Heating, Ventilation & Air Conditioning High Efficiency Systems Strategy*, Sydney, Australia.
Newman, P., 2014. Biophilic urbanism: a case study on Singapore. *Australian Planner*, 51(1), pp.47–65. Available at: http://www.tandfonline.com/doi/abs/10.1080/07293682.2013.790832.
Newman, P. et al., 2016. *Entrepreneur Rail Model*, Perth, Australia.
Newman, P., 2016. Perth as a "big" city: Reflections on urban growth. *Thesis Eleven*, 135(1), pp.139–151. Available at: http://the.sagepub.com/cgi/doi/10.1177/0725513616657906.
Newman, P., 1999. Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning*, 44(February), pp.219–226.
Newman, P., Beatley, T. & Boyer, H., 2009. *Resilient Cities: Responding to Peak Oil and Climate Change*, Washington, D.C.: Island Press.
Newman, P. & Jennings, I., 2008. *Cities as Sustainable Ecosystems: Principles and Practices*, Washington, D.C.: Island Press.
Newman, P. & Kenworthy, J., 1989. *Cities and Automobile Dependence: An International Sourcebook* Gower, ed., Aldershot, UK.

Newman, P. & Kenworthy, J., 2011. Peak Car Use: Understanding the Demise of Automobile Dependence. *World Transport Policy and Practice*, 17(2), pp.32–42.
Newman, P. & Kenworthy, J., 1999. *Sustainability and Cities: Overcoming Automobile Dependence*, Washington, D.C.: Island Press.
Newman, P. & Kenworthy, J., 2015. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*, Washington, D.C.: Island Press.
Newman, P., Kenworthy, J. & Glazebrook, G., 2013. Peak Car Use and the Rise of Global Rail: Why this is happening and what it means for large and small cities. *Journal of Transportation Technologies*, 3(4), pp.272–287.
Newman, P., Mason, A. & Gardner, H., 2012. *Regenerative cities*, Perth, Australia.
Newman, P. & Matan, A., 2013. *Green Urbanism in Asia: The Emerging Green Tigers*, Singapore: World Scientific Publishing.
Newton, P., Murray, S., et al., 2012. *AHURI Research & Policy Bulletin How do we regenerate middle suburban “ greyfield ” areas ?*, Melbourne, Australia.
Newton, P., 2010. Beyond Greenfields and Brownfields: The Challenge of Regenerating Australia’s Greyfield Suburbs. *Built Environment*, 36, pp.1–53.
Newton, P., Newman, P., et al., 2012. Greening the Greyfields : Unlocking the Redevelopment Potential of the Middle Suburbs in Australian Cities. *World Academy of Science, Engineering and Technology*, 71(11), pp.658–677.
Newton, P., 2014. Regeneration: Tackling the Greyfields. In T. Perinotto, ed. *Creating Sustainable Precincts*. Sydney, Australia: The Fifth Estate, pp. 106–111. Available at: http://evacoust.startlogic.com/TimeToyota.pdf.
Newton, P. et al., 2011. *Towards a new development model for housing regeneration in greyfield residential precincts*,
Newton, P.W., 2012. Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities. *Journal of Urban Technology*, 19(1), pp.81–102. Available at: http://www.tandfonline.com/doi/abs/10.1080/10630732.2012.626703.
Newton, P.W., 2014. Low Carbon Precincts for Low Carbon Living. *Carbon Management*.
Newton, P.W., 2008. *Transitions: Pathways Towards Sustainable Urban Development in Australia*, Springer Netherlands.
Norman, B., 2010. *A low carbon and resilient urban future: An integrated approach to planning for climate change*, Canberra, Australia: Commonwealth of Australia.
Norman, B., 2009. Principles for an intergovernmental agreement for coastal planning and climate change in Australia. *Habitat International*, 33(3), pp.293–299. Available at: http://dx.doi.org/10.1016/j.habitatint.2008.10.002.
Norman, B., 2016. Urban Sustainability : Joining the Dots Between Planning, Science, and Community. *Solutions*, (May-June), pp.46–54.
Norman, B. & Reid, J., 2016. In Quito, the world meets to discuss the future of cities. *The Conversation*, (October), pp.1–4. Available at: https://theconversation.com/in-quito-the-world-meets-to-discuss-the-future-of-cities-67125.
Ostrom, B.E., 2010. Beyond Markets and States : Polycentric Governance of Complex Economic Systems. , 100(June), pp.1–33.
Pauli, G.A., 2010. *The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs*, Toas, New Mexico: Paradigm Publications.
Pickett, S.T. a et al., 2011. Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management*, 92(3), pp.331–362. Available at: http://dx.doi.org/10.1016/j.jenvman.2010.08.022.
Pincetl, S., Bunje, P. & Holmes, T., 2012. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning*, 107(3), pp.193–202. Available at:

http://dx.doi.org/10.1016/j.landurbplan.2012.06.006.
du Plessis, C., 2012. Towards a regenerative paradigm for the built environment. *Building Research & Information*, 40(1), pp.7–22.
Ramaswami, A. et al., 2012. A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems: An Integrative Curriculum Across Seven Major Disciplines. *Journal of Industrial Ecology*, 16(6), pp.801–813.
Rauland, V., 2013. *Decarbonising Cities : Certifying Carbon Reduction in Urban Development*. Curtin University.
Rauland, V. & Newman, P., 2015. *Decarbonising Cities: Mainstreaming Low Carbon Urban Development*, Springer International Publishing.
Rawnsley, T. & Spiller, M., 2012. Housing and Urban Form: A New Productivity Agenda. In R. Tomlinson, ed. *Australia's Unintended Cities*. Collingwood, Victoria: CSIRO Publishing.
Rees, W. & Wackernagel, M., 2008. Urban ecological footprints: Why cities cannot be sustainable-and why they are a key to sustainability. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*, 16, pp.537–555.
Ritchie, A. & Thomas, R., 2013. *Sustainable Urban Design: An Environmental Approach*, Taylor & Francis.
Rittel, H.W.J. & Webber, M.M., 1973. Dilemnas in a general theory of planning. *Policy Sciences*, 4(December 1969), pp.155–169.
Robèrt, K. et al., 2002. Strategic sustainable development - selection, design and sysnergies of applied tools. *Journal of Cleaner Production*, 10, pp.197–214. Available at: http://www.sciencedirect.com/science/article/pii/S0959652601000610.
Robèrt, K.-H. et al., 2012. *Sustainability Handbook*, Lund, Sweden: Studentlitteratur.
Robèrt, K.-H., Broman, G.I. & Basile, G., 2013. Analyzing the Concept of Planetary Boundaries from a Strategic Sustainability Perspective: How Does Humanity Avoid Tipping the Planet? , 18(2). Available at: http://dx.doi.org/10.5751/ES-05336-180205.
Rockström, J., 2009. A safe operating space for humanity. *Nature*, 461(24), pp.472–475.
Rockström, J. et al., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity. , 14(2). Available at: http://pdxscholar.library.pdx.edu/iss_pub.
Roggema, R. & van Dobbelsteen, A., 2008. Building Resilience: Responding to a Turbulent World. In *UK Systems Society International Conference*. Oxford, UK.
Rohe, W.M., 2009. From Local to Global: One Hundred Years of Neighborhood Planning. *Journal of the American Planning Association*, 75(2), pp.209–230.
Roorda, C. et al., 2014. Transition Management in the Urban Context: Guidance Manual. , p.49.
Ruddiman, W.F. et al., 2015. Defining the epoch we live in. Is a formally designated "Anthropocene" a good idea? *Science*, 348(6230), pp.38–39.
Russell, J.M. & Gurevich, H., 2013. *Thrivability: Breaking Through to a World That Works*, Triarchy Press.
Sanders, R.G., Milford, L. & Rittner, T., 2013. Reduce Risk, Increase Clean Energy: How States and Cities are Using Old Finance Tools to Scale Up a New Industry. , (August), p.34.
Sarantakos, S., 1998. *Social Research* 2nd ed., Melbourne, Australia: Macmillan.
Schellnhuber, H.J. & Martin, M., 2014. *Climate-System Tipping Points*, Vatican City.
Schellnhuber, H.J., Rahmstorf, S. & Winkelmann, R., 2016. Why the right climate target was agreed in Paris. *Nature Clim. Change*, 6(7), pp.649–653. Available at:

http://dx.doi.org/10.1038/nclimate3013%5Cnhttp://10.1038/nclimate3013.
Schepelmann, P., Goossens, Y. & Makipaa, A., 2010. *Towards Sustainable Development: Alternatives to GDP for measuring progress*, Wuppertal, Germany: Wuppertal Institute for Climate, Environment and Energy.
Scheurer, J. & Curtis, C., 2008. *Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure*, Perth, Australia.
Scruggs, G., 2016. UN-Cities? Rumoured proposal gains steam. *Citiscope*.
Seitzinger, S. et al., 2012. Planetary Stewardship in an Urbanizing World: Beyond City Limits. *Ambio*, 41, pp.789–794.
Selzter, E. et al., 2010. *Making EcoDistricts: Concepts and Methods for Advancing Sustainability in Neighbourhoods*, Portland.
Seto, K. et al., 2014. *Human Settlements, Infrastructure, and Spatial Planning* O. Edenhofer et al., eds., Cambridge, UK and New York, NY, USA: Cambridge University Press.
Seto, K.C., Güneralp, B. & Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, 109(40), pp.16083–16088.
Seyfang, G. et al., 2014. A grassroots sustainable energy niche? Reflections on community energy in the UK. *Environmental Innovation and Societal Transitions*, 13, pp.21–44. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2210422414000227.
Sharifi, A. & Murayama, A., 2013. A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review*, 38, pp.73–87.
Smith, N., 2002. New globalism, new urbanism: gentrification as global urban strategy. *Antipode*, 34(3), pp.427–450.
Soderlund, J. & Newman, P., 2015. Biophilic architecture: a review of the rationale and outcomes. *AIMS Environmental Science*, 2(4), pp.950–969. Available at: http://www.aimspress.com/article/10.3934/environsci.2015.4.950.
Steffen, W., Richardson, K., et al., 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), pp.736–747.
Steffen, W. et al., 2011. The Anthropocene : From Global Change to Planetary Stewardship. *Ambio*, 40(7), pp.739–761.
Steffen, W., Broadgate, W., et al., 2015. The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*, 2(1), pp.81–98.
Steffen, W., Crutzen, J. & McNeill, J., 2007. The Anthropocene: are humans now overwhelming the great forces of Nature? *Ambio*, 36(8), pp.614–621.
Stern, N., 2006. The Stern Review on the Economic Effects of climate change. *Population and Development Review*, 32(December), pp.793–798.
Svane, Ö., 2007. Hammarby Sjöstad and the Process of Environmental Management. , 30(7), pp.1–10.
Talen, E. ed., 2013. *Charter of the New Urbanism, 2nd Edition*, McGraw-Hill Education.
Taylor, N., 2007. *Urban Planning Theory since 1945*, London, UK: Sage.
Thackara, J., 2005. *In the Bubble: Designing in a Complex World*, London, UK: MIT Press.
The Council of Economic Advisers, 2014. The cost of delaying action to stem climate change. , (July), pp.0–32. Available at: https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.

The U.S. Green Building Council, 2013. *The Business Case for Green Building*, Available at: http://www.worldgbc.org/activities/business-case/.
Thompson, H. & Waugh, A., 2009. *A Process Revealed*, FUEL Publ.
Thompson, S. & Maginn, P. eds., 2012. *Planning Australia. An overview of urban and regional planning* 2nd ed., Melbourne, Australia: Cambridge University Press.
Trainer, T., 2008. Transitions: Pathways Towards Sustainable Urban Development in Australia. In P. Newton, ed. Melbourne, Australia: CSIRO Publishing.
TriMet, 2015. *45 Years Making History and Transit in the Portland Region*, Portland, Oregon.
Truffer, B. & Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies. *Regional Studies*, 46(1), pp.1–21. Available at: http://www.tandfonline.com/doi/abs/10.1080/00343404.2012.646164.
UK GBCA & Zero Carbon Hub, 2010. *Sustainable Community Infrastructure*, London, UK.
UN-Habitat, 2013. *The Future we Want, the City we Need*, Nairobi.
UN DESA, 2011. *The Great Green Technological Transformation*, New York: United Nations Department of Economic and Social Affairs.
UN Habitat, 2016. *Urbanization and Development Emerging Futures. World Cities Report 2016*, Nairobi, Kenya: United Nations Human Settlements Programme.
UN System Task Team on the Post-2015 UN Development Agenda, 2012. *Realizing the Future we Want for All*, New York, NY.
UNEP, 2013. *City-Level Decoupling Urban resource flows Urban resource flows and the governance of infrastructure transitions. A Report of the Working Group on Cities of the International Resource Panel. A Report of the Working Group on Cities of the International Res*, United Nations Environment Programme.
UNEP, 2011. *Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel.Fischer-Kowalski, M., Swilling, M. von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Kra*,
UNFPA, 2007. *The state of the world population 2007: unleashing the potential of urban growth.*,
United Nations, 2013. *A New Global Partnership : Eradicate Poverty and Transform economies through Sustainable Development: The Report of the High-Level Panel of Eminent Persons on the Post-2015 Development Agenda*, New York.
United Nations, 2015a. *Adoption of the Paris Agreement*, Paris, France. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.
United Nations, 2016. *Habitat III New Urban Agenda. Draft outcome document for adoption in Quito, October 2016*,
United Nations, 1987. *Our Common Future - Brundtland Report*, New York, NY: Oxford University Press.
United Nations, 2015b. *World Population Prospects*,
United Nations, 2014. *World Urbanization Prospects: The 2014 Revision, Highlights*, Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.
United Nations General Assembly, 2015. *Transforming our world: The 2030 agenda for sustainable development*, NY.
University of Leicester, 2016. Media note: Anthropocene Working Group (AWG). Available at: http://www2.le.ac.uk/offices/press/press-releases/2016/august/media-note-anthropocene-working-group-awg [Accessed September 22, 2016].
VisionPDX, 2007. *Portland 2030: a vision for the future*, Portland, Oregon. Available at: http://www.portlandonline.com/bds/index.cfm?a=195005&c=46936.
Vollan, B. & Ostrom, E., 2010. Cooperation and the Commons. *Science*, 330(6006), pp.923–924.

Wackernagel, M. & Rees, W., 1998. *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers.
Wackernagel, M. & Rees, W.E., 1997. Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective. *Ecological Economics*, 20(1), pp.3–24. Available at: http://www.sciencedirect.com/science/article/pii/S0921800996000778.
Waldheim, C., 2012. *The Landscape Urbanism Reader*, Princeton Architectural Press.
Walker, D. & Swartz, J., 2016. *Carbon Pricing the Paris Agreement's Key Ingredient*,
Waters, C.N. et al., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science*, 351(6269), pp.137–147.
Von Weizsäcker, E. et al., 2009. *Factor Five: Transforming the global economy through 80% improvements in resource productivity.* Earthscan, ed., London, UK.
Weymouth, R. & Hartz-Karp, J., 2015. Deliberative Collaborative Governance as a Democratic Reform to Resolve Wicked Problems and Improve Trust. *Journal of Economic and Social Policy*, 17(1), pp.1–32.
Whitmee, S. et al., 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet*, 6736(15), pp.1973–2028. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0140673615609011.
Williams, K., 2012. Regenerative design as a force for change: thoughtful, optimistic and evolving ideas. *Building Research & Information*, 40(3), pp.361–364. Available at: http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.662389.
Wittmayer, J., Roorda, C. & Steenbergen, F. Van, 2014. Governing Urban Sustainability Transitions – Inspiring examples. , (September).
Wolman, A., 1965. *The Metabolism of Cities*,
Wolman, A., 1965. The Metabolism of Cities. *Scientific American*, 213(3), pp.179–190.
Woo, F., 2014. *Regenerative Urban Development*, Hamburg, Germany.
World Future Council, Nordic Folkecenter & Climate Service Center (CSC), 2013. From vision to action: A workshop report on 100% Renewable Energies in European Regions.
Yin, R.K., 2006. Case study methods. In J. L. Green, G. Camilli, & P. B. Elmore, eds. *Handbook of Complementary Methods in Education Research*. American Education Research Association, pp. 111–122.
Yin, R.K., 1994. *Case Study Reserach - Design and Methods* 2nd ed., London, UK: Sage Publications.
Zalasiewicz, J. et al., 2010. The New World of the Anthropocene. *Environmental Science & Technology*, 44(7), pp.2228–2231.
Zero Carbon Hub, 2009. *Defining a fabric energy efficiency standard for zero carbon homes*, Milton Keynes, UK.
Zhang, X. et al., 2015. Regenerative sustainability for the built environment – from vision to reality: an introductory chapter. *Journal of Cleaner Production*, pp.1–10. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652615013815.
Zvelebil, M., 2009. *Hunters in Transition: Mesolithic Societies of Temperate Eurasia and Their Transition to Farming*, Cambridge University Press.

Publications

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Review

Geoengineering in the Anthropocene through Regenerative Urbanism

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Abstract: Human consumption patterns exceed planetary boundaries and stress on the biosphere can be expected to worsen. The recent "Paris Agreement" (COP21) represents a major international attempt to address risk associated with climate change through rapid decarbonisation. The mechanisms for implementation are yet to be determined and, while various large-scale geoengineering projects have been proposed, we argue a better solution may lie in cities. Large-scale green urbanism in cities and their bioregions would offer benefits commensurate to alternative geoengineering proposals, but this integrated approach carries less risk and has additional, multiple, social and economic benefits in addition to a reduction of urban ecological footprint. However, the key to success will require policy writers and city makers to deliver at scale and to high urban sustainability performance benchmarks. To better define urban sustainability performance, we describe three horizons of green urbanism: *green design*, that seeks to improve upon conventional development; *sustainable development*, that is the first step toward a net zero impact; and the emerging concept of *regenerative urbanism*, that enables biosphere repair. Examples of green urbanism exist that utilize technology and design to optimize urban metabolism and deliver net positive sustainability performance. If mainstreamed, regenerative approaches can make urban development a major *urban geoengineering* force, while simultaneously introducing life-affirming co-benefits to burgeoning cities.

Keywords: sustainable cities; Anthropocene; Paris Agreement; COP21; regenerative design; green urbanism; urban geoengineering

1. Introduction

1.1. The Anthropocene

The impact of humans upon the biosphere is leaving a pervasive and persistent signature on Earth. This human geologic agency is the basis of proposals for a new geologic epoch—the Anthropocene [1–3]. This agency differs from all previous epochs in that human awareness provides this epoch with a "consciousness". It is this intentional anthropogenic agency in relation to environmental impact, upon which this article focuses. If negative Anthropogenic impact results from previous conscious decision making by humans, so it follows, that conscious decisions can also steer the planetary future away from the existential risks as outlined by the Intergovernmental Panel on Climate Change (IPCC) [4], to shape a positive outcome for the Anthropocene. However, there has not yet been a clear idea of how this can be done. This paper outlines how cities can harness their positive potential to regenerate the Anthropocene [5]. Cities lie at the nexus of environmental impact, mitigation and governance and as such represent an important target if one wishes to make a big impact on sustainability. Since the majority of the world's growing population is urban, and urbanizing [6], city regions are the frontier of future environmental impact, they can also become the arena best suited for mitigating this impact. This will be given focus by understanding the changes to urban metabolism that must be engendered to enable such a radical change in human history.

1.2. High Level Governance of Anthropogenic Climate Change

Anthropogenic climate change is well documented, having been the subject of mainstream science for around three decades [7,8]. As humanity tracks, monitors and recognizes the increasingly adverse environmental impacts and risks related to greenhouse gas (GHG) emissions [9] the urgency to act is becoming a powerful political agenda [10–12].

The last decade has seen a rapid rise in mainstream environmental consciousness and this is beginning to permeate national and international policy. Significant steps have been taken toward forging international agreements, most significantly with the announcement of the Paris Agreement (COP21) in December 2015 [13]. The objective of the agreement is to build momentum toward neutralizing the risk of climate change through stabilization or mitigation of GHG emissions. Mitigation, as defined by the IPCC, is a human intervention to reduce the sources or enhance the sinks of GHG [14].

The Paris Agreement is the first universal global climate deal (signed by 195 countries). It commits signatory nations to "aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above preindustrial levels" [13]. Increasing risks of climate inaction are outlined by the IPCC [15] with this in turn driving an increased urgency to consciously manipulate the planetary climate in the Anthropocene [14]. The Paris Agreement, while requiring emission reductions, does not explicitly provide pathways for achieving its goals. The details are the domain of each sovereign state to determine, but undoubtedly this commitment will require large scale socio-technical transformation [16–18]. The current path dependent lock-in of a hydrocarbon fuelled economy is well documented (see [19–21]). The smooth transition to a low carbon economy will be very difficult due to the high resistance to change typical of path dependence [16,18,22]. Climate change is a "wicked problem" [23] highly resistant to resolution due to complex interconnections between institutions and infrastructures of current conventional production processes and products. Resistance to change is further confounded by entrenched cultural values and assumptions that involve marketing, social groups, policy makers who provide regulatory frameworks, industry associations and various associated networks [24]. As a result of these mutual dependencies the tendency is for incremental change along predictable trajectories [17]. However, what is needed, and indeed what the Paris Agreement calls for, is wide-scale disruptive innovation to current systems of production, to ensure that atmospheric CO_2eq is kept below 450 ppm by 2100 to reduce the risk of severe climate change [4]. The Agreement mandates rapid change but what is needed are the tools for large-scale mitigation.

1.3. Geoengineering: The Silver Bullet?

The need for large-scale rapid decarbonization has driven investigations into a simple "silver bullet" for climate change mitigation. This has led to proposals for geoengineering [25,26]: the "deliberate, large-scale intervention in the Earth's natural systems to counteract global warming" [27]. Geoengineering approaches can be divided into two major classes, "carbon dioxide removal" (CDR) and "solar radiation management" (SRM) (alternatively known as "albedo management") [14,26,28]. Where CDR actively mitigates, SRM is largely used to reflect solar radiation and in this sense is proposed more as a temporary management tool for extreme events.

The IPCC working group III on Mitigation of Climate Change accepted that in the face of extreme climate events the need to quickly offset warming may be required [14]. The report goes on to warn that terrestrial geoengineering techniques would require large scale land use changes, involving local and regional risks, while ocean based techniques (such as iron fertilization) would involve "significant transboundary risks for ocean ecosystems". Similar risks also exist for solar radiation management

(SRM) which, involves reflective particles or aerosols in the upper atmosphere [14]. The IPCC report highlights questions around "costs, risks, governance, and ethical implications" relating to SRM in particular. These ethical issues were the focus of the "Oxford Principles" developed in 2011 "to provide a code of conduct for geoengineering research" [27]. In addition to environmental risks, the Oxford Principles identified "social risks", for example, "geoengineering research as an excuse to delay reducing emissions" and "knowledge risks" for example "risks that arise from what would happen if we were *not* able to undertake such research" (i.e., ignorance of the possible techniques that may avert an existential threat to society) [27]. The underlying risks outlined by the Oxford Principles are varied in nature and include practical, ethical and governance concerns.

Similar findings were published in a technical evaluation of impacts report by the US National Academy of Science in 2015, which stated that "climate intervention (geoengineering) is no substitute for reductions in carbon emissions and adaptation efforts aimed at reducing the negative consequences of climate change" [28]. Conventional geoengineering brings with it uncertainty related to unknown or unexpected outcomes in global ecological systems that could threaten the survival of human and other life.

In light of this uncertainty (ethical and governance as much as technical), we suggest city-centric *urban geoengineering* in lieu of conventional geoengineering approaches. This approach builds upon Fink's suggestions for geoengineering cities to stabilize climate [5], and would incorporate Flannery's "third way" CDR technologies [29]. Third way technologies "recreate, enhance or restore the processes that created the balance of GHG, which existed prior to human interference, with the aim of drawing carbon, at scale, out of the Earth's atmosphere and/or oceans" [29]. Flannery is looking for plants and minerals that can achieve this. Combining urban geoengineering with third way technologies, it is possible to bring the solution back into the heart of human habitats and the generator of most GHG emissions—the city. Coupling rapid climate change mitigation with low carbon urban growth will accelerate CDR processes and may avoid the need for temporary geoengineering measures such as SRM. Focusing upon the urban environment as the arena for change will reduce potential environmental risks to remote geographies such as unproductive land, the atmosphere or the sea, that are typically identified for geoengineering actions.

2. The Potential of Cities

2.1. The Phenomenal Growth of Cities

Population growth during the Twentieth Century increased threefold, while global market activity increased 50 fold, representing a 16 fold per capita increase in consumption [30]. Most of this increase in wealth can be attributed to the dramatic growth in city population from around 220 million urban dwellers in 1900 to 2.84 billion in 2000 [31]. By 2014, 54% of the world's population were residing in cities and by 2050 this figure is expected to be close to 70%; and with this increasing urbanization "sustainable development challenges will be increasingly concentrated in cities" [6]. Humans have become an "urban species".

Per capita consumption rates of energy [32,33], and many other resources [34], are typically lower for people living in higher density areas than their suburban or rural counterparts, but room exists for far greater improvements. Redesigning urban environments to drastically reduce per capita consumption has the potential to play a central role in reducing GHG emissions either through the provision of more efficient infrastructure, or, infrastructure that influences more efficient behaviour [35].

To accommodate the projected urban population growth of 2.5 billion people to 2050 from now [6], it will be necessary to build as much new urban infrastructure as existed globally in 1950, but instead of developing over centuries, this infrastructure will need to be built in a little over three decades (see Figure 1, based upon United Nations global growth projections [36]).

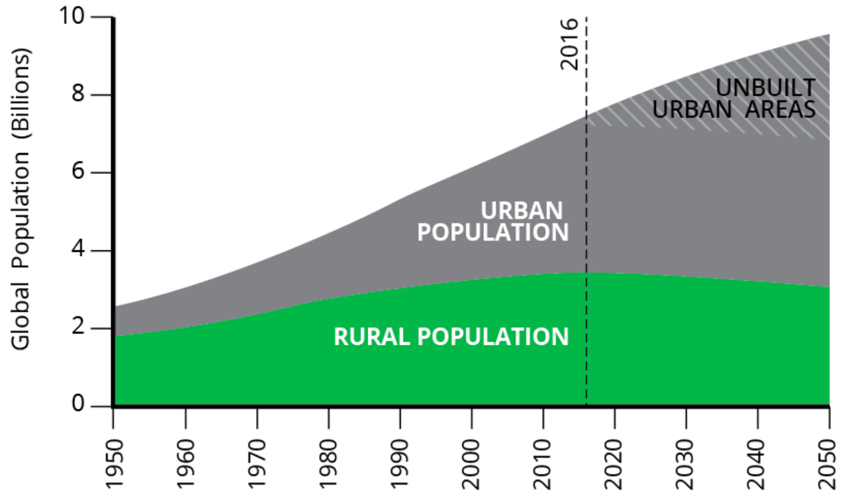

Figure 1. Urbanization population projections and unbuilt urban areas.

In addition to newly constructed urban areas, large existing urban areas will need to be redeveloped including, urban upgrades for the estimated 880 million urban dwellers living in slums and informal settlements [37], and urban renewal areas in developed cities experiencing growth. Redevelopment and renewal of these existing urban areas adds significantly to the global scale of city building over the coming decades. By way of example, Australia's modern and highly liveable cities, were among the fastest growing in the OECD in 2015. They have grown by 25% since 2000 [38], and the growth from 2016 to 2060 is projected to be another 40% [38]. Of this growth, 70% is projected to occur in the capital cities and every major city's long term planning policy has set targets for around 50%–70% infill development (i.e., redevelopment within existing urban areas). Meeting these infill policies will see large areas of Australia's existing, but relatively unsustainable urban fabric, undergo large scale renewal and rebuilding [39].

Opportunity for low carbon urban infrastructure can then be found in:

- cities and urban areas yet to be built;
- urban upgrades in slums;
- urban renewal in growing developed cities;
- urban retrofits of existing areas [40].

It is the unprecedented scale and rate of urban growth and renewal that presents both the challenge and the opportunity. Harnessing this massive urban growth to deliver sustainable cities has the potential to both reduce carbon and repair the biosphere, while also meeting multiple global goals (e.g., the United Nations Sustainable Development Goals [41]).

Innovators in the built environment sector are already demonstrating how *green urbanism* can radically reduce carbon emissions, while maintaining or even enhancing liveability [35,42–44]. Rapid urbanization presents an opportunity for cities to emerge as an environmental solution as opposed to generators of environmental problems, as long as they adapt to this historic task through strong leadership driving a powerful green urbanism as outlined below. This is the premise behind Sustainable Development Goal 11 "to make cities inclusive, safe, resilient and sustainable" and adopted by 193 nations in 2016. It is the rationale for international organizations such as C40 Cities [45] and ICLEI [46] that have had a strong sustainable city agenda for some time and for the creation of international standards such as *ISO 37120:2014—Sustainable development of communities—Indicators for city services and quality of life* [47], and *ISO 37101:2016(E) Sustainable Development in Communities—Management system for sustainable development* [48]. These organizations, goals and standards are all aimed at influencing behavior and outcomes. What is still missing in most jurisdictions is a mechanism to raise revenue for agencies responsible for overseeing urban processes to invest in and monitor sustainability measures. For emissions, this might take the form of a local carbon tax or other rate based income stream to provide payments to the various responsible agencies to help facilitate the required transition.

2.2. Urban Geoengineering and Green Urbanism

As described earlier, carefully planned urban development may provide infrastructure that helps cities decarbonize; through emission reduction, energy efficiency and third way technologies, which collectively perform an urban geoengineering function. The large decarbonizing potential of cities is only just beginning to be understood. Human settlements in the process of delivering necessary infrastructure to house a rapidly growing population can play an integral role in decarbonizing the planet [21,49–51].

However, global warming is just one of several planetary boundaries currently being transgressed. The potential for a genuinely "green urbanism" by cities and their bioregions, can go further than decarbonizing alone to help address several other planetary limits including land-system change, freshwater use, biodiversity integrity, and biochemical flows of Phosphorus and Nitrogen among others [52–54]. It is the integrated approach of green urbanism that addresses other planetary boundaries while providing habitat for humans that makes the large scale decarbonizing of cities preferable to other geoengineering approaches.

To perform an effective urban geoengineering function, urban development will need to go beyond net-zero (i.e., offsetting all embodied and operational carbon) to become net-positive [55,56]. This may be achieved through the creation of cities that are very efficient in terms of operational and embodied energy, and that allow the generation of more energy than is consumed over urban infrastructure lifecycles through the extensive use of renewable energy sources [57]. An example of this is the Solarsiedlung city block of 'plus energy' houses in Freiburg, Germany [58]. Only a coordinated and holistic approach to urban development with an emphasis on third way technologies and integrated urban design can achieve this, and only strong governance at all levels, especially the urban scale, can co-ordinate this [35,42,59]. The approach, as outlined below, is being called "regenerative urbanism".

Governance of a regenerative urban system that initiates urban geoengineering, will require measuring and monitoring of sustainability performance. Urban sustainability performance can be analyzed through a material and substance flow analysis [60,61]. Mapping the flow of resources through the city is a well-established, if underutilized, process usually described as urban metabolism [62–65]. Urban metabolism modeling provides a tool for understanding, monitoring and designing the performance of urban systems, not just in terms of GHG emissions, but also broader sustainability elements including renewables, water, waste, transport and food. Good governance of urban sustainability performance will require an efficient urban metabolism, facilitated through the delivery of more sustainable urban infrastructure.

2.3. Three Horizons of Urban Sustainability Performance

Measuring urban metabolic flows makes it possible to differentiate between three levels of green urbanism commitment: "green design", "sustainable development" and "regenerative urbanism". Each of these levels, or horizons, represents a step-change in urban planning innovation and systems integration. Horizon thinking is usually associated with business innovation to plan for future opportunities, its application to urban planning was first used by Newton [66]. We apply this approach to the three horizons of urban sustainability performance. Effectively, these notions correspond to three levels of efficiency in urban metabolism: green design has a lower ecological footprint than the usual extractive linear metabolism; sustainable development aims to be net zero in its footprint; however, regenerative cities demonstrate a circular metabolism that enables net positive outcomes [58,62,67]. Exemplars are provided to describe some real world examples of such regenerative urban systems. The three horizons are illustrated in Figure 2.

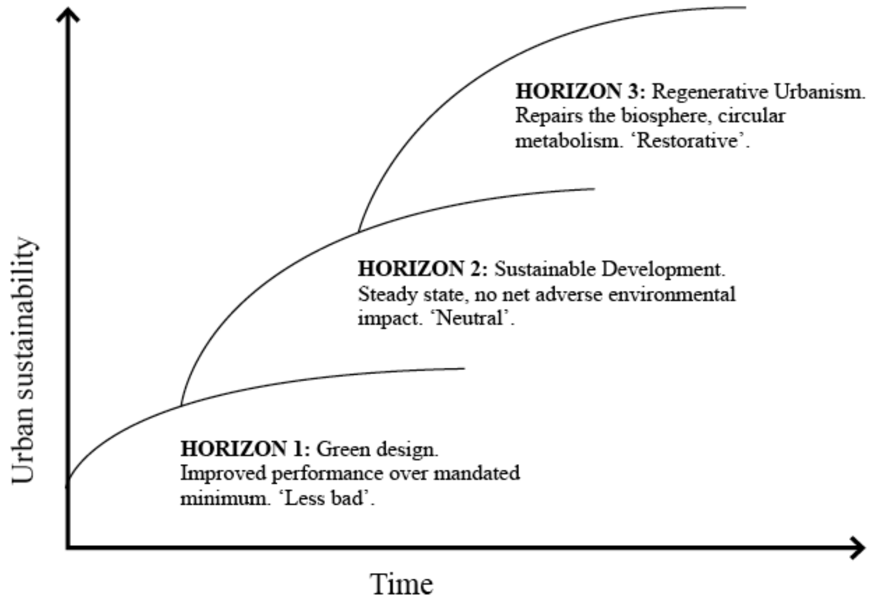

Figure 2. The three horizons of green urbanism.

Green development represents sustainability improvement upon the existing baseline required by local building codes or other statutory regulations. It is a "less bad" response to conventional (unsustainable) development. Typical improvements include energy and water demand reduction, resource efficiency measures and renewable or alternative technologies.

Sustainable development is defined by Brundtland [7] as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Essentially, this notion is "neutral", sustaining the environment over time with no net adverse impact. This approach focuses upon sustainable city initiatives that seek to have no net impact such as zero carbon urban developments like BedZED [68]. However, in many urban locations the local environment is already greatly degraded, particularly in terms of ecosystems services, prompting commentators such as Woo to suggest "it is no longer enough to only look at sustainable development because the ability of future generations to meet their own needs is *already compromised*" [69]. The notion is however useful for defining a threshold below which the environment (or components of the environment) continue to degrade, and above which the environment regenerates.

Regenerative urbanism applies regenerative design [70–72] to the urban environment. It involves consciously repairing a degraded environment and actively improving the biosphere whilst providing for the integration of urban systems that provide for human needs. This approach actively seeks to repair and regenerate sustainability indicators associated with planetary boundaries at the local scale (e.g., GHG emissions, water, nutrient cycles, etc.) through every step in urban development. At its most effective a regenerative urbanism will deliver urban infrastructure that results in less emissions, reduced water demand, cleaner energy, local food production, waste recovery and so on.

In terms of these three innovation horizons, simple green design approaches to development are now commonplace, sustainable development is occasionally observed and regenerative design can only be described as emergent. Yet, often there is no clear definition between the urban sustainability performance of any given "green" development and a plethora of terms may be used to describe the outcome such as "eco-city", "sustainable city", "smart city", "low-carbon city", "resilient city" to name a few [73,74]. What is critically important is the consistent definition of performance metrics as measured through an urban metabolism model [61,62,64,75,76]. From a city planning perspective whether a development is conventional, green, sustainable or regenerative, planners will need to understand the relative potential of an area to be transformed and weaknesses that may be improved.

The next section describes these three horizons in relation to energy (in terms of GHG emissions). It relates to decarbonizing cities and the role cities may play in implementing the Paris Agreement. A similar approach may be applied to any number of sustainability metrics including water, waste, food and biodiversity to measure and to understand how these elements are performing.

2.4. The Three Urban Horizons in Relation to Decarbonizing Cities

The three urban horizons can describe urban performance within a defined geographic area, at whatever scale, whether a plot, precinct or a whole city. Sustainable Development results from a steady state of basic resources [77] (e.g., net zero emissions, biodiversity). This steady state threshold forms a baseline below which urban sustainability improvements can be described as green design and above which can be called regenerative. Green design is less bad than conventional development (i.e., development that meets the minimum planning regulations), but ultimately still degrades the biosphere; whereas regenerative urbanism results in the net repair to one or more parts of the system.

To be regenerative in terms of climate mitigation, carbon dioxide equivalence (CO_2–e) will need to be net negative, either within the subject area boundary or through offsets at another location. Methods for calculating CO_2–e are complicated and are subject to carbon accounting standards such as the greenhouse gas protocol [78].

Usually, it is more useful to think of sustainability implications from a precinct or city scale rather than an individual plot because greater efficiencies can be achieved through a combination of integral, on-site and precinct-wide infrastructure, such as renewable energy [57,79,80]. Where the aspiration is for low carbon development, shortfalls can be addressed through off-site supply. Higher densities with distributed renewable energy supply and shared infrastructure provision at the precinct or city scale offer co-locational advantages with cost per dwelling decreasing as densities increase [81].

Green design represents an improvement upon conventional performance; in relation to energy its key components may be represented as a triangle [82,83] split into three sections as seen in Figure 3. The triangle base represents the major energy savings through demand management measures, i.e., less consumption; the middle band efficiency e.g., transport efficiency, heating and cooling efficiency, appliance efficiency; and the top of the triangle, renewable energy or other low carbon energy source e.g., photovoltaic panels. The triangle shape conceptualizes the relative emissions savings of each band with most of the effort and most of the GHG emission reductions met through demand management, leaving only a small need for renewable energy to meet local GHG reduction targets.

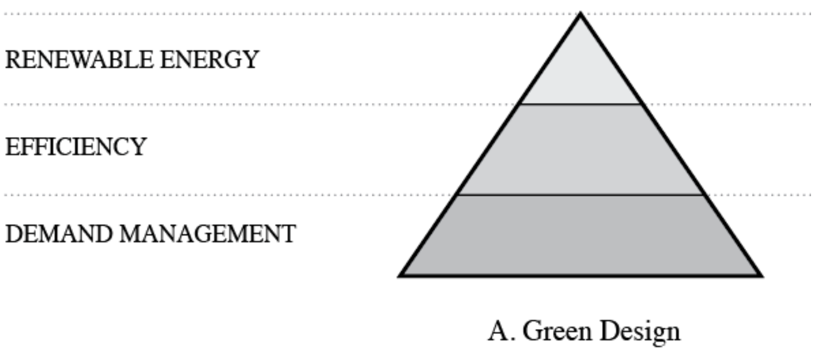

Figure 3. Conceptual diagram of the carbon reduction elements of Green Design.

Sustainable Development, in the context of GHG, aims to be "carbon neutral"; this is typically achieved by increasing the renewable energy component until the renewables offset operational and embodied energy (see B in Figure 4).

The introduction of urban geoengineering techniques, that could perform 'third way' CDR functions would allow cities to go one step further by actively regenerating the Anthropocene. For example, urban geoengineering could remove GHG from the atmosphere as discussed in further detail below under the heading "CDR technology". We consider this a regenerative function, because, in addition to offsetting all embodied and operational energy, the urban geoengineering function reduces atmospheric CO_2 to effectively mitigate climate change risk.

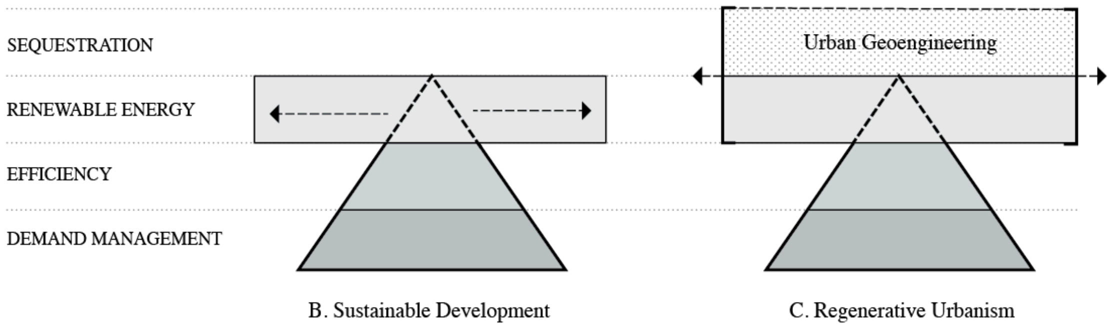

Figure 4. Conceptual diagram of the carbon reduction elements of Sustainable Development (**B**) and Regenerative Urbanism (**C**).

Considering diagram C in Figure 4, four distinct techniques can be used in a regenerative urbanism approach to reduce GHG including:

1 Structures that reduce energy demand and therefore reduce GHG emissions,
2 Operational efficiency measures that improve energy efficiency,
3 Renewable energy sources to displace GHG emitting fuels,
4 CDR techniques utilizing third way technology to actively remove GHG from the atmosphere (urban geoengineering).

Structures that reduce GHG emission demand

Examples of urban structural elements that reduce GHG emissions include:

- Urban growth boundaries for compact city footprints to reduce urban encroachment upon adjoining carbon sinks such as forested land, e.g., Portland, Oregon's urban growth boundary, a policy which has been in place since the 1970s [84];
- Targeted density increases that reduce energy needs for transport due to shorter distances between locations [21,33];
- Reduced embodied energy in materials [34,35];
- High thermal performance of buildings reducing heating and cooling energy demand [82,83,85,86];
- Urban forest and biophilic strategies that shade habitable areas to regulate heat island effect and regulate microclimates reducing heating and cooling energy demand [87,88].

Operational efficiency measures that improve energy performance

Examples of urban operational efficiencies include:

- Energy efficient appliances;
- Transport technology efficiencies;
- Utility technological efficiencies such as Trigeneration [89,90];
- Passive building design [91].

Renewable energy sources

Examples of urban and bioregional renewable energy sources include:

- Solar photovoltaics [80,92];
- Biofuels, biogas or combustible waste [93,94];
- Ground source, water source or geo-thermal energy [95,96].

CDR technology/urban geoengineering

Urban geoengineering, in combination with renewable energy in a low demand and highly efficient urban environment, can turn cities into CDR machines, while at the same time reducing emissions at source.

A range of novel techniques can be applied to urban geoengineering including:

- Carbon negative construction such as:
    - Carbon absorbing cement that takes CO_2 from industrial waste and incorporates it into cement (e.g., Solidia cement) and carbon negative plastics that capture CO_2 from the air (e.g., Newlight Technologies AirCarbon) [29]
    - "Energy Plus" buildings that generate more electricity than they consume thus offsetting other high carbon energy sources [82,97]
    - Prefabricated low carbon housing from biogenic materials (e.g., cross laminated timber, straw composite) that effectively sequester carbon if the biogenic materials are harvested from plantation sources [98,99].
- Carbon negative landscaping using Serpentine rocks that, when crushed, absorb CO_2 from the air [29];
- Carbon negative waste streams, such as biochar from combustible timber waste (e.g., from sources such as biogenic building material offcuts, forestry and agricultural waste) [29];
- Carbon negative industrial products, such as the industrial manufacturing of carbon nano fibres for many functions and carbon fibre replacing steel [29];
- Urban and bioregional forestry and biophilic urbanism to absorb carbon biomass [100–102].

3. Regenerative Cities

As modeling of urban metabolism, along with a general understanding of urban systems, improves, there is growing evidence that human settlements have large untapped sustainability potential. Not only may cities potentially have no net impact, but they may even become *regenerative*, not only in terms of energy, but also for water, food and biodiversity [66,103]. Each of these elements needs an understanding of urban stocks and flows, which can be provided through an urban metabolism analysis [76,104].

The ideal regenerative city (resulting from regenerative urbanism) would allow a settlement to:

- Create more energy than it needed.
- Use water sparingly with full recycling so it would not need to draw upon an external supply and enable regeneration of ground water systems and rivers.
- Regenerate natural systems in degraded areas to support biodiversity of a complexity similar to the pre-settlement bioregion's natural capacity.
- Reduce the scale and length of centralized infrastructure for energy, water and storm water infrastructure, and the embodied and operational energy required for this infrastructure.

Regenerative design aims to eliminate waste by finding new uses for residual products by treating them as resources, e.g., waste food becomes compost thereby reducing the waste going into the environment (e.g., landfill) and in turn reducing the need to import fertilizers. In this way, urban material flows are optimized with the intent to create a circular urban metabolism [58,62,64]. By applying a regenerative design approach to urbanism cities can begin to perform a restorative role in the biosphere. The process requires local management of resources and will help build a local green economy as outlined in Newman and Jennings [58] and as is rapidly happening in Australia's solar economy as described by Newton and Newman [105] and Green and Newman [106].

The regenerative potential of a location will vary, and specific needs will be highly dependent upon the climate. In this respect, regenerative design represents a very different approach from the universally applied Modernist "International Style" that has dominated city planning for most of the past century [107]. Far from being a utopian dream, there are numerous emerging examples with a variety of governance systems, such as:

- West Village, University of California (UC), Davis—the largest net zero carbon development in the USA—created by UC Davis with the local government [108];
- White Gum Valley or WGV (Perth, Australia)—a net positive energy precinct based on solar and batteries, with zero waste and high water goals—created by the WA Government, Fremantle Council and Curtin University;
- The Peterborough Carbon Challenge (marketed as "Vista")—in 2012 the largest zero carbon development in the UK—led by the UK Government as a "Carbon Challenge" demonstration site and delivered through a public private partnership [109];
- Both Hammarby Sjöstad and the Royal Stockholm Seaport—created by the Swedish and Stockholm governments—are regenerative in energy and water as well as exhibiting extremely high recycling waste rates (enabled by automated vacuum waste collection streams);
- Vauban, Freiburg in Germany—with its net positive renewable energy system, dubbed the "greenest city in Europe"—led by a not-for-profit civic group with facilitation from the local government [110].

A regenerative design approach seeks not only to improve environmental impact from minimum statutory requirements, but also to restore degraded environments in terms of all material flows [58,69,100], with particular emphasis upon energy, water and waste.

Preservation, restoration and biomimicry of natural systems can improve biodiversity when applied at scale, an approach known as biophilic urbanism [87,101]. Biophilic urbanism is demonstrated in Singapore where vegetation clearing and biodiversity loss have both been reversed through scientifically-based urban planting between, around and on buildings [111] (see Figures 5 and 6). The increase in urban biocapacity in Singapore, has led to an estimated 20% increase in canopy cover from 1987 to 2007. This has been driven by a biophilic urbanism policy requiring that high density urban areas embrace natural systems, by integrating vegetation into building facades, rooftops and other urban infrastructure [111]. The advantages are abundant, including CDR through biomass creation, biodiverse habitats, local food production and livability improvements including aesthetics and cooling microclimates.

There is a growing body of literature on the theory of regenerative design and regenerative cities documenting the feasibility of this approach as early innovators deliver demonstration projects [58,70,112,113]. Such changes can rapidly be mainstreamed and set off an exponential growth in regenerative urbanism. This can not only make human environmental impact in urban areas less bad, but can start to regenerate degraded environments so that urban areas shift from being an ecological burden to an ecological asset, opening the possibility for the geological record to demonstrate a reversal of the negative impacts of the Anthropocene.

Figure 5. Singapore Garden City (source, Peter Newman).

Figure 6. Park Royal Hotel in Singapore shows the city's commitment to biophilic urbanism, a component of the regenerative city agenda (source, Peter Newman).

4. Conclusions

The case for natural system-based geoengineering "silver bullets" is fraught with risks related to governance, ethics and technology, yet the need for viable climate change mitigation alternatives is growing. Most alternatives suggested to the world through IPCC are directed at national policies through global emissions reduction agreements such as the Paris Agreement. These top down policies are paralleled by bottom up approaches from grass roots groups and low carbon disruptive technologies being developed by industry. However, the biggest potential change agents can be found in the human resources that are brought together in cities as they can combine the top down regulatory and infrastructure power with the bottom up local concerns and disruptive technology demonstrations.

Cities can drive massive small scale change with the cumulative potential for large scale urban geoengineering. Cities represent the arena in which change can be best managed and monitored and the greatest potential lies with developing nations where the highest rates of population growth and urbanization will occur. This growth will bring about new opportunities to either follow the consumptive pattern of the modernist developed world or take the disruptive technologies of the future and leap frog into demonstrating how cities can be urban geoengineers. This will require integrated urban planning at all scales from regional to the household as well as considerable modification of existing legislation, policies and codes driven by the highest levels of national government; but case studies are beginning to emerge that demonstrate this is not only feasible but cost effective [57].

Civilization in the Anthropocene is threatened by numerous planetary boundary transgressions including, but not limited to, climate change. However, consciousness is growing around human actions that can monitor and manage the global environment in relatively benign ways and even begin to regenerate the biosphere. For example, the Paris Agreement provides the mandate for this change and regenerative urbanism provides an approach to achieve the goals of the agreement. The driver and the evidence base exists, so the next step is for scientists and policy makers to work collaboratively on an evidence-based urban policy that delivers the social needs of the city, while actively applying urban geoengineering and regenerative approaches to reduce the ecological footprint beyond zero. The future is not written and it is still possible that the stewardship of our species in Earth's history can be aligned with a period of hope and renewal for the regenerated Anthropocene.

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Abbreviations

The following abbreviations are used in this manuscript:

CDR	Carbon Dioxide Removal
IPCC	International Panel on Climate Change
GHG	Green House Gas
GU	Green Urbanism
RU	Regenerative Urbanism
SRM	Solar Radiation Management

References

1. Crutzen, P.J. Geology of mankind. *Nature* **2002**, *415*. [CrossRef] [PubMed]
2. Steffen, W.; Persson, Å.; Deutsch, L.; Zalasiewicz, J.; Williams, M.; Crumley, C.; Crutzen, P.; Folke, C.; Gordon, L.; Molina, M.; et al. The Anthropocene: From Global Change to Planetary Stewardship. *Ambio* **2011**, *40*, 739–761. [CrossRef] [PubMed]
3. Waters, C.N.; Zalasiewicz, J.; Summerhayes, C.; Barnosky, A.D.; Poirier, C.; Gałuszka, A.; Cearreta, A.; Edgeworth, M.; Ellis, E.C.; Ellis, M.; et al. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* **2016**, *351*, 137–147. [CrossRef] [PubMed]
4. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Bruuner, S., Eickemeier, P., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; p. 1454.
5. Fink, J.H. Geoengineering Cities to Stabilise Climate. *Proc. Inst. Civil Eng. Eng. Sustain.* **2013**, *166*, 242–248. [CrossRef]

6. United Nations Department of Economic and Social Affairs Population Division. *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352)*; United Nations: New York, NY, USA, 2014. Available online: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf (accessed on 17 October 2016).
7. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: New York, NY, USA, 1987.
8. Newman, P.; Kenworthy, J. *Cities and Automobile Dependence: An International Sourcebook*; Gower Publishing Company: Aldershot, UK, 1989.
9. Intergovernmental Panel on Climate Change (IPCC). Summary for Policy Makers. In *Climate Chang 2014: Impacts, Adapt Vulnerability. Contribution of Work Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 1–32.
10. Stern, N. The stern review on the economic effects of climate change. *Popul. Dev. Rev.* **2006**, *32*, 793–798.
11. United Nations Framework Convention on Climate Change (UNFCCC). *Clean Development Mechanism Methodology Booklet*; UNFCCC: New York, NY, USA, 2013.
12. Lynch, A.J.; Andreason, S.; Eisenman, T.; Robinson, J.; Steif, K.; Birch, E.L. *Sustainable Urban Development Indicators for the United States*; Penn Institute for Urban Research: Philadelphia, PA, USA, 2011.
13. United Nations. Adoption of the Paris Agreement. Available online: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (accessed on 17 October 2016).
14. Intergovernmental Panel on Climate Change (IPCC). *Working Group III—Mitigation of Climate Change*; IPCC: Geneva, Switzerland, 2014.
15. United Nations. *Climate Action Now, Summary for Policymakers 2015*; United Nations: New York, NY, USA, 2015.
16. Geels, F.W. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Res. Policy* **2002**, *31*, 1257–1274. [CrossRef]
17. Geels, F.W. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Res. Policy* **2010**, *39*, 495–510. [CrossRef]
18. Smith, A.; Voß, J.P.; Grin, J. Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Res. Policy* **2010**, *39*, 435–448. [CrossRef]
19. Girardet, H. *Creating Regenerative Cities*; Routledge: Abingdon, Oxon, 2015.
20. Droege, P. *Urban Energy Transition: An Introduction*; Elsevier Science: New York, NY, USA, 2008; p. 655.
21. Newman, P.; Kenworthy, J. *Sustainability and Cities: Overcoming Automobile Dependence*; Island Press: Washington, DC, USA, 1999.
22. Geels, F.W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environ. Innov. Soc. Transit.* **2011**, *1*, 24–40. [CrossRef]
23. Australian Public Service Commission. *Tackling Wicked Problems: A Public Policy Perspective*; Commonwealth of Australia: Canberra, Australia, 2007; p. 46.
24. Newton, P.W. Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities. *J. Urban Technol.* **2012**, *19*, 81–102. [CrossRef]
25. House of Commons Science and Technology Committee. *The Regulation of Geoengineering*; House of Commons Science and Technology Committee: London, UK, 2010.
26. National Academy of Science. *Climate Intervention: Reflecting Sunlight to Cool Earth*; National Academies Press: Washington, DC, USA, 2015.
27. University of Oxford. *PRESS RELEASE: "Oxford Principles" Provide a Code of Conduct for Geoengineering Research*; University of Oxford: Oxford, UK, 2011.
28. National Academy of Sciences. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*; National Academies Press: Washington, DC, USA, 2015.
29. Flannery, T. *Atmosphere of Hope: Solutions to the Climate Crisis*; Penguin Books Limited: London, UK, 2015.
30. Norgaard, R. Escaping Economism, Escaping the Econocene. In *Economy of Sufficiency*; Schniedewind, U., Santarius, T., Humburg, A., Eds.; Wuppertal Institute for Climate, Environment and Energy: Wuppertal, Germany, 2013; pp. 44–53.
31. United Nations Population Fund (UNFPA). *The State of the world Population 2007: Unleashing the Potential of Urban Growth*; UNFPA: New York, NY, USA, 2007.
32. Kenworthy, J. Total daily mobility patterns and their implications for forty-three global cities in 1995 and 2005. *World Transp. Policy Pract.* **2014**, *20*, 41–55.

33. Kenworthy, J.; Laube, F. *Millenium Cities Database for Sustainable Transport*; International Association for Public Transport: Brussels, Belgium, 2001.
34. Gardner, H.; Newman, P. *Reducing the Materials and Resource Intensity of the Built form in the Perth and Peel Regions*; Curtin University Sustainability Policy (CUSP) Institute: Perth, Australia, 2013.
35. Newman, P.; Kenworthy, J. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*; Island Press: Washington, DC, USA, 2015.
36. United Nations. *World Urbanization Prospects 2014: Highlights*; United Nations: New York, NY, USA, 2014.
37. UN Habitat. *Urbanization and Development Emerging Futures*; World Cities Report 2016; United Nations Human Settlements Programme: Nairobi, Kenya, 2016.
38. Krockenberger, M. *Population Growth in Australia*; The Australia Institute: Canberra, Australia, 2015.
39. Newton, P.; Newman, P.; Glackin, S.; Trubka, R. Greening the Greyfields: Unlocking the Redevelopment Potential of the Middle Suburbs in Australian Cities. *World Acad. Sci. Eng. Technol.* **2012**, *71*, 658–677.
40. Delhagen, E.; McKearnan, S.; Nicholas, S.; Hamilton, B.; Neme, C.; Wang, E. *Scaling up Building Energy Retrofitting in US Cities—A Resource Guide for Local Leaders*; Living Cities: Washington, DC, USA; Institute for Sustainable Communities: Montpelier, VT, USA, 2009.
41. United Nations. *A New Global Partnership: Eradicate Poverty and Transform Economies through Sustainable Development: The Report of the High-Level Panel of Eminent Persons on the Post-2015 Development Agenda*; United Nations: New York, NY, USA, 2013.
42. Newman, P.; Beatley, T.; Boyer, H. *Resilient Cities: Responding to Peak Oil and Climate Change*; Island Press: Washington, DC, USA, 2009.
43. Beatley, T. *Green Urbanism: Learning From European Cities*; Island Press: Washington, DC, USA, 2012.
44. Beatley, T.; Newman, P. *Green Urbanism Down Under: Learning from Sustainable Communities in Australia*; Island Press: Washington, DC, USA, 2012.
45. C40 Cities. Available online: http://www.c40.org/ (accessed on 17 October 2016).
46. ICLEI. Low Carbon Cities. Available online: http://www.iclei.org/activities/agendas/low-carbon-city.html (accessed on 17 October 2016).
47. International Organization for Standardization (ISO). *Sustainable Development of Communities—Indicators for City Services and Quality of Life*; ISO: Geneva, Switzerland, 2014.
48. International Organization for Standardization (ISO). *International Standard Sustainable Development in Communities—Management System for Sustainable Development*; ISO: Geneva, Switzerland, 2016.
49. Rauland, V. *Decarbonising Cities: Certifying Carbon Reduction in Urban Development*; Curtin University: Perth, Australia, 2013.
50. Droege, P. *100% Renewable Energy—And Beyond—For Cities*; World Future Council: Hamburg, Germany, 2010.
51. Girardet, H. *Cities People Planet: Liveable Cities for a Sustainable World*; Wiley-Academy: Chichester, UK, 2004.
52. Rockström, J. A safe operating space for humanity. *Nature* **2009**, *461*, 472–475. [CrossRef] [PubMed]
53. Rockström, J.; Steffen, W.L.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.; et al. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecol. Soc.* **2009**, *14*, 32.
54. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*. [CrossRef] [PubMed]
55. Birkeland, J. *Positive Development: From Vicious Circles to Virtuous Cycles Through Built Environment Design*; Earthscan: London, UK, 2008.
56. Cole, R.J. Net-zero and net-positive design: A question of value. *Build. Res. Inf.* **2015**, *43*, 1–6. [CrossRef]
57. Rauland, V.; Newman, P. *Decarbonising Cities: Mainstreaming Low Carbon Urban Development*; Springer: Cham, Switzerland, 2015.
58. Girardet, H. Regenerative Cities. Available online: www.worldfuturecouncil.org (accessed on 17 October 2016).
59. Newman, P.; Jennings, I. *Cities as Sustainable Ecosystems: Principles and Practices*; Island Press: Washington, DC, USA, 2008.
60. Baccini, P. A city's metabolism: Towards the sustainable development of urban systems. *J. Urban Technol.* **1997**, *4*, 27–39. [CrossRef]
61. Baccini, P.; Brunner, P.H. *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*; MIT Press: Cambridge, MA, USA, 2012.

62. Newman, P. Sustainability and cities: Extending the metabolism model. *Landsc. Urban Plan.* **1999**, *44*, 219–226. [CrossRef]
63. Kennedy, C.; Cuddihy, J.; Engel-yan, J. The Changing Metabolism of Cities. *J. Ind. Ecol.* **2007**, *11*, 43–59. [CrossRef]
64. Broto, V.C.; Allen, A.; Rapoport, E. Interdisciplinary Perspectives on Urban Metabolism. *J. Ind. Ecol.* **2012**, *16*, 851–861. [CrossRef]
65. Wolman, A. The Metabolism of Cities. *Sci Am.* **1965**, *213*, 179–190. [CrossRef] [PubMed]
66. Newton, P.W. Horizon 3 planning: Meshing liveability with sustainability. *Environ. Plan. B Plan. Des.* **2007**, *34*, 571–575. [CrossRef]
67. Newman, P.; Mason, A.; Gardner, H. *Regenerative Cities*; ARUP and Curtin University: Perth, Australia, 2012.
68. BioRegional. *BedZED: Toolkit Part II A Practical Guide to Producing Affordable*; BioRegional: London, UK, 2009.
69. Woo, F. *Regenerative Urban Development*; World Future Council: Hamburg, Germany, 2014.
70. Lyle, J.T. *Regenerative Design for Sustainable Development*; Wiley: New York, NY, USA, 1996.
71. Du Plessis, C. Towards a regenerative paradigm for the built environment. *Build. Res. Inf.* **2012**, *40*, 7–22. [CrossRef]
72. Hes, D.; du Plessis, C. *Designing for Hope: Pathways to Regenerative Sustainability*; Taylor & Francis: Boca Raton, FL, USA, 2014.
73. De Jong, M.; Joss, S.; Schraven, D.; Zhan, C.; Weijnen, M. Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *J. Clean. Prod.* **2015**, *109*, 25–38. [CrossRef]
74. Joss, S. Eco-cities and Sustainable Urbanism. In *International Encyclopedia of the Social and Behavioral Sciences*, 2nd ed.; Wright, J., Ed.; Elsevier: Oxford, UK, 2015; Volume 6, pp. 829–837.
75. Kennedy, C.; Pincetl, S.; Bunje, P. The study of urban metabolism and its applications to urban planning and design. *Environ. Pollut.* **2011**, *159*, 1965–1973. [CrossRef] [PubMed]
76. Gandy, M. Rethinking urban metabolism: Water, space and the modern city. *City* **2004**, *8*, 363–379. [CrossRef]
77. Daly, H. The Steady-State Economy. In *Sustainable Urban Development Reader*; Wheeler, S.M., Beatley, T., Eds.; Taylor & Francis: New York, NY, USA, 2014; pp. 47–52.
78. Greenhouse Gas Protocol. Available online: http://www.ghgprotocol.org/ (accessed on 17 October 2016).
79. Newton, P. Beyond Greenfields and Brownfields: The Challenge of Regenerating Australia's Greyfield Suburbs. *Built Environ.* **2010**, *36*, 1–53. [CrossRef]
80. Newton, P.; Newman, P. The geography of solar photovoltaics (PV) and a new low carbon urban transition theory. *Sustainablity* **2013**, *5*, 2537–2556. [CrossRef]
81. Newton, P. Regeneration: Tackling the Greyfields. In *Creating Sustainable Precincts*; Perinotto, T., Ed.; The Fifth Estate: Sydney, Australia, 2014; pp. 106–111. Available online: http://evacoust.startlogic.com/TimeToyota.pdf (accessed on 17 October 2016).
82. Reidy, C.; Lederwasch, A.; Ison, N. *Defining Zero Emission Buildings*; Australian Sustainable Built Environment Council: Surry Hills, Australia, 2011.
83. Zero Carbon Hub. *Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes*; Zero Carbon Hub: London, UK, 2009.
84. Nelson, A.C.; Moore, T. Assessing urban growth management. The case of Portland, Oregon, the USA's largest urban growth boundary. *Land Use Policy* **1993**, *10*, 293–302. [CrossRef]
85. Hyde, R.; Rajapaksha, U.; Rajapaksha, I.; Riain, M.O.; Silva, F. A Design Framework for Achieving Net Zero Energy Commercial Buildings. In Proceedings of the 46th Annual Conference of the Architectural Science Association (ASA/ANZAScA), Griffith University, Gold Coast, Australia, 14–16 November 2012.
86. Stulz, R.; Lütolf, T. What Would Be the Realities of Implementing the 2000 Watt Society in Our Communities? Available online: http://www.energy-cities.eu/IMG/pdf/imagine_session1_stulz_en.pdf (accessed on 17 October 2016).
87. Beatley, T. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into our Lives. *William Mary Environ. Law Policy Rev.* **2009**, *34*, 209–238.
88. Davison, A.; Kirkpatrick, J. Re-inventing the Urban Forest: The Rise of Arboriculture in Australia. *Urban Policy Res.* **2013**, *32*, 145–162. [CrossRef]
89. Bunning, J.; Beattie, C.; Rauland, V.; Newman, P. Low-Carbon Sustainable Precincts: An Australian Perspective. *Sustainability* **2013**, *5*, 2305–2326. [CrossRef]

90. UK Green Building Council; Zero Carbon Hub. *Sustainable Community Infrastructure*; UK Green Building Council: London, UK, 2010.
91. Green Building Council of Australia. A Decade of Green Building. Available online: https://www.gbca.org.au/uploads/170/34474/A_decade_of_green_building_.pdf (accessed on 17 October 2016).
92. Kost, C.; Schlegl, T.; Thomsen, J.; Nold, S.; Mayer, J. *Levelized Cost of Electricity—Renewable Energies*; Fraunhofer ISE: Freiburg, Germany, 2012.
93. GIZ; ICLEI. *Operationalizing the Urban NEXUS: Towards Resource Efficient and Integrated Cities and Metripolitan Regions*; GIZ: Eschborn, Germany; ICLEI: Bonn, Germany, 2014.
94. ClimateWorks Australia. Tracking Progress Towards a Low Carbon Economy. Available online: http://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_tracking_progress_discussion_paper_nov2012.pdf (accessed on 17 October 2016).
95. Office of Energy. *Renewable Energy Handbook 2010*; Office of Energy: Perth, Australia, 2010.
96. Droege, P. *100% Renewable: Energy Autonomy in Action*; Routledge: London, UK, 2012.
97. Newton, P.W.; Tucker, S.N. Pathways to decarbonizing the housing sector: A scenario analysis. *Build. Res. Inf.* **2011**, *39*, 34–50. [CrossRef]
98. Acosta, M.S.; Mastrandrea, C.; Lima, J.T. Wood Technologies and Uses of Eucalyptus wood from Fast Grown Plantation for Solid Products. In Proceedings of the 51st International Convention of Society of Wood Science and Technology, Concepción, Chile, 10–12 November 2008.
99. Thompson, H.; Waugh, A. *A Process Revealed*; FUEL Publishing: London, UK, 2009.
100. Beatley, T.; Newman, P. Biophilic cities are sustainable, resilient cities. *Sustainablity* **2013**, *5*, 3328–3345. [CrossRef]
101. Kellert, S.R.; Heerwagen, J.; Mador, M. *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*; Wiley: New York, NY, USA, 2011.
102. Beatley, T. *Biophilic Cities: Integrating Nature Into Urban Design and Planning*; Island Press: Washington, DC, USA, 2011.
103. Girardet, H. Creating a Sustainable Adelaide. Available online: http://www.thinkers.sa.gov.au/lib/pdf/Girardet_Report.pdf (accessed on 17 October 2016).
104. Pincetl, S.; Bunje, P.; Holmes, T. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landsc. Urban Plan.* **2012**, *107*, 193–202. [CrossRef]
105. Newton, P.; Newman, P. *Low Carbon Green Growth: Tracking Progress in Australia's Built Environment Industry Towards a Green Economy*; Swinburne University of Technology: Melbourne, Australia; Curtin University: Bentley, Australia; The Green Building Council of Australia: Sydney, Australia, 2013.
106. Green, J.; Newman, P. Citizen Utilities: The Emerging Power Paradigm. A Case Study in Perth, Australia. *Energy Policy* **2016**, in press.
107. Thomson, G.; Newman, P. Urban Fabric and Urban Footprint. *Resour. Conserv. Recycl.* **2017**, in press.
108. UC Davis. *UC Davis West Village, Energy Initiative Annual Report 2013–2014*; UC Davis: Davis, CA, USA, 2014.
109. English Partnerships. Carbon Challenge: Standard Brief. Department of Communities and Local Government: London, UK, 2007.
110. Scheurer, J.; Newman, P. *Vauban: A European Model Bridging the Green and Brown Agendas*. Available online: www.unhabitat.org/grhs/2009 (accessed on 17 October 2016).
111. Newman, P. Biophilic urbanism: A case study on Singapore. *Aust. Plan.* **2014**, *51*, 47–65. [CrossRef]
112. Du Plessis, C.; Brandon, P. An ecological worldview as basis for a regenerative sustainability paradigm for the built environment. *J. Clean. Prod.* **2014**, *109*, 53–62. [CrossRef]
113. Cole, R.J. Transitioning from green to regenerative design. *Build. Res. Inf.* **2012**, *40*, 39–53. [CrossRef]

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Urban fabrics and urban metabolism – from sustainable to regenerative cities

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ABSTRACT

This paper uses urban metabolism as a way to understand the sustainability of cities. It suggests that the city organism can reduce its metabolic footprint (resource inputs and waste outputs) whilst improving its livability. Like organisms, different cities have different metabolisms. This paper demonstrates that different parts of a city (walking, transit and automobile urban fabrics) also have different urban metabolisms. A detailed case study from the city of Perth, Australia, is used to demonstrate metabolic variations in different parts of the city. Understanding urban metabolism and the processes that drive it is the key to transitioning from ecologically extractive to sustainable cities. Through targeted improvements it is even possible for some elements of the city to become regenerative so that they restore parts of the degraded urban environment thus reversing damage to the biosphere.

1. Introduction

1.1. Aims and objectives

The objectives of this paper are twofold. The first objective is to demonstrate how different urban form and infrastructure (urban fabrics) play an important role in determining urban resource flows i.e., different urban fabrics have different urban metabolisms. While most early studies on urban metabolism tended to focus upon the whole city or city regions e.g., (Baccini, 1997; Kennedy et al., 2011; Newman et al., 1996; Warren-Rhodes and Koenig, 2001), the case study presented in this paper describes differences that have been observed in different parts of Perth, Australia – a medium sized city of two million people. We suggest a causal link between reductions of urban metabolism and the underlying urban fabric.

The second objective aims to apply this knowledge in a practical manner to help deliver a regenerative city. In this sense urban metabolism may be used as a design tool by city makers to optimize the efficiency of the underlying urban fabric, calibrate development to maximize regenerative design outcomes, and catalyze urban sustainability transitions. This is necessary because the present generation of the human population is facing unprecedented global grand challenges including rapid population growth, increasing consumption patterns, resource scarcity, climate change, biodiversity loss and social inequity (Bina et al., 2016) and cities can do more than just reduce their impact but can regenerate past impacts.

Recent work on the planetary boundaries framework (Rockström et al., 2009; Steffen et al., 2011, 2015) suggests that a failure to shift the trajectory of current environmental impact presents an existential risk to *homo sapiens*. In their assessment of planetary boundaries Steffen et al. (2015) suggest that policy, governance and business approaches to the two core planetary boundaries – climate change and biosphere integrity – need to change.

There have been numerous papers on the need to find a 'safe operating space' for human activity that lies within planetary boundaries (Costanza, 2008; Du Plessis and Brandon, 2014; Rockström, 2009; Rockström et al., 2009; Seitzinger et al., 2012). However, the justification to rapidly respond to these grand challenges has recently moved beyond an ethical reason to a political one. The ratification of two major international policies by most member states of the United Nations – the Sustainable Development Goals (SDGs) (United Nations General Assembly, 2015) and the Paris Agreement (United Nations, 2015a) put in place a global political mandate for change. While both of these policies outline clear targets or objectives to direct humanity away from a potential existential crisis caused by present unsustainable human activity, they do not offer the mechanisms for achieving the required shift.

This paper offers some potential solutions. It does this by demonstrating how the underlying urban fabric heavily influences urban metabolism. By better understanding this relationship, science can help inform urban decision-makers to deliver not just

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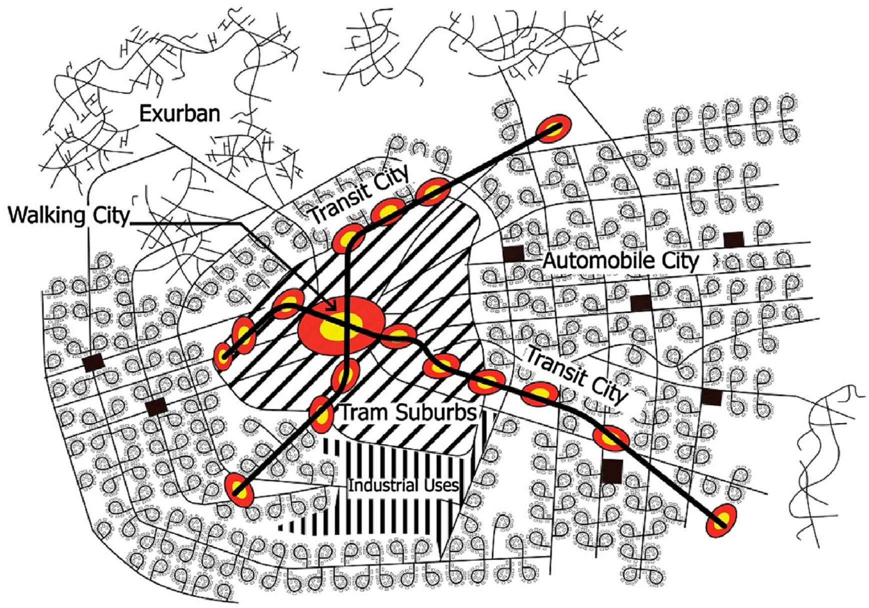

Fig. 1. Automobile urban fabric, transit urban fabric and walking urban fabric, a mixture of three urban fabric types of a typical city.
Source: Newman and Kenworthy, 2015

sustainable but regenerative built form that is capable of driving local and regional transitions that can seriously address planetary boundaries. If this can be done at scale, then a global network of regenerative cities has the potential to play a major role in this global challenge.

Cities present an opportunity because the human population is rapidly urbanizing. In 2014, 54% of the world's population were residing in cities and by 2050 this figure is expected to be close to 70% concentrating sustainable development challenges within cities" (United Nations Department of Economic and Social Affairs Population Division, 2014). Harnessing this wave of urbanization as a means for delivering sustainable human settlements could represent a major opportunity for reducing ecological footprint. Indeed the *New Urban Agenda* coming out of Habitat III in October 2016 calls for an urban paradigm shift that will "redress the way we plan, finance, develop, govern and manage cities and human settlements, recognizing sustainable urban and territorial development as essential to the achievement of sustainable development and prosperity for all". Actions to achieve this would include "integrated urban and territorial planning and design in order to optimize the spatial dimension of the urban form and to deliver the positive outcomes of urbanization" (United Nations, 2016, pp. 3–4). But to do so would require calibration and improvement of urban performance through ongoing urban metabolism assessment to ensure urban sustainability performance targets are met or exceeded so that cities can be a major force in reversing planetary boundary challenges.

Kennedy et al. (2011, p. 1968) describe the potential of the data rich urban metabolism for practical application to urban design and planning. Through the urban metabolism analysis presented in this paper we offer some conclusions that will be useful to urban planners to understand where the best leverage points may be to help provide infrastructure that best supports citizen efforts to reduce and then reverse the ecological footprint of cities.

The paper offers a brief overview of the historic origins of cities that have led to the widespread creation of unsustainable urban form, it describes our approach to urban metabolism and the use of regenerative design as an aspirational target for delivering the regenerative city, before presenting an urban metabolism analysis prepared on Perth. This is the first study we are aware of that has been developed to demonstrate the variations in urban metabolism across different urban fabrics within the same city and can be used to show the kind of dramatic changes that cities need to address.

1.2. Background

1.2.1. Historic origins of cities

Over the last 10,000 years since the advent of agriculture, *homo sapiens* transitioned from nomadic hunter-gatherer to farming settlements (Zvelebil, 2009). This transition marks a shift from living within an ecosystem to extraction from an external ecosystem to support human life. The agglomeration benefits for culture and trade increase with the size of the settlement (Florida, 2002; Glaeser, 2011; Rawnsley and Spiller, 2012). This condition has resulted in increasingly larger urban settlements. Modern cities have been generally designed as extractive engines drawing resources from natural systems, processing these resources to generate value, and producing wastes whose impacts are externalized. These input output transactions were likened to an organism by Wolman (1965); and this way of thinking has experienced a resurgence in popularity in recent years (e.g, Baccini and Brunner, 2012; e.g. Gandy, 2004; Girardet, 2010; Newman and Kenworthy, 1999). Just as organisms have metabolism, cities have a metabolism – an urban metabolism to maintain their structure, grow and respond to their environment and which can impact heavily on its local, regional and global environment. Not only do different cities have different metabolisms, different *parts* of the city also demonstrate considerable variations in urban metabolism. This paper will seek to quantify urban metabolism in these different city parts. This new understanding of how cities work can show how such cities may shift from being extractive to regenerative so they once again allow human society to live within local, regional and global ecosystem boundaries.

1.2.2. The nature of the problem

To reflect the central role of human activity upon the geology and ecology upon the current phase of earth history, it has been proposed and widely accepted that this geologic epoch be called "the Anthropocene" (Crutzen and Stoermer, 2000; Steffen et al., 2011). Material and substance flow analysis (Baccini and Brunner, 2012;

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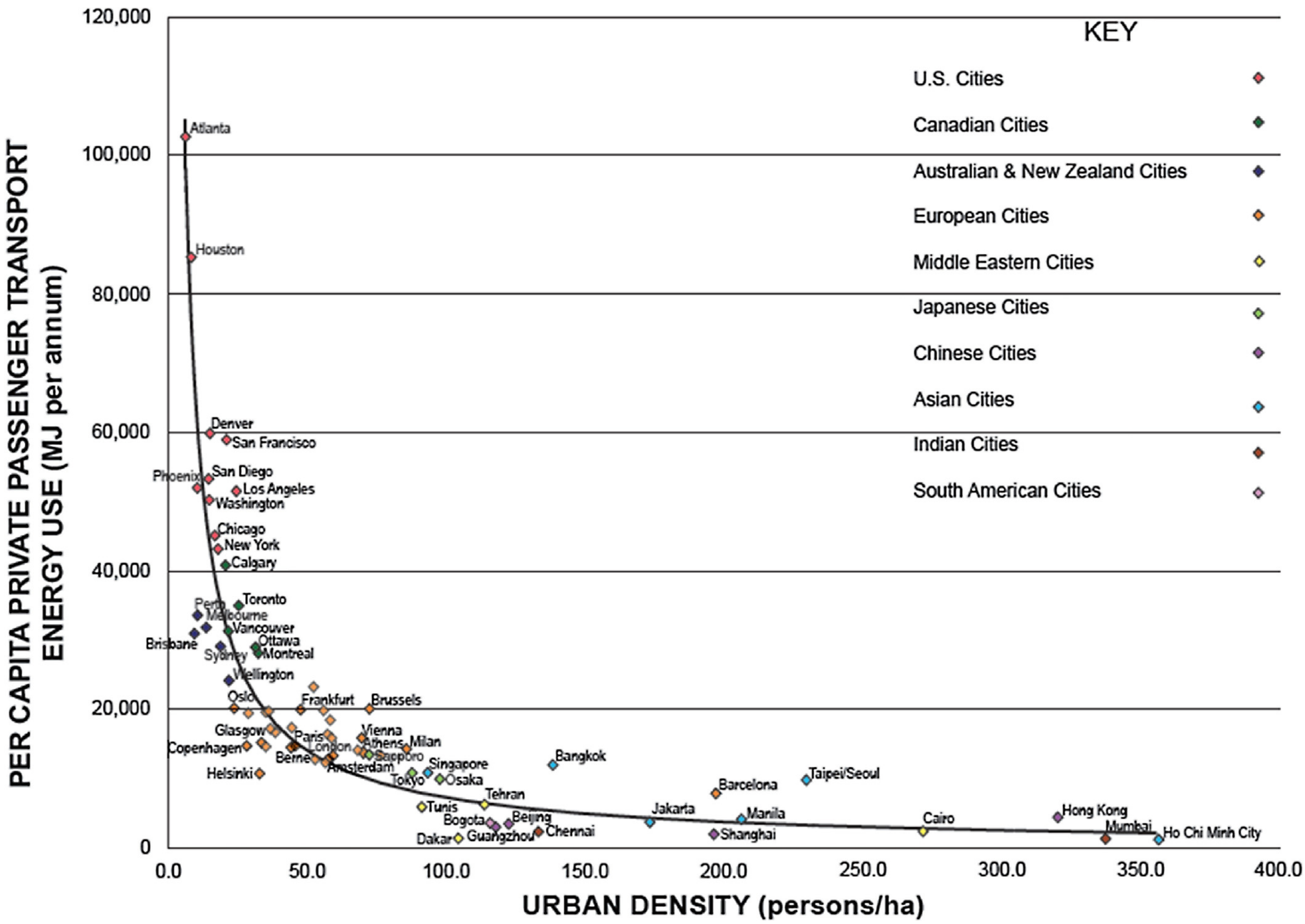

Fig. 2. Urban density and transport fuel in global cities, 1995.
Source: Newman and Kenworthy, 2015; Global Cities Database.

Kennedy et al., 2007; e.g. Newman and Kenworthy, 1999) demonstrate that human impact upon the ecosphere is ubiquitous, with the extraction and processing of resources from natural systems to generate economic value resulting in the accumulation of waste materials and substances in the atmosphere, biosphere and hydrosphere faster than they can be replenished or processed (Global Footprint Network, 2016; Wackernagel and Rees, 1998).

In 2015 the 'ecological overshoot' was estimated to be '54% above the planet's biocapacity' meaning we need 1.5 planets to live sustainably (Global Footprint Network, 2016). Quantifying anthropogenic environmental impact has been given a more detailed scientific basis by Rockström (2009) and Steffen et al. (2015) through planetary boundary analysis.

2. Regenerative design and urban fabrics

2.1. Regenerative design

The degeneration of the ecosphere witnessed in the Anthropocene is an unconscious outcome of human system design. Is it possible then, to use our emerging knowledge of urban metabolism, to consciously design systems that support human needs while also regenerating the ecosphere?

It is. The concept of regenerative design has been applied to landscape architecture for a quarter of a century. Most famously by John Lyle who describes the process as "*replacing the present linear system of throughput flows with cyclical flows at sources, consumption centers and sinks...(It) has to do with rebirth of life itself, thus with hope for the future*" (Lyle, 1999, pp. 11–12). It is possible to apply these principles to entire human settlements such that the Anthropocene becomes resilient and sustainable.

For millennia humans were agrarian or nomadic but now rapid urbanization and rapid population growth are concentrating human activity into cities. This is important as we will demonstrate in this paper that urban form and infrastructure play an important role in determining urban resource flows (cf. Newman and Kenworthy, 2015, 1999), so redesign of urban areas can help facilitate sustainability by optimizing resource flows and developing circular metabolisms (GIZ and ICLEI, 2014).

Redesigning urban areas as "regenerative cities" builds upon the work of landscape architects such as Lyle (1996) but applies the concept to the whole urban system. This paper will use recent research to discuss the various aspects of the ecological-infrastructural system of cities as they relate to urban metabolism. By recognizing where opportunities lie and where limitations exist it becomes possible to understand how urban systems may be optimized whilst continuing the historic role of cities as the generator of economic and social opportunities for a growing urban population.

The notion of the Regenerative City was outlined in 2010 by the World Future Council as a city that regenerates its ecological footprint not just minimizes it (Girardet, 2010). Girardet (2015) defines a truly regenerative city as one that exhibits the following characteristics:

- An environmentally enhancing, restorative relationship between the cities and the natural systems they depend on;
- renewable energy systems; and
- new lifestyle choices and economic opportunities which will encourage people to participate in this transformation process.

The opportunity for regenerative cities applies equally to new or retrofit urban areas but the greatest opportunities lie in the vast urban areas yet to be built. The analysis below helps give substance to these possibilities by relating how urban growth can help or hinder in this regenerative process by focusing on particular urban fabrics.

The application of regenerative design to cities may represent the greatest opportunity for a rapid planetary sustainability transition. The vast potential of cities may present an alternative to geoengineering to avert climate change as described by Fink (2013) and a regenerative overlay to this can bring additional benefits to the planet's burgeoning cities (Rauland and Thomson, 2015).

Defining the vision for a new urban agenda as attempting to develop regenerative cities creates a paradigm-shifting goal. Such a goal will require urban metabolism analysis to seek opportunities for the continual optimization of urban performance. The Global Footprint Network (2016) assess that the world went into ecological overshoot in the 1970s and since this time the world's population has doubled. Global population projections suggest growth of another 3–4 billion people by the end of this century (United Nations, 2015b). Rather than seeking a net balance of zero to maintain equilibrium in order to 'meet the needs of future generations', the goal must now be to use this growth to regenerate the depleted ecosphere and to build up stocks of natural capital wherever possible through regenerative design applied to human settlements and systems.

2.2. Urban metabolism studies in Australia

Australian cities have very high ecological footprints around three times the global average (Turner and Foran, 2008). Several urban metabolism studies have been prepared as part of the State of the Environment Reporting for the Australian Government,[1] the first of these reports in 1996 included a comprehensive urban metabolism assessment for Sydney (see: Newman et al., 1996).

Subsequent reports track progress against a range of indicators and the most recent urban metabolism assessment of the major capital cities in the 2016 State of the Environment Report (Jackson et al., 2016) demonstrates that per capita trends for energy, water and transport fuel are generally decreasing (see Table 1).

What is most striking is the significant increase in sustainability measures including a 67% increase in renewable energy, 27% increase in recycling, 17% decrease in car use per person and a modest increase in public transport patronage of around 2.5% after previous declines.

The variations in resources, wastes and livability across cities are significant, but recent studies have demonstrated that significant variations are also found between different parts of a city.

This paper seeks to relate how any city can target a simultaneous reduction in their footprint whilst improving their livability through a better understanding of different parts of the city. It uses the new theory of urban fabrics to explain the relationships and to suggest how a city can respond to urban metabolism through urban planning and transport planning, two of the most powerful tools available in urban development. Finally it will discuss how the concept can move beyond the sustainable cities vision to a regenerative cities perspective.

2.3. Urban fabrics

Having a perspective on how cities as a whole region or urban ecosystem function with a metabolism based process is useful for understanding how urban metabolism can be reduced. However, cities are made up of different structural parts which vary considerably in their resource input requirements and waste outputs (Newman and Kenworthy, 2015). Examining the fundamental causes of these differences enables us to go beyond bland policies to much more specific ones that are based upon true cause and effect within transport and town planning professional practice. This paper seeks to determine how three fundamental urban fabrics that are found in any city, can be related to their metabolism and hence how the theory can enable policy formulation to reduce footprints.

2.4. The theory of urban fabrics

The theory of urban fabrics is developed in Newman and Kenworthy (2015) to show how transportation systems create city form and function. The ideas are influenced by earlier work related to transportation and urban form (Muller, 2004; Newman and Kenworthy, 1999) but have been developed further[2] and are now being used in some Scandinavian urban planning and research (Söderström et al., 2015).

2.5. History of urban fabrics

Cities are shaped by many historical and geographical features, but at any stage in a city's history the patterns of land use can be changed by altering their transportation priorities, this topic is given detailed treatment in Newman and Kenworthy (2015), and are summarized in the following paragraphs. Marchetti (1994) and Zahavi and Talvitie (1980) demonstrated a universal travel time budget averaging around 1 h/person/day. Kenworthy and Laube (2001) found the *Marchetti constant* applied to every city in the Global Cities Database, as well as in data on UK cities for the last 600 years (Standing Advisory Committee on Transport 1994). Further analysis of 2005-6 complete travel data by mode (walking, cycling, public transportation, cars and motorcycles) on forty-one global cities using average modal travel speeds, showed that the mean and median travel time per day was 66 and 65 min respectively (see Kenworthy (2014) for the travel data used).

The Marchetti constant therefore helps us to see how cities are shaped (Newman and Kenworthy, 1999). Cities grow to being about 'one hour wide' based on the speed with which people can move in them. If they go beyond this they start to be dysfunctional and therefore begin to change infrastructure and land use to adapt again to this fundamental principle (Van Wee et al., 2006).

Below we will show how different urban fabrics have developed from different transport types and how they should be recognized, respected and regenerated and can indeed help us achieve a reduced urban metabolism.

[1] Reports have been prepared every 5 years since 1996, all Australian State of the Environment reports may be downloaded from: https://www.environment.gov.au/science/soe.

[2] For more detail and development of some of these ideas and their application to practice see: urbanfabrics.fi.

Table 1
Trends in urban metabolism in Australia, 201–15. Author's calculations, data.

Metabolism Factor	Trend in Australia, 2011–2015
Energy	Household energy consumption per person dropped 7%; Renewable energy by households increased 67%. Household energy intensity decreased 20%, Manufacturing energy intensity increased 3%, Commercial and Services decreased 2%. Commercial building energy intensity decreased by 0.3%
Water	Water consumption per capita decreased 2%, with large variations across cities.
Transport	Car use per person declined 17%; Public transport increased 2.5% per annum.
Land Take	Urban footprint increased but per capita land take decreased
Solid Waste	Waste produced increased 9.1% but waste recycling increased by 27% so overall there was a 15% decrease in waste to landfill (60% of waste now recycled). Household waste 29%, high recycling; Construction waste 29%, least recycling; Manufactured waste 19%, most recycling.

Source: State of Environment Report 2011 (Hatton et al., 2011) and State of the Environment Report 2016 (Jackson et al., 2016).

2.6. Characterizing three urban fabrics

The theory of urban fabrics was developed by Newman, Kenworthy and Kosonen (2015) to help planners see that there are three main city types, not one (automobile fabric) as suggested by modernist city planning since the 1940′s. The theory enables planners to create strategies for managing the different fabrics and especially how to see that some urban fabrics have inherently more sustainable properties that need to be optimized and extended to other parts of the city.

There are three city types from history that form the basis of urban fabric theory: walking cities, transit cities and automobile cities. Most cities today have a mixture of all three urban fabrics. The fundamental problem with 20th century town planning has been the belief that there is only one type of city: the automobile city. As will be shown below it is the automobile city that is the most resource consumptive type of urban fabric. A resurgence in the other urban fabrics has begun to reduce automobile dependence as a city planning paradigm and thus focuses our ability to reduce and eventually regenerate urban footprints.

A conceptual diagram of the three city fabric types is set out in Fig. 1 and are outlined in their historical development based on the above principles.

Walking Cities are the oldest typology as walking, or at best animal-powered transportation, was the only form of transport available to enable people to move across cities. Dense, mixed-use areas generally over 100 persons per hectare characterize walking urban fabric. The slow transport speeds averaging around 3–4 km/h limited most cities to three or four kilometers diameter with the most intensively developed areas usually around a central focal point such as the main city square or market.

Walking cities were the major urban form until the 1850s and many modern cities are built around a nucleus of an older walking city, but they struggle to retain the walking urban fabric due to the competing automobile city fabric which now overlaps it (Newman and Kenworthy, 2015). Reacting to this competition many modern cities are now attempting to reclaim the fine-grained street patterns associated with walkability (Gehl, 2011) but often don't have the tools to do so as modernist planning manuals rarely focus on pedestrian needs, however this is slowly changing for example the new NACTO manuals (National Association of City Transportation Officials) that emphasize the importance of the human experience.

Transit Cities from about 1850–1950 were based on trains (from 1850 the steam train began to link cities and then became the basis of train-based suburbs) followed by trams (from the 1890s) that extended the old walking city. Both could travel faster than walking – trams at around 10–20 km/h and trains at around 20–40 km/h.

Trams and trains supported corridor development where densities could be reduced to around 50 persons per ha yet walking fabric still remained around transit stops. Such urban fabric could now spread out forming the inner city transit urban fabric 10–20 km across (5–10 km radius with an average around 8 km) and with trains forming the outer city transit urban fabric 20–40 km (10–20 km radius) (Marchetti, 1994; Newman and Kenworthy, 2015).

More recently, fast trains have enabled the transit urban fabric to extend well beyond a 20 km radius (McIntosh et al., 2013) and where fast trains averaging 80 km/h are built across big cities a polycentric transit fabric emerges around major stations.

Automobile Cities from the 1950s onward were no longer constrained to fixed corridors. The flexibility and speed (average 50–80 km/h on uncongested roads) of the automobile allowed cities to spread well beyond a 20 km radius with some cities achieving an 80 km diameter (40 km radius) in all directions, and at low density with zoning separating uses, to further disaggregate urban intensity.

Low urban intensity reduces the potential for cost effective transit and as a result sprawling suburbs became the basis of automobile dependence (Newman and Kenworthy, 1989) and automobility (Urry, 2004). Cities in the new world from around 1950 have used their growth to build automobile dependent suburbs as their main urban fabric (Newman and Kenworthy, 2015).

There is a need to see that there are real issues associated with the dominance of automobile urban fabric, especially where it extinguishes the best features of walking and transit fabric and creates a much bigger urban metabolism. If the data on planetary boundaries is assessed in detail (see Steffen et al., 2015) it is obvious that a dramatic increase in impact occurred after 1950 in most of the factors considered to be causal; the automobile city fabric has been the main urban development focus in this post 1950 period.

3. Metabolism and urban fabric

Newman and Kenworthy (2015) have shown that there is a significant set of differences between these three kinds of urban fabrics in their areas, elements and qualities that can form the basis of statutory and strategic town planning. Each fabric can also be shown to have different metabolism qualities.

3.1. Energy

The term automobile dependence was developed in the 1980′s to express how cities were now being built around the car; this was dramatized using a graph of density versus transport fuel in 32 cities (Newman and Kenworthy, 1989). There are now around 100 cities in the database and the same graph is evident showing how transport energy exponentially reduces with increases in density (See Fig. 2). As we explain further in Section 3.3 low density automobile urban fabric has other implications on energy, both embodied and operational.

Table 2
Resource input variations between urban form types (see Appendix A for table assumptions).

INPUT (Per Person Per Year)	Automobile Urban Fabric	Transit Urban Fabric	Walking Urban Fabric
Resources			
Fuel in Megajoules (MJ)[1]	50 000	35 000	20 000
Power in Megajoules (MJ) [2]	9 240	9 240	9 240
Gas in Megajoules (MJ) [2]	4 900	2 940	2 940
Total Energy in Gigajoules (GJ)[2]	64.14	47.18	32.18
Water in Kilolitres (Kl)[2]	70	42	35
Food in Kilograms (kg)[3]	451	451	451
Land in Metres Squared (m^2)[4]	547	214	133
Urban Footprint in Hectares (ha)[5]	2.29	1.97	1.78
Basic Raw Materials (BRM) for New Building Types Per Person[6]			
BRM 1) Sand in Tonnes (T)	111	73	57
BRM 2) Limestone in Tonnes (T)	67	44	34
BRM 3) Clay in Tonnes (T)	44	29	23
BRM 4) Rock in Tonnes (T)	66	43	33
Total BRM in Tonnes (T)	288	189	147

Table 3
Waste output variations between urban form types (see Appendix B for table assumptions).

OUTPUT (Per Person Per Year)	Automobile Urban Fabric	Transit Urban Fabric	Walking Urban Fabric
Waste			
Greenhouse Gas (Fuel, Power & Gas) in Tonnes (T)[1]	8.01	5.89	4.03
Waste Heat in Gigajoules (GJ)[2]	64.14	47.18	32.18
Sewage (incl. storm water) in Kilolitres (KL)[3]	80	80	80
Construction & Demolition (C&D) Waste in Tonnes (T)[4]	0.96	0.57	0.38
Household Waste in Tonnes (T)[5]	0.63	0.56	0.49

From this data three groupings of cities emerge: the American and Australian cities which were the most car dependent, European cities which are in the middle and use fuel at about a third of the first group; and Asian and Latin American cities with the least car dependence and least fuel use.

As each city has a mixture of three urban fabrics what this suggests is that the first group are dominated by automobile city urban fabric, the second group by transit city urban fabric and the third by walking city urban fabric.

Although this work has been broadly discussed in the literature some criticisms such as Höjer and Mattsson (2000) rightly identify that there are additional factors required if the causal relationship between density and car use is to hold – it is possible to deliver high density automobile fabric if the conditions for transit or walking are not provided, however, the results are often suboptimal with regard to sustainability and livability (Thomson et al., 2016). Indeed it is precisely the opportunities that population density offers to meet thresholds to support more sustainable infrastructure (e.g., transit ridership, catchments for service provision, housing density to allow short infrastructure lengths to support distributed utilities etc.) that enable higher density urban fabric to be more sustainable. Höjer and Mattsson's (2000) observation of the need for these additional factors is echoed by others such as Hall (2013) who observes that the more holistic and integrated the approach to urban planning the greater the opportunity for a good outcome.

3.2. Basic raw materials

Basic raw materials (BRM) are the sand, clay and stone that form the foundation for building construction. They literally are built into the fabric of a city.

Basic raw material studies are rare (e.g. Hendriks and Petersen, 2000). Recent data collected by the Curtin Sustainability Policy Institute (CUSP) and Arup (Gardner and Newman, 2013) on Perth enables us to see the significant variations that can be observed in urban metabolism across different parts of the city. The normal quantities of material that went into construction in three parts of the city were examined: central/inner which is very similar to the old walking city; middle suburbs which are similar to the transit city; and outer/fringe suburbs that are the automobile city.

The variations across the city can be demonstrated graphically in Fig. 3 and the data are shown in Table 2 below. The variations are huge (due to the amount of fabric required in construction) and are even greater when the factor of technologically innovative construction techniques is applied. In Fig. 3, the area of the circles represents the proportional volume of basic raw materials required for new building types per person. In the Perth case study the BAU automobile urban fabric requires about almost twice as much basic raw materials (288 t/person) compared to walking urban fabric (147 t/person).

3.3. Metabolism of the three urban fabrics

The full urban metabolism of the three urban fabric samples in Perth is set out in Table 2, which shows resource input variations between urban form types, and Table 3, which shows waste output variations between urban form types, (Gardner and Newman, 2013). These data show the variations in energy, water, land, food, and basic raw materials in the three areas of the city as well as the wastes produced from this. There are very different metabolism flows in the three different fabrics. Inputs such are significantly reduced in the denser walking and transit urban fabric compared to automobile fabric for example:

- Transport fuel per capita usage is more than halved in walking urban fabric compared to automobile urban fabric,
- Water use is significantly less – this is largely a function of not having to irrigate large garden areas in Perth's hot and dry summers
- Land consumption is over 3.5 times less per capita substantially reducing urban encroachment upon surrounding agricultural land and valuable ecological areas (South Western Australia where Perth is located is a global biodiversity hotspot)
- Basic raw materials are roughly half.

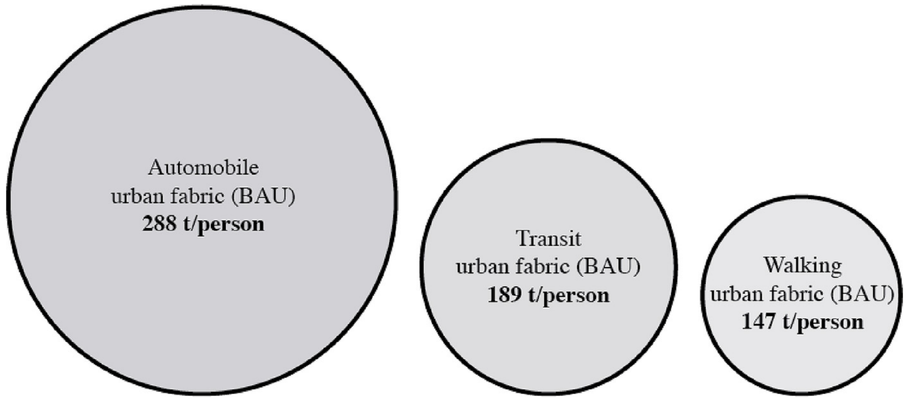

Fig. 3. Perth's basic raw material demand in terms of three urban fabrics.

Source: Gardner and Newman (2013)

The high basic raw material demand in BAU automobile urban fabric is due to both the additional material used in low density dwellings, for example the provision of a double garage but also the additional infrastructure required to service those plots both on the plot such as fill and driveways and off the plot such as additional length of infrastructure (e.g., roads or pipes) to service fewer dwellings for the same length (e.g., ten times the road length is required to service dwellings at 10 persons/ha (a common density for automobile fabrics) versus 100 person/ha (a common density for walking fabric).

Similar efficiencies in terms of outputs were seen in the denser walking and transit urban fabrics as shown in Table 3, particularly in terms of greenhouse gas (GHG) and waste heat; and construction and household waste.

The fundamental structural difference in the three urban fabrics dominates the differences between the three kinds of urban systems.

3.4. Optimizing urban fabrics

An additional layer of analysis captured in Table 4 (inputs) and Table 5 (outputs) demonstrates the considerable urban metabolism improvements if Technological and Construction Innovation (TCI) is introduced. The greatest gains being found in the reduction of basic raw materials (BRM) and construction and development (C&D) waste through the introduction of efficiency measures such as prefabricated building techniques. As Fig. 4 illustrates per capita requirements of walking urban fabric with TCI can be reduced to around 15 t/capita, almost twenty times as efficient as BAU automobile fabric (288 t/capita) in the same city (Gardner and Newman, 2013, p. 22).

4. Using urban fabric to reduce and regenerate urban metabolism

4.1. Town planning implications

Modernist urban planning is almost universally applied to cities and creates predominantly an automobile city set of fabric areas and fabric qualities, with their associated metabolism. Overcoming the dominance of this paradigm will be required to shift the current trajectory away from planetary boundary transgressions outlined by Steffen et al. (2011). More sustainable patterns of urbanization are also the subject of the United Nation's new urban agenda (2016).

This transition has begun to occur as the world is witnessing 'peak car' and a dramatic growth in transit and walking city fabric (Newman and Kenworthy, 2015). The new era appears to be shifting away from automobile urban fabric this is largely a function of economics. The walking city enables greater face-to-face interaction and this function has been recognized as increasingly significant for the growing economic functions associated with the knowledge economy, the creative economy and the services economy (Florida, 2002; Hall, 1999; Newton, 1991). This demands that we have a more coherent set of planning norms that can more easily accommodate a reduction in metabolism and improved livability associated with less automobile urban fabric. The town planning system is however going to need to change away from its statutory regulations on densities, car parking, mixed use and other key regulations that end up producing automobile urban fabric.

Wherever possible when planning for greenfield and brownfield urban areas automobile fabric should be minimized in favor of higher density transit and walking fabric so as to maximize resource efficiency for the more difficult urban components such as transport fuel, solid waste and building materials.

In addition new developments should seek infrastructure synergies at the energy, water and waste nexus (GIZ and ICLEI, 2014), such integration of utilities can optimize efficiency between each through an industrial ecology.

How then do we begin to practice town planning based on the theory of urban fabrics to advance the regenerative city concept? How do planners manage cities in this rapidly changing set of factors outlined above and where the 20th century modernist certainties about automobile urban fabric are now losing their appeal? Transitioning to sustainable urban forms that support an efficient circular urban metabolism will require a combination of the right urban fabric, infrastructure integration, and technology as outlined below.

4.2. Designing urban fabric to optimize urban metabolism

At any stage in a city's history the patterns of land use can be changed and the building opportunities can be taken to enable a regenerative approach.

If cities are shaped by their transportation systems which in turn have a major impact upon urban metabolism then the most important policy and planning direction to reduce the ecological footprint for the city is to restrict the development of automobile urban fabric in favor of transit and walking fabric. However, when redeveloping existing urban areas it will be necessary to carefully co-ordinate land use intensity concurrently with the imposition of new transportation systems over the urban fabric or else this mismatch will render them largely dysfunctional.

Creating new, or regenerating old, urban areas for sustainability requires first a consideration of the transport mode and building

Table 4
Resource input variations between urban form types due to technology and construction innovation (see Appendix A for table assumptions).

INPUT (Per Person Per Year)	Automobile Urban Fabric	Transit Urban Fabric	Walking Urban Fabric
Resources			
Fuel in Megajoules (MJ)[1]	50000	35000	20000
Power in Megajoules (MJ) [2]	4620	4620	4620
Gas in Megajoules (MJ) [2]	2450	2450	2450
Total Energy in Gigajoules (GJ)[2]	57.07	57.07	57.07
Water in Kilolitres (Kl)[2]	70	70	70
Food in Kilograms (kg)[3]	451	451	451
Land in Metres Squared (m^2)[4]	547	547	547
Urban Footprint in Hectares (ha)[5]	2.22	2.22	2.22
Basic Raw Materials (BRM) for New Building Types Per Person[6]			
BRM 1) Sand in Tonnes (T)	56	22	5.7
BRM 2) Limestone in Tonnes (T)	34	13.2	3.4
BRM 3) Clay in Tonnes (T)	22	8.7	2.3
BRM 4) Rock in Tonnes (T)	33	13	3.3
Total BRM in Tonnes (T)	145	57	15

Table 5
Waste output variations between urban form types due to technology and construction innovation (see Appendix B for table assumptions).

OUTPUT (Per Person Per Year)	Automobile Urban Fabric	Transit Urban Fabric	Walking Urban Fabric
Waste			
Greenhouse Gas (Fuel, Power & Gas) in Tonnes (T)[1]	7.13	4.98	2.95
Waste Heat in Gigajoules (GJ)[2]	57.07	39.90	23.65
Sewage (incl. storm water) in Kilolitres (KL)[3]	80	80	80
Construction & Demolition (C&D) Waste in Tonnes (T)[4]	0.29	0.22	0.18
Household Waste in Tonnes (T)[5]	0.63	0.56	0.49

typologies as these shape and define the urban fabric. An integrated approach offers greater opportunities for optimization of urban metabolism (Bunning et al., 2013; GIZ and ICLEI, 2014; Newman, 1999; Newton et al., 2012a).

An individual building can be optimized in terms of its metabolism however development needs to address at least the neighborhood or precinct scale to benefit from the additional opportunities for optimization offered by urban fabric and district utility and community services. Integrated precinct design has the potential to deliver transitional, decentralized, sustainable neighborhoods that cumulatively work toward delivering a regenerative (or at least more sustainable) city. The precinct is the ideal scale to trial innovative processes and technologies, successful prototypes can in turn inform urban policies or guide institutionalized financial incentives to ultimately mainstream the type of sustainable urbanism needed to reduce the ecological footprint of cities through the optimization of their urban metabolism.

The potential to create regenerative opportunities are significantly improved if a center or sub-center are the fundamental urban fabric that is being regenerated.

But particular strategies will still be needed for each component of urban footprint to collectively reduce its urban metabolism and work toward the delivery of a regenerative city. For example:

1. Energy can become regenerative if the fuel used to build and operate buildings and build and run transport, is renewable and greater than is actually being consumed by the city and can be used to help power and fuel the surrounding bioregion. This is likely highly energy efficient buildings and maximizing the available sites to create renewable energy from sun, wind and geothermal sources to power electric systems in buildings and transport as well as renewably-powered gas (Droege, 2008; Newman and Kenworthy, 2015),
2. Water can become regenerative if there is a big emphasis on water efficiency as well as collecting rain water and ground water, and recycling waste water and any excess is used to help regenerate aquifers and water bodies in the bioregion. This can be done with current technologies,
3. Biodiversity can become regenerative if it is built into every part of the urban fabric. Such biophilic urbanism approaches will need to enable green roofs, green walls and water sensitive design to create more habitat opportunities than existed prior (Beatley, 2009; Kellert et al., 2011; Newman, 2014; Newman and Matan, 2013). While this is not possible when urban development encroaches upon intact ecosystems, is can occur where urban development or expansion is into degraded agricultural or urban land. The greening of degraded urban land is a common theme in best practice urban regeneration for example where hardscape such as roads can be retrofitted or surface parking redeveloped and revegetated (Dunham-Jones and Williamson, 2008; Gehl and Rogers, 2013; Newton et al., 2012b). Bioregional needs in biodiversity can be assisted by the city with its different structural habitats and intensive human power (e.g., gardening and remnant urban habitat conservation),
4. Waste can be reduced to very small amounts but not regenerated unless very large amounts of energy are used due to thermodynamic limitations. However the return of carbon, phosphorus, nitrogen and other trace elements to surrounding soils in the bioregion can be done through recycling. Nutrient recycling can also provide rich growing mediums for urban agriculture (Newman and Jennings, 2008),
5. Materials can be significantly reduced if new technologies in building materials and construction techniques (such as modular off-site construction) can be used and recycling is optimized; however thermodynamic limits mean that productive material outputs can never be greater than material inputs unlike water and energy (Gardner and Newman, 2013).

The transformation of automobile fabric would appear to offer the greatest opportunities for sustainability improvements. This is good news for the cities of the USA, Australia and Canada with their high ecological footprint but also large areas of automobile fabric that may be regenerated. This is not to say there is no place for automobile fabric in cities as lower density automobile fabric does offer some advantages in particular:

- Greater privacy,
- Space for private gardens, including deep rooted planting for trees,
- Opportunities to incorporate ecosystem services such as biodiversity habitats, carbon sequestration and urban agriculture.

However, the aggregate benefits to a city, and its surrounding hinterland, are increased with the higher population density of transit and walking urban fabric because they offer:

- Viable catchments to meet business cases for improved public transport, distributed utilities, and greater service, job and retail density,
- Greater proximity to services, shops and jobs to reduce vehicle kilometers travelled and to support a vibrant walking and cycling community,
- Reduced embodied energy through lower material requirements e.g., shared walls, or shorter infrastructure lengths with much lower per capita cost,
- Reduced encroachment upon adjoining productive land or valuable ecosystems.

In addition to optimizing urban fabric, a regenerative design overlay can further drive down the ecological footprint of an area. An integrated approach to the provision of urban systems, and monitoring by an urban metabolism analysis, can offer city makers a powerful tool for further environmental gains and build a powerful narrative of positive change. Regenerative design considerations might include:

- Urban applications of industrial ecology, e.g. seeking synergies between, and productive uses for, solid and liquid waste which might be used to create biogas or fertilizer for urban food production,
- Technology and construction innovation to reduce material inputs and improve building performance e.g. prefabrication,
- Substitution of centralized (and usually hydrocarbon powered) energy, water and waste management systems with distributed infrastructure e.g. solar photovoltaics, trigeneration, water sensitive urban design, grey water, black water and nutrient harvesting,
- Seeking to understand and enhance the bioregional qualities of the subject urban area and reflecting this in the built form and public space, as opposed to the conventional practice of homogenous application of Modernist planning principles that have facilitated the global spread of automobile urban fabric.

5. Conclusions

Given that human populations are rapidly urbanizing, the city provides a great opportunity for (re)designing urban fabric to reduce ecological footprint.

The continued degradation of the ecosphere requires a city planning response that goes beyond the maintenance of material flow equilibrium, rather it warrants a regenerative design approach to actively build natural capital.

This paper demonstrates that city planning decisions are highly influential in delivering sustainable cities because different urban fabrics have different urban metabolisms. This is most convincingly demonstrated in the Perth case study that clearly shows the significant advantages in terms of resource efficiency that walking and transit fabric offer over automobile fabric in most resource and waste issues of urban metabolism. The Perth case study indicates that the basic raw material demand of walking fabric with a technology and construction innovation (e.g., application of regenerative design principles) has the potential to improve urban efficiencies almost twenty times over the conventional automobile urban fabric in the same city.

However, additional studies that compare the urban metabolism of different parts of other cities would be beneficial, as would governance mechanisms for implementation. Never the less the size of the differences in urban metabolism with urban fabric suggests that cities can indeed make major contributions to ecosphere functioning.

The (re)design of a city's urban fabric to reduce ecological footprint, has the potential to offer regional solutions that address several grand challenges of this generation, including

- climate change through reduced energy use,
- resource scarcity through more efficient material use,
- reduced rates of biodiversity loss and encroachment upon rural land through compact city footprints.

An Urban Metabolism approach supported by material flow analysis provides a powerful tool for monitoring cities but if different urban fabrics are made a focus of urban policy then the potential to create regenerative change becomes possible to imagine.

Collectively these opportunities can be taken to create a more regenerative city in terms of reversing its footprint from large to small to negative. However it cannot be done unless the economic and social generators from the site are simultaneously being achieved. The articulation of a regenerative city vision provides a clear and positive direction for the application of urban metabolism models, however, as with all visions its implementation will be dependent upon strong leadership and alignment of key actors, institutions and business models around this vision, particularly how the statutory planning system can include and assess low metabolism urban fabric in its system.

The combination of these potential urban metabolism improvements – optimizing urban fabric, overlaying regenerative design and introducing biophilic urbanism – would help mitigate climate change and biodiversity loss in urban areas – addressing the core planetary boundaries.

Appendix A. – INPUT ASSUMPTIONS

Assumptions–Table 2 (BAU)

1) Fuel per capita by suburb is provided by Chandra (2006) and the predictive model by Trubka et al. (2010) confirms the general variation from inner to outer.
2) Power Gas and Water were provided by Perth's utilities. The power variations with Urban Form are not clear so were left the same between types. Gas is used mostly for heating and was put at 60% for multiunit/smaller dwellings. Gas use will decrease in greyfields and brownfields due to reduced heating requirements for multi/smaller dwellings. The assumed reduction is 60% for both greyfields (transit fabric) and brownfields (walking fabric). Water varies with size of garden and is considered to reduce to 60% in small blocks and to 50% with multistorey buildings.
3) Food consumption per person per year is calculated from National Nutrition Survey Foods Eaten Australia 1995 Compiled by the Australian Bureau of Statistics and the Department of Health and Aged Care. Figures for select foods (meat including fish, cereal including cereal dishes, fruit and veg and milk products) added for 25–44 age categories. Foods separated into meat and non-meat categories. Total values attained then divided by 1000 to get daily kg intake. This is in turn multiplied by 365 to get yearly kg intake per person. The rounded figures are 70 kg per person per year intake of meat and 381 kg per person per

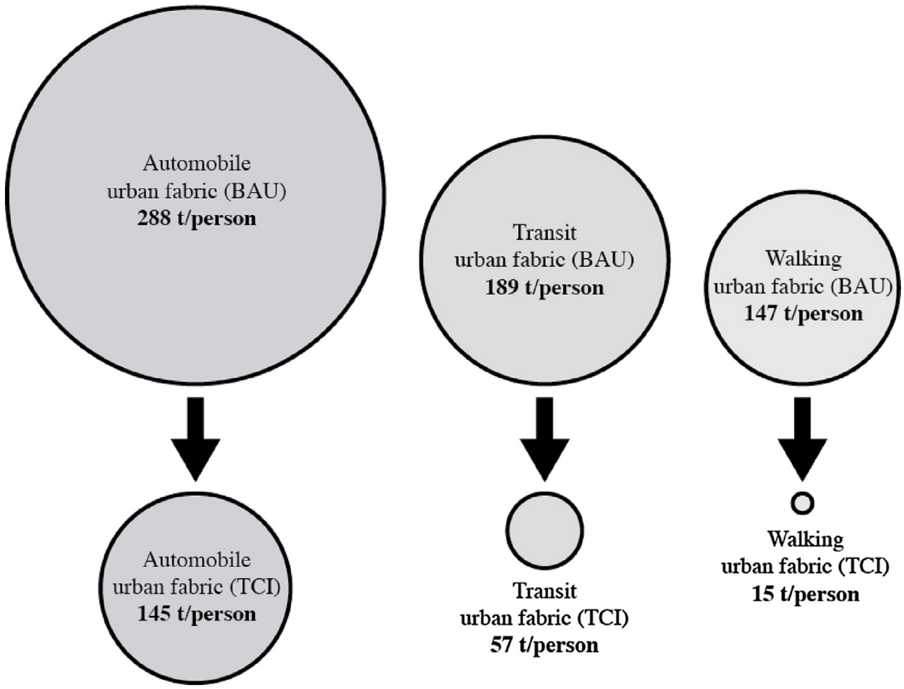

Fig. 4. Perth's basic raw material demand in terms of three urban fabrics plus Technology and Construction Innovation (TCI) Adapted from: Gardner and Newman (2013).

year intake of selected non meat products. This added together gives a total figure of 451 kg per person per year food intake. It was assumed that the amount of food consumed by the individual on a yearly basis would not change between urban form types.

4) Land Size was acquired from an Urban Development Institute of Australia (UDIA) Blog (See http://blog.udiawa.com.au/article/increased-appetite-for-smaller-lots (accessed May 7th)), which identified the median lot size as being 419 m^2 as of June 2012. This figure was multiplied by 3 to include other urban land like roads & commercial space associated with each dwelling. Lot sizes will become increasingly diminished for Middle and Inner redevelopment areas so lot sizes of 150 m^2 and 80 m^2 (x3) where chosen as suitably representative samples.
5) Urban footprint calculated using following factors obtained from (Wackernagel and Rees, 1998)
   a) Energy: 100 GJ produced per ha.
   b) Water: 233 KL produced per hectare.
   c) Land: ha of urban land as in 4 above.
   d) Food: Used Canadian per Person yearly requirement 1.30 ha/capita.

The urban footprint is then calculated by dividing the three urban forms energy, water, landscape and food input values by their equivalent factors and then adding the results together.

6) Original BRM Figures obtained from (CCI 2007), Table 10, adjusted due to occupancy levels of outer 2.3, middle 2.1 and inner 1.8. The data provided was for single detached dwellings and multi- unit dwellings. (60% less). The anticipated inner development is reduced to 40% due to smaller units. Thus assumed consumption of materials was 60% for Middle and 40% for inner.

Assumptions–Table 4 (TCI)

Assumptions as above except where noted below

1. Fuel per capita, water, food and land – No change from BAU as the forme of the city is not changed by TCI and hence no change from BAU.
2. Power and gas – assume use of off-site construction with reductions of 50% greenfields (automobile fabric), 60% greyfields (transit fabric) and 70% brownfields (walking fabric) due to design precision, energy efficient materials, construction and control (Wong and Tang, 2012)
3. Basic raw materials – sand, limestone, clay and rock – assume use of off-site construction with reductions of 60% greenfields (automobile fabric), 70% greyfields (transit fabric) and 90% brownfields (walking fabric) due to design precision enabling exact amounts of materials, and shared walls in higher densities (Wiedmann and Barrett, 2007).

Appendix B. – OUTPUT ASSUMPTIONS

Assumptions–Tables 3

1. Energy (Fuel, Power & Gas) conversio into Greenhouse Gases (GHG) defined as being by a factor of 0.125 t (T) of CO2 per Gigajoule (GJ) of Energy.
2. Waste Heat output has been calculated as being equal to total energy input.
3. Sewage Discharge Per person per year figure of 80KL derived from NSW government document, (See http://www.dlg.nsw.gov.au/dlg/dlghome/documents/information/section5.pdf (accessed 7th May 2015)) which provided daily per person average of between 150 and 300 l. Figure rounded to 200 l per person then multiplied by 365 (no days in year) and then divided by 1000 (converting litres to kilolitres). 73 KL figure obtained then rounded to 80 KL to give rounded even figure.
4. Construction and Demolition (C&D) waste combined and sourced from the W.A. Governments Feb 2003 Summary Report of Waste to Landfill Perth Metro Region (See http://www.wasteauthority.wa.gov.au/media/files/documents/wastelfsummary.pdf. ((accessed 7th May 2015) Used Total Waste Stream for Building and Demolition figure for 2000/2001

period of 1243,584 t (T) and divided it by 2001 ABS Census Population figure of 1, 302, 126 (See http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/4A775DD1B80BEB3CCA256C6000033701/$File/20305_2001.pdf (accessed 7th May 2015)), for Perth-Mandurah region. Middle and Inner suburbs were reduced according to estimations of reduced expected C&D waste generation.

5. Household waste was calculated in the same way but due to expected reductions in garden waste between three Urban Forms (Outer most & Inner Least). The Summary report indicated on page 21 that 20.9% of Household (termed municipal in doc), waste is garden waste, so middle and inner suburbs where reduced accordingly. This reduction was impacted by the difference in average occupancy between greenfields (automobile fabric) (2.3), greyfields (transit fabric) (2.1) and brownfields (walking fabric) (1.8).

Assumptions Table 5 (TCI)

Assumptions as above except where noted below:

1. GHG, waste heat, sewage – No change from BAU as the form of the city is not changed by TCI and hence no change from BAU.
2. Construction and demolition (C&D) waste – For all urban fabrics assumes use of off-site construction reduces construction waste by 70% due to processes and ease of recycling on-site factory. Assumes no demolition in outer greenfields (automobile fabric) areas; greyfields (transit fabric) assumes deconstructing or recycling rather than demolition with a 50% reduction of demolition waste; brownfields (walking fabric) assumes deconstructing or recycling rather than demolition with a 50% reduction of demolition waste. DataSource: Crough, D (2013) Unitised Building Australia, Property Council of Australia, Density Wars conference.
3. Household waste – expected reduction factor applied to census data. Data source: Government of Western Australia, Waste Management Board, Summary Report of Waste to Landfill: Perth Metropolitan Region (1 July 1998–20 June 2002), February 2003, pg 16. Australian Bureau of Statistics, 2001 Census of Population and Housing: Perth A Social Atlas, October 2002, pg 1.

References

Baccini, P., Brunner, P.H., 2012. Metabolism of the Anthroposphere: Analysis, Evaluation Design. MIT Press.

Baccini, P., 1997. A city's metabolism: towards the sustainable development of urban systems. J. Urban Technol. 4, 27–39, http://dx.doi.org/10.1080/10630739708724555.

Beatley, T., 2009. Biophilic urbanism: inviting nature back to our communities and into our lives. William Mary Environ. Law Policy Rev. 34, 209–238.

Bina, O., Mateus, S., Pereira, L., Caffa, A., 2016. The future imagined: exploring fiction as a means of reflecting on today's Grand Societal Challenges and tomorrow's options. Futures, http://dx.doi.org/10.1016/j.futures.2016.05.009.

Bunning, J., Beattie, C., Rauland, V., Newman, P., 2013. Low-Carbon sustainable precincts: an australian perspective. Sustainability 5, 2305–2326, http://dx.doi.org/10.3390/su5062305.

Chandra, L., 2006. Modeling the impact of urban form and transport provision on transport-related greenhouse gas emissions. In: Masters Thesis. Murdoch University, Perth.

Costanza, R., 2008. Stewardship for a full world. Curr. Hist. 107, 30–35.

Crutzen, P.J., Stoermer, E.F., 2000. Anthropocene. Glob. Change Newsl., 17–18.

Droege, P., 2008. Urban energy transition: an introduction. Elsevier Sci., http://dx.doi.org/10.1016/B978-0-08-045341-5 (00029-3).

Du Plessis, C., Brandon, P., 2014. An ecological worldview as basis for a regenerative sustainability paradigm for the built environment. J. Clean. Prod., 1–9, http://dx.doi.org/10.1016/j.jclepro.2014.09.098.

Dunham-Jones, E., Williamson, J., 2008. Retrofitting Suburbia: Urban Design Solutions for Redesigning Suburbs. John Wiley & Sons.

Fink, J.H., 2013. Geoengineering cities to stabilise climate. Proc. ICE – Eng. Sustain. 166, 242–248, http://dx.doi.org/10.1680/ensu.13.00002.

Florida, R.L., 2002. The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life. Basic Books.

GIZ, ICLEI, 2014. In: GIZ, ICLEI (Eds.), Operationalizing the Urban NEXUS: Towards Resource Efficient and Integrated Cities and Metripolitan Regions. Eschborn, Germany.

Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. City 8, 363–379, http://dx.doi.org/10.1080/1360481042000313509.

Gardner, H., Newman, P., 2013. Reducing the materials and resource intensity of the built form in the Perth and Peel regions. Curtin University and Arup, Perth, Australia.

Gehl, J., Rogers, R., 2013. Cities for People. Island Press.

Gehl, J., 2011. Life Between Buildings: Using Public Space. Island Press.

Girardet, H., 2010. Regenerative Cities, 20.

Girardet, H., 2015. Creating Regenerative Cities. Routledge.

Glaeser, E., 2011. Triumph of the City. Pan Macmillan, UK.

Global Footprint Network, 2016. Global Footprint Network [WWW Document]. URL http://www.footprintnetwork.org/.

Höjer, M., Mattsson, L.G., 2000. Determinism and backcasting in future studies. Futures 32, 613–634, http://dx.doi.org/10.1016/S0016-3287(00)00012-4.

Hall, P., 1999. Cities in Civilization: Culture, Innovation, and Urban Order, A Phoenix Giant Paperback. Phoenix Giant.

Hall, P., 2013. Good Cities, Better Lives: How Europe Discovered the Lost Art of Urbanism, Planning, History and Environment Series. Routledge, New York, NY.

Hatton, T., Cork, S., Harper, P., Joy, R., Kanowski, P., Mackay, R., McKenzie, N., Ward, T., Wienecke, B., 2011. Australia State of the Environment 2011, Independent Report to the Australian Government Minister for Sustainability, Environment. Water, Population and Communities, Canberra, Australia.

Hendriks, C., Petersen, H. (Eds.), 2000. Sustainable Raw Materials: Construction and Demolition Waste. RILEM Publishers, France.

Jackson, W., Klekociuk, A., Emmerson, K., Keywood, M., Hibberd, M., Cresswell, I., Murphy, H., Coleman, S., Johnston, E., Clarke, C., Argent, R., Mackay, R., Metcalfe, D., Evans, K., Bax, N., Smith, D., 2016. State of the Environment Report. Department of Sustainability Environment Water Population and Communities, Canberra, Australia.

Kellert, S.R., Heerwagen, J., Mador, M., 2011. Biophilic Design: The Theory Science and Practice of Bringing Buildings to Life. Wiley.

Kennedy, C., Cuddihy, J., Engel-yan, J., 2007. The changing metabolism of cities. J. Ind. Ecol. 11.

Kennedy, C., Pincetl, S., Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. Environ. Pollut. 159, 1965–1973, http://dx.doi.org/10.1016/j.envpol.2010.10.022.

Kenworthy, J., Laube, F., 2001. Millenium Cities Database for Sustainable Transport. International Association for Public Transport., Brussels.

Kenworthy, J., 2014. Total daily mobility patterns and their implications for forty-three global cities in 1995 and 2005. World Transp. Policy Pract. 20, 41–55.

Lyle, J., 1999. Design for Human Ecosystems: Landscape Land Use, and Natural Resources. Island Press.

Lyle, J.T., 1996. Regenerative design for sustainable development. In: Professional Series. Wiley, New York, NY.

Marchetti, C., 1994. Anthropological invariants in travel behavior. Technol. Forecast. Soc. Change 47, 75–88.

McIntosh, J., Newman, P., Glazebrook, G., 2013. Why Fast Trains Work An assessment of a fast regional rail system in Perth. Aust. J. Transp. Technol. 3, 37–47.

Muller, P.O., 2004. Transportation and urban form – stages in the spatial evolution of the american metropolis. Geogr. Urban Transp.

Newman, P., Jennings, I., 2008. Cities as Sustainable Ecosystems: Principles and Practices. Island Press.

Newman, P., Kenworthy, J., 1989. Cities and Automobile Dependence: An International Sourcebook. Aldershot, UK.

Newman, P., Kenworthy, J., 1999. Sustainability and Cities: Overcoming Automobile Dependence. Island Press.

Newman, P., Kenworthy, J., 2015. The End of Automobile Dependence: How Cities Are Moving Beyond Car-Based Planning. Island Press, Washington, D.C.

Newman, P., Matan, A., 2013. Green Urbanism in Asia: The Emerging Green Tigers. World Scientific.

Newman, P., Birrell, B., Holmes, D., Mathers, C., Newton, P., 1996. Human settlements. In: Taylor, R. (Ed.), Australia State of the Environment. CSIRO Publishing, Collingwood, Victoria.

Newman, P., 1999. Sustainability and cities: extending the metabolism model. Landsc. Urban Plan. 44, 219–226, http://dx.doi.org/10.1016/S0169-2046(99)00009-2.

Newman, P., 2014. Biophilic urbanism: a case study on Singapore. Aust. Plan. 51, 47–65, http://dx.doi.org/10.1080/07293682.2013.790832.

Newton, P., Murray, S., Wakefield, R., Murphy, C., Khor, L., Morgan, T., 2012a. AHURI Research & Policy Bulletin How Do We Regenerate Middle Suburban Greyfield Areas?

Newton, P., Newman, P., Glackin, S., Trubka, R., 2012b. Greening the greyfields: unlocking the redevelopment potential of the middle suburbs in australian cities. World Acad. Sci. Eng. Technol. 71, 658–677.

Newton, P., et al., 1991. Telematic underpinnings of the information economy. In: Brotchie (Ed.), Cities of the 21 st Century: New Technologies and Spatial Systems. Longman Cheshire, Melbourne, Australia.

Rauland, V., Thomson, G., 2015. Mainstreaming sustainable precincts: sharing experiences. In: Perinotto, T. (Ed.), Sustainable Precincts (E-Book). The Fifth Estate, Sydney Australia.

Rawnsley, T., Spiller, M., 2012. Housing and urban form: a new productivity agenda. In: Tomlinson, R. (Ed.), Australia's Unintended Cities. CSIRO Publishing, Collingwood, Victoria.
Rockström, J., Steffen, W.L., Noone, K., Persson Å, Chapin Iii, F.S., Rockstrom, J., Steffen, W.L., Noone, K., Persson, A., Chapin, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., De Wit, C., Hughes, A., Van Der Leeuw, T., Rodhe, S., Sorlin, H., Snyder, S., Costanza, P.K., Svedin, R., Falkenmark, U., Karlberg, M., Corell, L., Fabry, R.W., Hansen, V.J., Walker, J., Liverman, B., Richardson, D., Crutzen, K., Foley, P., Lambin, J., Lenton, E., Scheffer, T.M., Folke, M., Schellnhuber, C., Nykvist, H.J., De Wit, C.A., Van Der Leeuw, T., Rodhe, S., Sörlin, H., Snyder, S., Costanza, P.K., Svedin, R., Falkenmark, U., Karlberg, M., Corell, L., Fabry, R.W., Hansen, V.J., Walker, J., Liverman, B., Richardson, D., Crutzen, K., Foley, P.J., 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity, 14., http://dx.doi.org/10.1038/461472a.
Rockström, J., 2009. A safe operating space for humanity. Nature 461, 472–475, http://dx.doi.org/10.1109/TIP.;1;2011.2165549.
Söderström, P., Schulman, H., Ristimäki, M., 2015. Urban Form in the Helsinki and Stockholm City Regions. Finnish Environment Institute, Helsinki, Finland.
Seitzinger, S., Svedin, U., Crumley, C., Steffen, W., Abdullah, S., Alfsen, C., Broadgate, W., Biermann, F., Bondre, N., Dearing, J., Deutsch, L., Dhakal, S., Elmqvist, T., Farahbakhshazad, N., Gaffney, O., Haberl, H., Lavorel, S., Mbow, C., McMichael, A., DeMorais, J., Olsson, P., Pinho, P., Seto, K., Sinclair, P., Stafford Smith, M., Sug, L., 2012. Planetary stewardship in an urbanizing world: beyond city limits. Ambio 41, 789–794, http://dx.doi.org/10.1007/s13280-012-0353-7.
Steffen, W., Persson, Å., Deutsch, L., Zalasiewicz, J., Williams, M., Crumley, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Rockström, J., Scheffer, M., Schellnhuber, H.J., Svedin, U., Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Ramanathan, V., 2011. The anthropocene: from global change to planetary stewardship. Ambio 40, 739–761.
Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., 2015. Planetary boundaries: guiding human development on a changing planet. Science 80 (347), 736–747, http://dx.doi.org/10.1126/science.1259855.
Thomson, G., Newton, P., Newman, P., 2016. Urban regeneration and urban fabrics in australian cities. Urban Regen. Renew. 10.
Trubka, R., Bilsborough, D., Newman, P., 2010. The Costs of Sprawl, Environment Design Guide, GEN84: 1–11.
Turner, G., Foran, B., 2008. Resource consumption and resource depletion. In: Newton, P. (Ed.), Transitions: Pathways Towards Sustainable Urban Development in Australia. CSIRO Publishing and Dordrecht, Springer Melbourne Australia, pp. 35–55.
United Nations Department of Economic and Social Affairs Population Division, 2014. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). United Nations Department of Economic and Social Affairs Population Division, New York United, http://dx.doi.org/10.4054/DemRes.2005.12.9.
United Nations General Assembly, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. United Nations General Assembly, NY, http://dx.doi.org/10.1007/s13398-014-0173-7.2.
United Nations, 2015a. Adoption of the Paris Agreement, Framework Convention on Climate Change Adoption of the Paris Agreement , Paris, France.
United Nations, 2015b. World Population Prospects, World Population Prospects: The 2015 Revision. Key Findings and Advance Tables.
United Nations, 2016. Habitat III New Urban Agenda Draft Outcome Document for Adoption in Quito, October., pp. 2016.
Urry, J., 2004. The system of automobility. Theory Cult. Soc. 21, 25–39.
Van Wee, B., Rietveld, P., Meurs, H., 2006. Is average daily travel-time exposure constant? In search of explanations for an increase in average travel time. J. Transp. Geogr. 14, 109–122.
Wackernagel, M., Rees, W., 1998. Our Ecological Footprint: Reducing Human Impact on the Earth New Catalyst Bioregional Series. New Society Publishers.
Warren-Rhodes, K., Koenig, A., 2001. Escalating trends in the urban metabolism of Hong Kong: 1971–1997. AMBIO A J. Hum. Environ. 30, 429–438, http://dx.doi.org/10.1579/0044-7447-30.7.429.
Wiedmann, T., Barrett, J., 2007. A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House: SEI & ISA UK Research Report 07-04. York, UK.
Wolman, A., 1965. Metabolism of Cities. Sci. Am. 213, 179–190.
Wong, F., Tang, Y., 2012. Comparative Embodied Carbon Analysis of the Prefabrication Elements Compared with In-situ Elements in Residential Building Development of Hong Kong. World Academy of Science.
Zahavi, Y., Talvitie, A., 1980. Regularities in travel time and money expenditures. Transp. Res. Rec., 13–19.
Zvelebil, M., 2009. Hunters in Transition: Mesolithic Societies of Temperate Eurasia and Their Transition to Farming New Directions in Archaeology. Cambridge University Press.

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Urban regeneration and urban fabrics in Australian cities

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Abstract This paper describes Australian urban regeneration in terms of urban fabric — *walking*, *transit* or *automobile*, and geography — *brownfield* and *greyfield* arenas. Case studies are used to highlight the importance of understanding urban fabric when considering development and regeneration across any geography. Urban regeneration in Australian cities has been occurring in brownfields locations for the past three decades, driven initially by government intervention, but is now a strong market force. The 'peak car' phenomenon is now associated with an even stronger demand for urban regeneration stretching beyond the inner city into the middle suburbs or greyfields. This paper provides a brief history of major regeneration influences followed by an overview of the processes, policies and practices that can enable the next phase of urban regeneration in all three urban fabrics, particularly the greyfields.

Keywords: *urban regeneration, brownfields, greyfields, urban infill, automobile dependence, precinct redevelopment, transit oriented development, suburban re-urbanisation.*

INTRODUCTION

Reflecting global patterns, Australia's cities demonstrate a new trend towards urban regeneration rather than greenfields development based on the phenomenon of 'peak car'.[1] The push to build car-dependent suburbs on the urban fringe has slowed and the regeneration of the city and suburbs is well underway. Greenfields development in Australia is now under significant review due to economic, social and environmental costs that have been well documented.[2] After a long history of seeking garden suburbs on the fringe, the demand in Australian cities to move back into more accessible urban locations through 'infill' housing (ie new housing built on previously developed land) is on the rise. Most states have developed new strategic planning documents favouring as much urban regeneration as possible.[3] This paper will examine some of the causes for this phenomenon using the theory of urban fabrics, supported by some case studies that have helped generate confidence in the value of urban regeneration, and how it can be further assisted in Australian cities.

URBAN FABRIC THEORY AND URBAN REGENERATION

The fabric of a city is the combination of buildings, public realm and infrastructure, ie all the built landscape that we create to live in, work in and relax in. Urban fabric tends to respond to the transport-related opportunities that are provided in a city as there is a fundamental and global need to keep within the Marchetti travel time budget of around one hour.[2] The three kinds of city types or transport-related urban fabrics have been described as walking fabric, transit fabric and automobile fabric and every city can be seen to have the three urban fabrics expressed together in the form of different elements, functions and qualities.[3] The theory of urban fabrics can help explain why it is that urban regeneration is not only accelerating but is likely to continue growing; this is described in detail below, following a brief historic overview of typical urban growth patterns observed in Australia's major cities.

AUSTRALIAN URBANISATION DRIVERS

Australia is highly urbanised, with around 80 per cent of its 24m population living in urban areas, and the majority of this population reside within the eight large capital cities.[4] The siting of the capital cities was determined in the colonial era; all — with the notable exception of Canberra (the post-colonial Federal capital) — were clustered around harbours or navigable rivers to cater for the sailing ships of that period.

The era of walking city urban fabric existed from the first cities and was located either directly adjacent to the ports, such as in Sydney, or within short travel by horse and cart, for example Adelaide. Walking urban fabric dominated until the 1850s–80s, when it was taken over in the industrial era by train and tram-based urban fabric spreading cities out 20km or so along corridors that contained both residential and industrial activity. This era lasted until the 1950s, when automobile-based urban fabric began to spread cities out 50km or more from the Central Business District (CBD).

Australian cities, like cities in other developed counties, have witnessed ports and industrial activity shifting out of the inner areas in the late 20th century, freeing up many 'brownfield' sites for urban regeneration. The 'Building Better Cities' programme in Australia sparked a number of urban regeneration projects in major brownfield sites and brownfield regeneration has since become a strong market process[5].

The 21st century has seen the automobile city period begin to wane and collapse as traffic congestion has prevented car-based transport from continuing to provide the travel time edge that it gave over trains and trams. In Table 1, the data on comparative speeds of transit (train, tram and bus) to traffic and rail to traffic in the

Table 1: Comparative Speeds of public transport (bus and rail) to traffic and also rail to traffic in global cities.

COMPARATIVE SPEEDS IN GLOBAL CITIES	1960	1970	1980	1990	1995	2005
Ratio of overall public transport system speed to road speed						
American cities	0.46	0.48	0.55	0.50	0.55	0.54
Canadian cities	0.54	0.54	0.52	0.58	0.56	0.55
Australian cities	0.56	0.56	0.63	0.64	0.75	0.75
European cities	0.72	0.70	0.82	0.91	0.81	0.90
Asian cities	–	0.77	0.84	0.79	0.86	0.86
Global average for all cities	0.55	0.58	0.66	0.66	0.71	0.70
Ratio of metro/suburban rail speed to road speed						
American cities	–	0.93	0.99	0.89	0.96	0.95
Canadian cities	–	–	0.73	0.92	0.85	0.89
Australian cities	0.72	0.68	0.89	0.81	1.06	1.08
European cities	1.07	0.80	1.22	1.25	1.15	1.28
Asian cities	–	1.40	1.53	1.60	1.54	1.52
Global average for all cities	0.88	1.05	1.07	1.11	1.12	1.13

Source: Newman and Kenworthy, 2015

Global Cities Database show that rail has become competitive with traffic over the past 20 years in most of the world's cities.[6] At the same time as this transport change there has been an economic change with the growth of the knowledge economy creating a need for more face-to-face interactions and hence denser urban form. Thus walking urban fabric and transit fabric have experienced a resurgence in popularity in all developed cities including all Australian cities.

THE ADVANTAGES AND REVIVAL OF WALKING AND TRANSIT URBAN FABRIC

Walking urban fabric enables greater face-to-face interaction and this function has been recognised as increasingly significant for the growing economic functions associated with the knowledge economy, the creative economy and the services economy.[7–9] Face-to-face activities related to human capital and tacit knowledge exchange do not develop around automobile-related urban fabric like shopping centres but are best located in historic walking centres and around sub-centres such as old station precincts, new transit oriented developments[10,11] or the older 'urban villages' established in the pre-auto suburbs of cities.[12]

There is therefore a strong economic driver for an urban fabric to enable people to live or work near quality transit or quality active transport (walking, cycling) environments and this will be associated with economic regeneration. Cultural change associated with social media and mobile phones, which are easier to use in transit or walking than in cars, as well as the spatial efficiencies of non-car-based transport and urban form, has also led to the growing phenomenon known as 'peak car'.[3] There is therefore a growing market for urban regeneration rather than greenfields automobile-based fabric in Australia, and this is likely to continue. Figure 1 shows the reversal of density decline in the cities from the global cities database.

The evidence from around the world's cities is that walking and transit oriented urban fabrics have been regenerating rapidly in the past 20 years and that the time has come to see how this can now move into the decaying middle suburbs (greyfields) built around the car from the 1950s and where urban regeneration is now beginning to focus its attention.

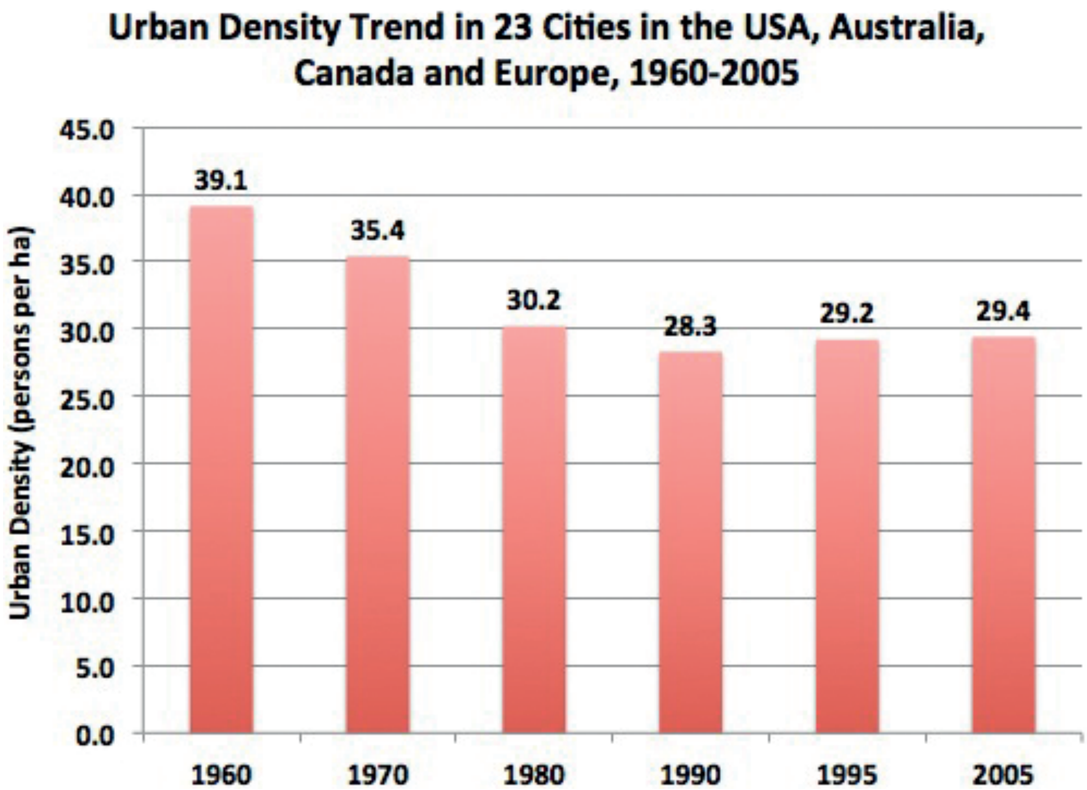

Figure 1: Reversal of density as seen from the global Cities Database

Source: Newman and Kenworthy, 2015

These urban regeneration trends are developed further below from an Australian perspective.

THE SHIFT FROM SPRAWL TO URBAN REGENERATION

A consistent challenge for the planners of Australia's largest cities since the mid-1950s has been the containment of urban sprawl, given that the dominant mode of new housing development continued to be detached low-density (78 per cent of all residential stock in 1971, 74 per cent in 2011).[13] This remains a major problem for Australia's metropolitan agencies, all of which established targets for 'infill' housing development in an attempt to redirect population and housing investment inwards rather than outwards to continue urban sprawl. These targets range from around 50 per cent in most capital cities (including Melbourne) to 70 per cent in Sydney.[14]

Following decades of de-population when post-War suburbanisation was at its height, the inner suburbs of Australia's major cities are now experiencing strong re-urbanisation[13] (see Figure 2). There have been a number of forces at work here, as outlined above, related to changing traffic and transit options as well as changing economic functions and their need for more face-to-face urban fabric. The changing locational requirements of early mercantile (pre-container port) and manufacturing activities have meant that their sites have been progressively abandoned as workplaces, to be replaced by higher-order service industries (financial, business, legal, retail) together with information, knowledge and creative

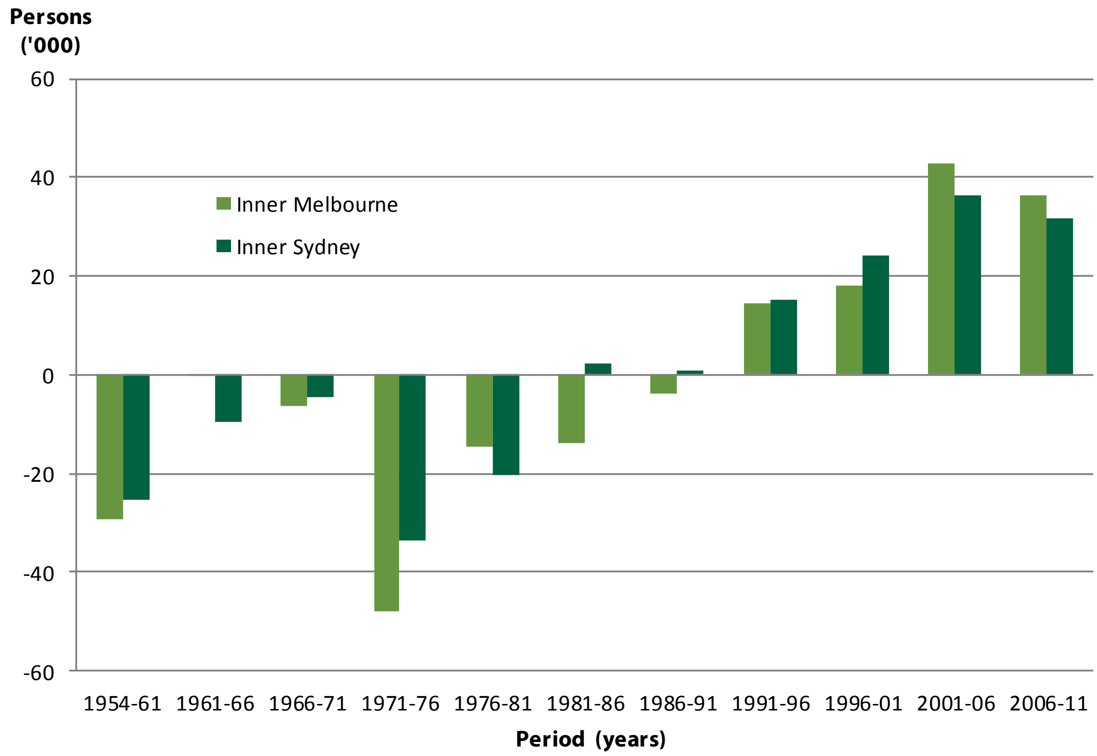

Figure 2: Population change in inner Melbourne and inner Sydney

Source: Jeremy Reynolds, Department of Planning and Community Development, Victoria

industries — representing a major turnaround in Australia's industrial urban geography.[15] The higher income workers in these industries also began moving inwards to be closer to their jobs, as did people seeking education and other urban services available mostly in these intensively built urban fabrics.

Thus, a series of waves of gentrification have been characteristic of the housing as well as the population of inner suburbs in cities such as Melbourne and Sydney since the early 1970s, a process that continues to the present.[16]

Australia's major cities, however, are failing to achieve the aspirational infill targets for housing established in their strategic plans[17] and as a consequence a significant percentage of dwelling construction projects continues to occur on greenfield sites in the outer peri-urban suburbs, although they are no longer the total market they were at the height of the automobile urban fabric boom. Governments have recognised for some time that there are well-catalogued environmental, social and economic problems associated with sprawl,[18,19] but the old way of opening up new fringe land has often been much easier than urban regeneration. The regular revision and extension of urban growth boundaries by state governments has thus been occurring, despite their own plans to do more urban regeneration. A planning conflict exists between feeding the market created by large-scale project home builders on the fringe, coupled with the persistence of the 'Australian dream' of a free-standing dwelling on a 1,000m^2 block of land; and, feeding the market for more transport-efficient, economically efficient but difficult to provide urban infill dwellings back into the city. At its essence this conflict represents a culturally and institutionally entrenched Modernist planning model that involves high land consumption, is premised upon auto-dependence and is fuelled by the dominant development business models.[20]

What is currently lacking are workable models for more intensified levels of contiguous urban regeneration in Australian cities — and principally in the older car-based middle suburbs (as outlined below). There are many reasons why this trend to reduced automobile dependence is very positive terms of resources, infrastructure and economic efficiency, as discussed in more detail in Newton and Doherty.[21] At its best, urban regeneration is a higher-order redevelopment process that extends beyond an individual building to incorporate a more complete re-creation of an entire block or precinct of (typically) adjoining parcels of property and the associated urban infrastructures (water, energy, waste — all capable of operating more sustainably as distributed infrastructures[22]). Urban regeneration for reduced automobile dependence (the new and dominant agenda in most cities, and certainly in Australian cities) is about creating new urban fabric more akin to the historic walking and transit urban fabrics than the low density, scattered land uses associated with post-War car-dependent suburbs. It represents a new sustainable planning paradigm for 21st-century Australian urban economies.[3,23–26]

ARENAS FOR URBAN REGENERATION

Infill, as a key concept in metropolitan development, needs to be distinguished in relation to the scale at which it occurs: parcel or precinct. Infill also needs to be distinguished in terms of the urban arena in which it takes place: brownfields or greyfields. Different development models involving planning, urban design, finance, construction and community engagement appear to be required for each.[27]

Brownfields constitute abandoned or under-used industrial or commercial sites associated with an earlier era of economic activity. Typically they include the docklands precincts that served the sea trade prior to containerisation, outdated commercial high-rise buildings, abandoned manufacturing sites, sections of railways, vacant petrol stations, and formerly viable retail sites. They are typically:

- owned by a single party, usually government or industry;
- of a scale which is closer to that provided by greenfield sites for development;
- contaminated to some degree, depending upon the nature of prior use; and
- unoccupied, obviating the need for community engagement at a level required of greyfields.[13]

Greyfields, unlike brownfields, usually have no need for site remediation. Furthermore, they predominantly lie between the more vibrant CBD and inner city housing market and the more recently developed greenfield suburbs, providing greater access to employment, public transport and services than the latter zone.[13] Greyfields in the Australian context have been defined as those ageing but occupied tracts of inner and middle ring suburbia that are physically, technologically and environmentally failing and which represent under-capitalised real estate assets.[27]

In the sections that follow, we explore avenues for *precinct scale urban regeneration* in both brownfield and greyfield settings of a metropolitan region as a core response to the need for less automobile dependence and a more sustainable urban development.

BROWNFIELD REGENERATION

By the early 1980s a significant number of prominent brownfield sites were apparent in the major cities, but there was no development model available capable of providing a way forward with a level of risk acceptable to the private sector, given the size of the projects, finance required, available planning, design and property development expertise. Until the election of the Hawke-Keating Labour government in 1983 there had been no federal government (apart from the Whitlam Labour government that briefly held office in 1972–75) who accepted that they had a mandate to help shape the nation's cities; that role was routinely assigned to state governments. The significance and complexity of city development, however, requires involvement of all three tiers of government in a federal system, including national leadership and funding.[13]

The Hawke-Keating initiative, 'Building Better Cities' commenced in 1991 as a nationwide federal–state government joint development programme designed to engage with the property and construction sector. Its objective was to improve integration across government agencies and industry to facilitate strategic urban development, with a particular emphasis on the redevelopment of brownfield sites.[13]

Through the Better Cities programme the federal government took an active interest in carefully selecting strategic projects (area strategies) capable of major urban renewal. As a nation-building initiative of the federal government between 1991 and 1996, the Better Cities programme can be credited with leading the brownfield regeneration of Australia's inner cities.[28]

As a result of the Better Cities programme, brownfields have become attractive to the property development and finance industries, which have been able to create a development model to undertake major projects such as:

- Southbank, Docklands and Federation Square in Melbourne.
- Ultimo-Pyrmont, Darling Harbour and Barangaroo in Sydney.
- Newport Quays in Port Adelaide.
- Southbank in Brisbane.
- East Perth and Subiaco in Perth.

The programme highlighted the importance of partnerships, integrated planning, urban renewal and priming sites for private sector involvement.[29] They represent an important contribution to the revitalisation of abandoned urban land and to the net additional housing stock in growing cities, but at a level which is unlikely to meet aggregate metropolitan demand for new infill housing.[13]

GREYFIELD REGENERATION

Greyfield regeneration, aspires to include a more substantial rejuvenation of the under-performing, privately owned housing in the inner and middle suburbs of Australia's cities, but to date this has proved difficult to achieve, as explained below.

None of the Australian metropolitan planning agencies distinguish between the different types and yields of housing redevelopment that occur in brownfield versus greyfield settings. Yet they are distinctly different and instructively so[26] (see Table 2). The first point to note from an analysis of all new infill dwellings constructed in Melbourne between 2004 and 2010 is that the most common categories of redevelopment are either 1:1 (19.2 per cent), where a dwelling is demolished and replaced (termed a

Table 2: Components of infill housing development, Melbourne, 2004-2010

	Residential yield of infill residential development							
	1:1	**1:2–4**	**1:5–9**	**1:10–19**	**1:20–49**	**1:50–99**	**1:100+**	**Total**
Brownfield	1.3%	0.5%	0.7%	2.8%	4.1%	5.9%	**19.2%**	34.4%
Greyfield	**17.9%**	**32.3%**	6.3%	2.3%	3.2%	2.3%	1.3%	65.6%
Totals (%)	19.2%	32.8%	7.0%	5.1%	7.3%	8.2%	20.5%	100.0%
(N)	21,947	37,614	**8,029**	**5,833**	**8,309**	**9,374**	23,487	114,593

Source: Newton and Glackin, 2014

'knockdown–rebuild'), or 1:2–4 (32.8 per cent), where a single dwelling is demolished and two to four townhouses are constructed in its place. There is significant spatial fragmentation with this category of infill development — it is not occurring in those 'precincts' where metro planning policies intended.[30] The other major category of housing redevelopment project is 1:100+, where a block of apartments, normally above four floors in height, is developed on a (large) site previously occupied by one building. The latter category of redevelopment project is mostly restricted to brownfields at present, while the greyfields are attractive to the former two categories, as allowed by prevailing local and state government planning provisions. A further critical point to note is the relative absence of redevelopment projects represented by yields of 1:5–9 (7.0 per cent), 1:10–19 (5.1 per cent) and 1:50–99 (8.2 per cent).[13] These are the medium-density projects involving a level of intensification currently at odds with metropolitan planning as they require multiple sites to be drawn into a precinct for redevelopment and there is no mechanism or tools to facilitate such land assembly.

Similar patterns can be observed in Perth, which has experienced massive economic-driven population growth, swelling from 1.2m residents in 1991 to just over 2m by 2014.[31] The growth of the outer suburbs has been the primary driver of urban development in Perth for 50 years, with the central city CBD region losing virtually all of its population by the late 1990s. Since the mid-2000s an economic boom has heralded a reversal, with supportive planning policies, population growth and the resurgence of interest in central living seeing the City of Perth population surge from 700 to nearly 30,000 people by 2015.[32] New housing from urban infill reached 28 per cent in the period 2009–14 and the target for the next phase of urban development is increasing to 47 per cent in as Perth continues along its projected rapid growth trajectory from 2m to 3.5m in 2050.[33]

Perth's recent density increases are largely centralised and sprawling suburban development while slowing still dominates with low-density detached (largely greenfield) and semi-detached housing typologies still comprising around 80 per cent of the new building stock, with this typology proving more persistent in Perth than witnessed in the east coast cities[34] (Figure 3).

Perth's strategic plan, *Directions 2031*,[35] echoes the planning approach of other capital cities, by promoting a better balance between greenfield and infill development. Widespread rezoning has promoted infill, with approximately 26,300 dwellings demolished in Greater Perth between 2001/02 and 2011/12; unsurprisingly the vast majority (76.1 per cent) of total demolitions were within the central sub-region, but, this redevelopment has brought about only marginal intensification, averaging only 1.8 residential lots for every dwelling demolished during that period.[36]

As with Melbourne, the problem

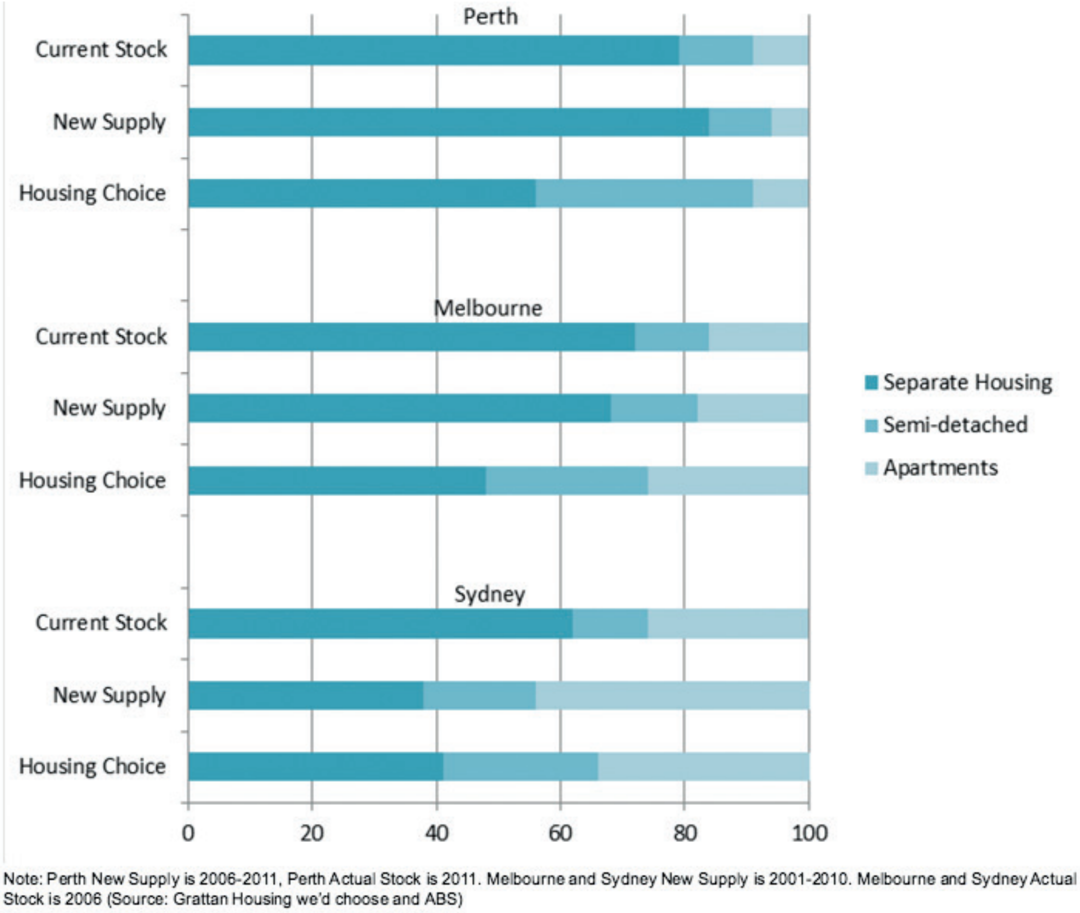

Figure 3: Comparison of current stock, housing choice and new supply: Perth Melbourne and Sydney

Source: State of Western Australia, 2014

remains that knock-down rebuild dominates housing infill. The obvious market for redevelopment using denser kinds of urban typologies such as apartment complexes (as in brownfield developments) is not happening in inner and model suburbs due to developers only focusing on one block at a time and no planning tools or mechanisms to assist larger land assembly.

Figure 4 shows an example of this auto-dependent 'group dwelling' (strata title) infill, following demolition and subsequent subdivision in the middle ring Perth suburb of Canning. While parcel-based infill typically increases density two or fourfold, the resultant small lots in multiple ownership make land assembly, and therefore future regeneration, increasingly difficult.

Policies that increase density only slightly and still require high car parking provision reinforce an automobile-based fabric, albeit without the benefits of the house in a garden as advocated by Howard's Garden Cities concept[37] — the catalyst for Australia's garden suburbs. Concern around 'disappearing backyards' and private green space in general has been raised as a topic of concern by numerous commentators.[38,39] Where the plot size is so reduced and residual unbuilt areas are typically sacrificed to car infrastructure (both parking and access),

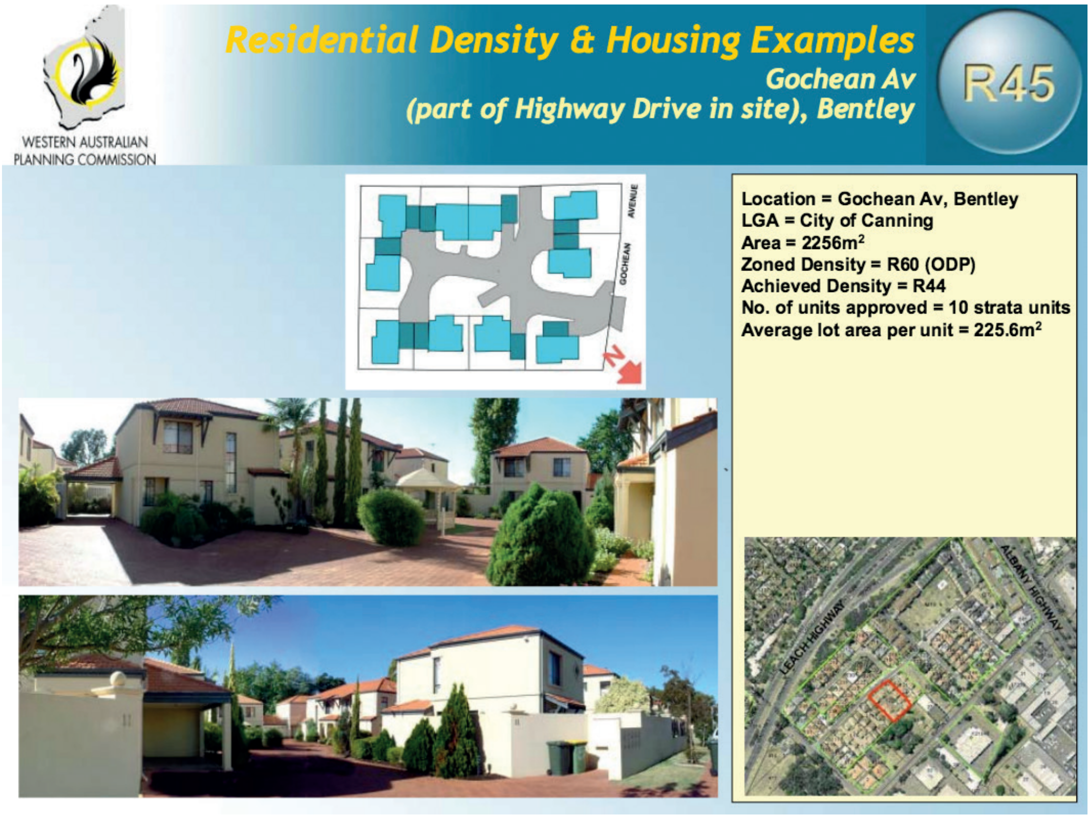

Figure 4: In Perth, the most typical infill is 'deemed to comply' under generic local planning controls but locks in suboptimal (auto-dependant) urban form.

Source: Western Australian Planning Commission, 2004

many redevelopment areas are becoming a parody of the traditional suburb and risk lock-in of this suboptimal automobile fabric due to increased ownership fragmentation and continued reliance upon private vehicles.

A comprehensive urbanism, as opposed to fragmented infill, necessitates a shift to precinct scale rather than piecemeal infill. This requires:

- A focus on new denser housing typologies and open space associated with medium and high density development.
- New partnerships that involve community participation in addition to the occasional public/private partnerships and more ubiquitous private sector developments.
- New modes of constructing the built environment of the future.
- The establishment of new property redevelopment brokers capable of catalysing greyfield regeneration and land assembly redevelopment agencies.[30,40]

Greyfield regeneration as conceived hereto represent a process for a more intentional transformation of neighbourhoods, rather than waiting for degeneration to reach such a tipping point that major public intervention is required.[13]

PRECINCT SCALE GREYFIELD REGENERATION

There are three arenas for greyfield precinct regeneration relevant to Australian cities, these are — activity centres and transit oriented development, linear public transport corridors, and residential precinct regeneration.

ACTIVITY CENTRES AND TRANSIT ORIENTED DEVELOPMENT

Activity centres have been a focus for intensification of greyfield sites predating the current strategic plans of most Australian capital cities. Activity centres are associated with concentrations of retail and commercial activity at levels ranging from 'central' (CBD-scale) to 'village' and are a response to a need to minimise travel times of resident populations to work and to other services as cities expand and outgrow a single, central activity node (eg. in the Australian context, Sydney's 'City of Cities' plan and the '20 minute city' embody concepts of the poly-centred city). They now constitute a renewed focus for intensified development, coupled with transit oriented development (TOD) projects, for all larger cities.[13] These activity centres strung along transit corridors are indeed what is meant by transit urban fabric, although in the past 50 years they have been overrun with automobile urban fabric and now are seeking to regenerate more of their transit orientation and walkability.

The principles of TOD and regenerating transit urban fabric are well established: a stimulus for urban renewal and enhancement of a centre's image that clusters a greater mixture of land uses and housing, at higher densities, around high-quality public transport services configured as the heart of the enlarged community. They also benefit from having a number of development models that are effectively being applied to TOD projects: government-led (eg Gold Coast University hospital precinct and other projects along the new Gold Coast light rail), private-sector-led (eg Brisbane's Albion Mill precinct) and public/private partnerships (eg Green Square Town Centre in Sydney).[13]

In Perth, recent planning changes have seen the transition of some auto-dependant suburbs to more strategic higher density infill. The catalyst for this change has been state level strategic plans that have promoted the principles of TOD at key locations. Two notable examples are 'Cockburn Central' (in the City of Cockburn LGA) and more recently 'Canning City Centre' (in the City of Canning LGA). In both cases an urban structure plan has provided a site-specific framework for higher density, mixed use, transit oriented regeneration.

Planning for Cockburn Central was triggered by major investments in Perth's domestic railway system. Cockburn Central comprises 12ha of rezoned land abutting the recently completed (2007) Mandurah railway line, 24km south of central Perth.

The vision for a TOD outlined in the Cockburn Regional Centre Structure Plan[41] (see Figure 5) was risky because higher density, mixed use apartment typologies had not been tested with the market this distance from the city centre. To encourage an attractive product, the city established Town Centre Design Guidelines and a Design Review Panel to emphasise design quality, which has paid dividends through the surprisingly rapid development and sale of units.

By September 2015, ten residential buildings providing 565 dwellings had been completed; when fully redeveloped Cockburn Central will included around 2,000 dwellings[41] for a total build-out that will result in a gross density of over 160 dw/ha across the 12ha site, substantially higher than *ad-hoc* incremental infill. This transit oriented approach to regeneration provides a useful alternative model to achieve substantial improvements in land consumption efficiency for the region and create the kind of knowledge economy

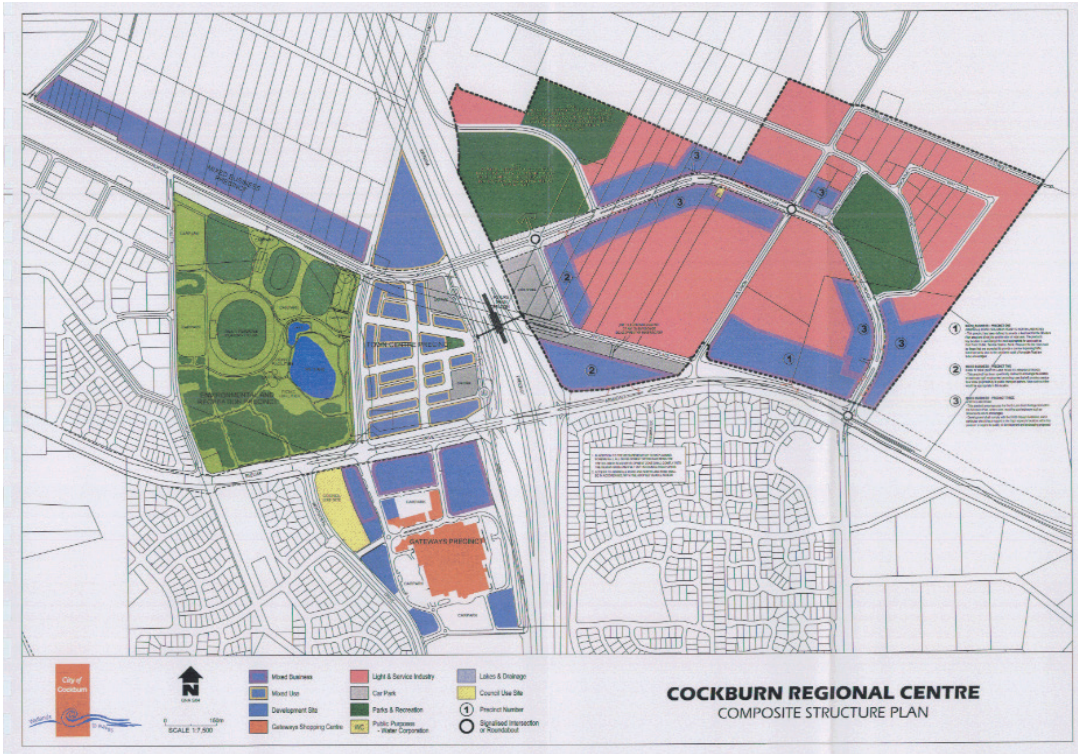

Figure 5: Cockburn regional centre composite structure plan, Perth

Source: LandCorp, 2006

services that go with such dense centres. The success of this model has improved local acceptance of TOD in highly car-dependent suburbs, in turn encouraging planning departments to set higher aspirational commitment at other TOD locations such as Canning City Centre.

Canning City Centre is a similar, but much larger, regeneration project than Cockburn Central. The 160ha of rezoned activity centre land incorporates Cannington Train Station and Perth's largest shopping centre, Westfield Carousel. The regeneration area has over 400 land owners but currently only has a small existing residential population (<1,000) with the remaining land comprising a mixture of residential, commercial, light industrial, utilities, sporting and institutional uses (see Figure 6).

A draft structure plan has created a policy environment that supports the precinct scale transformation into a high-density, mixed use regional activity centre with targets for 10,000 new dwellings, 60,000m^2 increased retail space and an equivalent area of new commercial space. The regeneration aims to shift the urban fabric from auto-dependant sprawl (see Figure 7) to a walkable, highly liveable (in terms of amenity density) and productive (in terms of jobs, residences and services per unit area) urban environment (Figure 8).

Since the release of the draft structure plan in October 2013,[42] the city has witnessed significant investment interest, with over 600 new high-density apartments approved by the middle of 2015;[43] but as with rezoning in suburbs, actual redevelopment is patchy so far.

While the structure plan provides the policy framework for a TOD, the existing energy and water infrastructure capacity maybe insufficient for the planned growth

Figure 6: Canning City Centre structure plan boundary 2015, Perth

Source: Provided by City of Canning

adding considerable development cost. In this case, continued council leadership may enable a more flexible, sustainable and cost effective distributed infrastructure solution and elevate the city centre as a national urban regeneration exemplar demonstrating the best of transit and walking fabric.

Sydney has a range of similar TODs and urban regeneration along its three new rail lines (especially the new light rail) and big plans for the waterfront area known as the Bays Precinct. But well-delivered TODs are not as common as they perhaps ought to be, given the broad strategic policy support. Barriers hindering a more rapid uptake include community resistance to higher densities or high-rise, difficulties related to land assembly, higher redevelopment costs in areas adjacent to heavy rail infrastructure, inconsistent planning controls and strata legislation.[32]

The TOD-based approach to urban regeneration follows the urban fabric that is traditionally created by trains — like pearls on a string. However it is also possible to create tram-based urban fabric which is linear.

LINEAR PUBLIC TRANSPORT CORRIDORS

A more recent proposal for urban redevelopment suggests linear transport corridors as an additional focus for more intensive medium-rise development. The requirements for this to work are set out by Adams *et al*.[44]

The *Transforming Australian Cities* study was jointly commissioned by the Victorian Department of Transport and the City of Melbourne to respond to the urban growth challenge whereby 'in

Figure 7: Current urban form within the Canning City Centre structure plan boundary looking north along the proposed future main street

Photo: G.Thomson, 2015

Figure 8: Illustrative photomontage of the policy intent for an attractive, walkable neighbourhood main street (Cecil Avenue)

Source: Canning City Centre Structure Plan Draft, October 2013 under 40 years Melbourne needs to build the equivalent city and infrastructure that has taken 175 years to build' to accommodate a doubling of population to 8m.[44] The report proposes alternatives to typical suburban sprawl, based upon a 'linear city' consisting of medium-rise high-density development that aims 'to maximise development along new and future road public transport corridors'[44] (see Figure 9) following the kind of urban fabric created by trams from the 1880s to the 1930s. Planning controls are 'not currently equipped to handle rapid development approvals'; therefore the study recommends a shift from 'development assessment' to 'development facilitation', describing a methodology for the identification of opportunity areas that could be redeveloped to proactively engender change.

Most Australian cities' suburban areas have very low dwelling densities of between 10 and 20 dwellings per hectare (net), while many international cities have average densities around 200 dw/ha (net) without the need to resort to high-rise (building heights almost universally range between six and eight storeys).[13]

Adams *et al.*[44] conclude that if this approach were applied to Melbourne, four to eight-storey development along urban

Maribyrnong Road, Maribyrnong study area, currently

Possible future

Figure 9: Photomontage illustrating proposed linear infill from 'Transforming Australian Cities'

Source: Adams *et al.*, 2009

corridors at densities akin to Barcelona could accommodate 2,400,000 additional population, with a further 1,400,000 to be accommodated within existing activity centres and known redevelopment sites. Melbourne's population is projected to increase continuously (from around 4m) to between 7.6m and 9.8m by 2061,[45] so theoretically this model could absorb Melbourne's projected growth for the next 40 or so years.

A complication here is that activity centres and transport corridors have to date failed to attract the level of new residential and commercial redevelopment that is capable of removing pressure from the new greenfield and fragmented greyfield residential developments characteristic of Melbourne's current growth.[30] The economic status of the neighbourhood where the infill is taking place reveals that apartment-scale redevelopment appears to be currently successful only in those areas where resident opposition is likely to be lower (ie brownfields) and where affordability is higher; ie in suburbs of above average economic status (given the significant cost/m^2 difference of high-rise construction[19]). These findings are also aligned with the infill studies of Sydney and Perth where it was found that merely zoning for high density in a low-value area will not lead to its development[46] as density needs amenity if private investment is to be found to provide the funds.

Furthermore, research by McCloskey *et al.*[47] suggests that the transport co-benefits of transit corridor intensification are likely to be limited, given the geography of employment in Melbourne; less than half of all employed persons who live within one kilometre of a train station or tram stop actually use these transport modes for their journey to work. However the point to such transit oriented development is that most other trips are done locally as so much more happens locally than in car-based areas, hence the demand is likely to be driven by people looking to travel less for multiple destinations.[3] The debate about linear corridors of urban regeneration will continue to be quite strong, as medium-density redevelopment along a whole street takes up much more space than a high-density set of TODs in a string of pearls. Thus the opportunity for political intervention by local groups is much greater and so far has largely prevented the linear Adams vision for urban regeneration to be achieved.

RESIDENTIAL PRECINCT REGENERATION

It has been argued elsewhere[30] that current brownfield and greyfield approaches to urban redevelopment are necessary but not sufficient to regenerate our cities. The reality is that the designated strategic redevelopment areas (activity centres and transport corridors) have been relatively ineffective in generating new housing, and fragmented infill continues to be the major provider of new housing in the established suburbs.[30] Because this informal infill generally falls outside of the government policy-focused areas (unlike its greenfield and brownfield counterparts, greyfield residential precinct regeneration lacks an established model to drive the process in other than a minimalist, fragmented fashion), it has been neglected as an issue for investigation or action.[13]

NEW MODELS OF INNOVATIVE SUSTAINABLE GREYFIELD RESIDENTIAL PRECINCT REGENERATION

The piecemeal redevelopment that has characterised much infill activity represents a sub-optimal solution for regenerating housing, energy, water and waste systems and local amenity via enhanced mixed use development and active transport (eg walking, cycling and public transit access) options, all best done at a precinct level.[25,48] The advantages of precinct scale regeneration, particularly with regard to greater cohesion of the urban fabric and improved opportunities for integrated, distributed (eco-) infrastructure, have been described in detail by Newton *et al*.[40,49]

Two avenues of response can be identified, as follows.

PUBLIC HOUSING: A CATALYST FOR NEIGHBOURHOOD REGENERATION

Much of the public housing stock built in the decades immediately following the Second World War is now physically obsolete, but well located — *and* has a single owner. Ageing public sector housing represents approximately 5 per cent of total metropolitan stock in any Australian city — an important catalyst for neighbourhood regeneration.[50] The challenge is how best to regenerate these properties.

One such example is the multi-award-winning K2 apartments in the inner south-eastern Melbourne suburb of Windsor. An open competition in 2000 led to the construction of four connected buildings comprising 96 medium-density public housing units on a 4,800m^2 site previously occupied by the Royal Victorian Institute for the Blind.

The scheme breaks stereotypes of public housing by providing a high-quality living environment for residents as well as exceptional sustainability credentials and sets the benchmark for medium-density public housing development in Australia. It is an important demonstration project in that it showcases a desirable alternative development model for greyfield sites in a higher-density mid-rise typology. The redeveloped site achieves a gross density of 200 dwellings per hectare while still dedicating approximately 20 per cent of the site coverage to soft landscape.[13]

In Perth, another government-initiated exemplar redevelopment in a middle suburb has begun in the suburb of White Gum Valley. This project, called WGV, has a mix of denser urban fabric than in the surrounding 1950s houses on big blocks and will provide around 80 new dwellings (Figure 10) including some social housing. It has a range of community amenity including water-sensitive urban design and is seeking to be zero carbon (through solar and batteries) as well as the other goals set by One Planet Living. Instead of a NIMBY reaction from the community, many local people have requested to shift into the development as it enables down-sizing as well as community-based amenity.

Exemplars such as K2 and WGV are important in demonstrating the value of good design in delivering triple bottom line urban development outcomes, as well as helping promote medium density as an attractive housing typology capable of wider replication. Replicability of innovative design is a major quest. These demonstration projects provide models for greyfield affordable and social housing stock to catalyse precinct regeneration. The community housing sector appears best placed to pursue this opportunity, given the current lack of capital and development expertise in the public housing sector.[50] In both these cases, however, the greyfields precincts were already in government ownership and hence were large enough for medium and high-density urban fabric.

PRECINCT SCALE REGENERATION OF PRIVATELY OWNED GREYFIELD HOUSING

A significant proportion of current piecemeal greyfield housing

Figure 10: White Gum Valley redevelopment, Perth

Source: LandCorp

redevelopment involves the construction of between two and six new dwellings on either the consolidation of a few adjoining residential properties or one large individual site, in situations where the value of the land typically represents 80 per cent or more of the value of the total property asset prior to redevelopment. As outlined, this represents a fragmented, suboptimal response to redevelopment and provides little basis for significant urban regeneration, much less achieving an urban fabric that can enable housing targets to be met. The challenge remains to develop new mechanisms to do this in a comprehensive and publicly acceptable manner. This goal was the focus of a major study by the Australian Housing and Urban Research Institute that brought together 70 leading built environment thinkers over a 12-month period to explore how infill redevelopment could be undertaken more effectively on a precinct basis to meet a range of strategic metropolitan planning objectives.[19]

The study revealed that the greyfield residential precinct regeneration approach *is* desirable and feasible, but a number of barriers would need to be overcome for successful implementation. Much of the innovation needed was found to be organisational and institutional, supported by some technological innovations. Figure 11 identifies the areas (shaded) where major change needs to occur to achieve a new, viable development model for greyfield residential precincts (see AHURI[19]).

'GREENING THE GREYFIELDS'

In 2011 a national research project was funded by the Co-operative Research Centre (CRC) in Spatial Information called 'Greening the Greyfields'. The project was run by universities in Perth and Melbourne and was later joined by a group from Christchurch in New Zealand. The project had two core goals:

a) To create a set of digital planning tools that could unlock the potential for precinct scale greyfield regeneration.

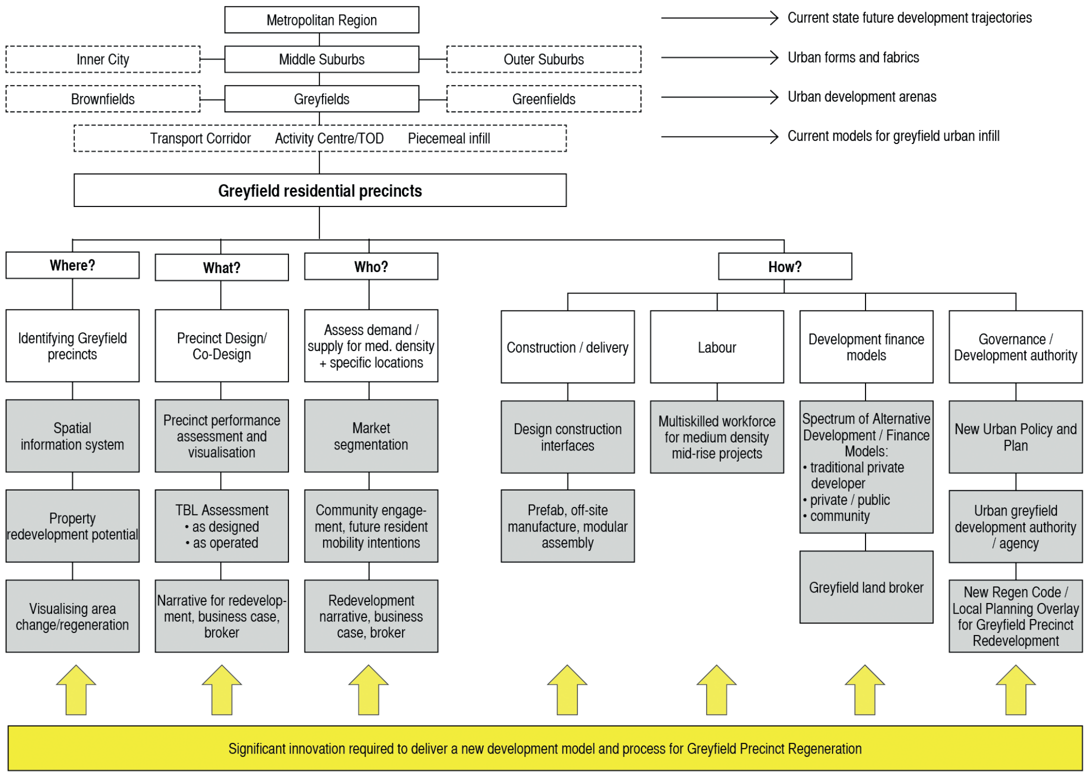

Figure 11: Innovation arenas and 'future logic' for greyfield residential precinct development

Source: adapted from Newton *et al.*, 2011

b) To create a planning approach that could unlock the potential for precinct scale greyfield regeneration.

DIGITAL PLANNING TOOLS

Over the last five years as part of the Greening the Greyfields project a set of tools has been created and tested including:

- **Envision** — a GIS-based approach to identify the areas best suited for urban redevelopment using multi-criteria analysis that can be scaled for various applications. This has been used to create a Housing Strategy in the City of Canning.
- **ReZone** — a tool to enable potential yields to be calculated through rezoning.
- **Viability** — a tool to test for the financial viability of various development densities.
- **Envision Scenario Planner (ESP)** — a tool to assess various precinct developments to allow planning and assessment of factors such as embedded and operational carbon, transport, water use, parking, capital and construction costs.[52]

These tools can be found on www.greyfieldplanning.com.au.

PLANNING APPROACH

Achieving a greater level of residential intensification and broader-based urban regeneration in the greyfields, particularly at a precinct scale, will require planning innovation in several arenas identified by Newton *et al.*[19] and discussed in some detail in Newton and Glackin[30] (see Figure 11). Foremost among these, perhaps, is new urban policy capable of articulating a long-term strategy for targeting urban regeneration in the greyfield inner and middle suburbs. What may be required is something equivalent to the brownfields oriented Building Better Cities programme: establishing a government greyfields regeneration authority equivalent in power to those created to develop the greenfields and the brownfields in a number of states. These regeneration organisations could be complemented by more localised and/or small-scale intervention vehicles that are more common in the US and UK, especially where local councils lack the required expertise[53]; or by capacity building within municipalities in relation to preparation of housing strategies and local spatial plans for neighbourhood change and regeneration that mesh with metropolitan and urban sub-region development objectives.[54] The core requirement is land assembly — because only if smaller parcels can be consolidated into large enough precincts to permit an integrated approach for designing an urban fabric will regeneration opportunities be optimised.

The limitations of current planning prevent the uptake of greyfield precinct redevelopment and, unless otherwise convinced, developers will continue to pursue the well-tested 'safe' piecemeal approaches to residential infill. Therefore, there is a need for a new robust planning instrument (eg overlay or code) for the redevelopment of greyfield residential precincts that can unlock their significant potential.[13]

CONCLUSION

Australian cities are undergoing urban regeneration with a strong market for a greater supply of denser urban housing and mixed use development in its brownfield and greyfield locations. The economic, social and environmental need for greater walking urban fabric and greater transit urban fabric is now generating this demand.

From an urban planning and design perspective, reducing automobile dependence and creating more sustainable urban development requires a new policy focus that has precinct scale regeneration of brownfields and greyfields at its core. Brownfield urban development models capable of widespread replication in our cities are now being implemented. The emerging models for greyfields need further consideration and demonstration. To this end, however, in Plan Melbourne Refresh — an options paper published by the Victorian Government's Department of Planning in late 2015 as precursor to the release of a new long-term strategic plan for Metropolitan Melbourne — formal recognition was made of the need for greyfield precinct renewal:[55] 'a vision of precinct planned infill that provides local government and the community with a framework to better direct and achieve more sustainable outcomes from small scale cumulative change in residential areas.'

References

1. Newman, P. and Kenworthy, J. (2011), 'Peak Car Use: Understanding the Demise of Automobile Dependence', *World Transport Policy and Practice*, Vol. 17, No. 2, pp. 32–42.
2. Newman, P. and Kenworthy, J. (1999), *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press, Washington, DC.
3. Newman, P. and Kenworthy, J. (2015), *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*, Island Press, Washington, DC.
4. Commonwealth of Australia (2013), 'State of Australian Cities 2013', Australian Government, Department of Infrastructure and Transport, Major Cities Unit, p. 404.
5. Neilson, L. (2008), 'The "Building Better Cities" Program 1991–96: A Nation-building Initiative of the Commonwealth Government', in Butcher, J.

(ed). *Australia Under Construction: Nation-building Past, Present and Future*, ANU Press, Canberra, pp. 83–117.
6. Newman, P., Kenworthy, J. and Glazebrook, G. (2013,) 'Peak Car Use and the Rise of Global Rail: Why this is happening and what it means for large and small cities', *Journal of Transportation Technologies*, Vol. 3, No. 4, pp. 272–287.
7. Newton, P. (1991), 'Telematic Underpinnings of the Information Economy', in Brotchie *et al.* (eds), *Cities of the 21st Century: New Technologies and Spatial Systems*, Longman Cheshire, Melbourne, Australia.
8. Hall, P. (1999), *Cities in Civilization: Culture, Innovation, and Urban Order*, Phoenix Giant.
9. Florida, R. L. (2002), *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*, Basic Books.
10. Glaeser, E. (2011), *Triumph of the City*, Pan Macmillan, London.
11. Rawnsley, T. and Spiller, M. (2012), 'Housing and Urban Form: A New Productivity Agenda', in Tomlinson, R. (ed), *Australia's Unintended Cities*, CSIRO Publishing, Collingwood, Victoria.
12. Buxton, M. (2000), 'Energy, Transport and Urban Form in Australia', in Burton, E., Jenks, M. and Williams, K. (eds), *Achieving Sustainable Urban Form*, Routledge, London.
13. Newton, P. and Thomson, G. (2016), 'Urban Regeneration in Australia'. In: Roberts, P., Sykes, H., Granger, R., editors. Urban Regeneration. 2nd ed. London, UK: SAGE Publications.
14. Council NHS (2011), 'State of Supply Report 2011', Canberra.
15. Gipps, P., Brotchie, J., Hensher, D., Newton, P. W. and O'Conner, K. (1997), 'The Journey to Work: Employment and the Changing Structure of Australian Cities', in *Research Monograph* No. 3, Australian Housing and Urban Research Institute, Melbourne, Australia.
16. Taylor, E. and Watling, R. (2011), 'Long Run Patterns of Housing Prices in Melbourne', in *Proceedings of the State of Australian Cities Conference*, Melbourne, Australia.
17. Residential Development Council of the Property Council of Australia and Australian Housing and Urban Research Institute, 2012, 'Planning Governance and Infill Housing Supply in Metropolitan Areas', Melbourne, Australia.
18. OECD (2012), 'Compact City Policies: A Comparative Assessment', OECD Green Growth Studies, Paris.
19. Newton, P., Murray, S., Wakefield, R., Murphy, C., Khor, L. A. and Morgan, T. (2011), 'Towards a New Development Model for Housing Regeneration in Greyfield Residential Precincts', AHURI Final Report.
20. Molotch, H. (1976), 'The City as a Growth Machine: Toward a Political Economy of Place', *American Journal of Sociology*, Vol. 82, No. 2, pp. 309–332.
21. Newton, P. W. and Doherty, P. (2014), 'The Challenges to Urban Sustainability and Resilience: What Cities Need to Prepare For', in Pearson, L., Roberts, P. and Newton, P. (eds), *Resilient Sustainable Cities*, Routledge, London.
22. Newton, P. W. (2012), 'Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities', *Journal of Urban Technology* [Internet], Vol. 19, No. 1, pp. 81–102, available at: http://www.tandfonline.com/doi/abs/10.1080/10630732.2012.626703 (last accessed 12th March, 2016).
23. Cunningham, S. (2008), *ReWealth: Stake Your Claim in the $2 Trillion Redevelopment Trend That's Renewing the World*, McGraw-Hill, New York.
24. UNDESA (United Nations Department of Economic and Social Affairs) (2012), 'Back to our Common Future: Sustainable Development in the 21st Century (SD21) project', available at: http://sustainabledevelopment.un.org/content/documents/UN-DESA_Back_Common_Future_En.pdf (last accessed 12th March, 2016).
25. Newton, P. (2015), 'Framing New Retrofit Models for Regenerating Australia's Fast Growing Cities', in *Retrofitting Cities for Tomorrow's World*, Wiley-Blackwell, London.
26. Newton, P. and Glackin, S. (2015), 'Regenerating Cities: Creating the Opportunity for Greyfield Precinct Infill Development', in Legacy, C. and Leshinsky, R. (eds), *Instruments of Planning: Tensions and Challenges for Delivering More Equitable and Sustainable Cities*, Routledge, London.
27. Newton, P. (2010), 'Beyond Greenfields and Brownfields: The Challenge of Regenerating Australia's Greyfield Suburbs', *Built Environment*, No. 36, pp. 1–53.
28. Neilson, L. (2008), 'The "Building Better Cities" Program 1991–96: A Nation-building Initiative of the Commonwealth government. In: Butcher J. (ed). Australia Under Construction: Nation-Building Past, Present and Future. Canberra: Australian National University E Press; 2008.
29. Freestone, R. (2012), 'An Historical Perspective', in Thompson, S. and Maggin, P. (eds), *Planning Australia*, 2nd edn, Cambridge University Press, Melbourne, Australia, pp. 73–97.
30. Newton, P. and Glackin, S. (2014), 'Understanding Infill: Towards New Policy and Practice for Urban Regeneration in the Established Suburbs of Australia's Cities', *Urban Policy and Research*, Vol. 32, No. 2, pp. 121–143.
31. ABS (2015), 'Regional Population Growth, Australia', Cat. No. 3218.0, Canberra.
32. Rauland, V. and Newman, P. (2015), *Decarbonising Cities: Mainstreaming Low Carbon Urban Development*, Springer International Publishing.
33. Department of Planning (2015), 'Perth and Peel at 3.5 Million', Perth, Australia.
34. Department of Housing and Planning, Western Australian Government (2015), 'The Housing We'd Choose: A Study for Perth and Peel [Internet]', Perth, Australia, available at: http://www.planning.wa.gov.au/dop_pub_pdf/

housing_full_report.pdf (last accessed 12th March, 2016).
35. WAPC (2010), 'Directions 2031 and Beyond', Perth, Australia.
36. Western Australian Planning Commission (2014), 'Urban Growth Monitor'.
37. Howard, E. (1902), *Garden Cities of Tomorrow*, Swan Sonnenschein & Co. Ltd.
38. Hall, T. (2007), 'Where Have All the Gardens Gone? An Investigation into the Disappearance of Back Yards in the Newer Australian Suburb, Urban Research Program, Research Paper 13. Griffith University. Brisbane Australia.
39. Duckworth-Smith, A. (2015), 'Backyard Bonanza: Improving the Quality of "Popular" Suburban Infill', *Australian Planner* [Internet], Vol. 52, No. 4, pp. 297–313, available at: http://www.tandfonline.com/doi/full/10.1080/07293682.2015.1086808 (last accessed 12th March, 2016).
40. Newton, P., Murray, S., Wakefield, R., Murphy, C., Khor, L. and Morgan T. (2012), 'How Do We Regenerate Middle Suburban "Greyfield" Areas?' AHURI Research & Policy Bulletin.
41. LandCorp (2006), 'Cockburn Regional Centre Structure Plan', Perth, Australia.
42. Canning, City of (2013), 'Draft Canning City Centre Structure Plan', Perth, Australia.
43. Wilkie, A. (2015), 'Canning Infill Flows', *Business News Western Australia* [Internet], Perth, Australia, 16th March, available at: https://www.businessnews.com.au/article/Canning-infill-flows (accessed 1st February, 2016).
44. Adams, R., Eagleson, S., Whitworth, F., Goddard, S., Prizibella, S., Sidebottom, T., Webster, R., Stanley, J. and Loader, C. (2009), *Transforming Australian Cities*, Melbourne, Australia.
45. ABS, 2013, '3222.0 — Population Projections, Australia, 2012 (base) to 2101'.
46. Rowley, S. and Phibbs, P. (2012), 'Delivering Diverse and Affordable Housing on Infill Development Sites', Final Report No. 193, Melbourne, Australia.
47. McCloskey, D., Birrell, R. and Yip, R. (2009), 'Making Public Transport Work in Melbourne', *People Place and Policy*, Vol. 17, No. 3, pp. 49–59.
48. Dunham-Jones, E. and Williamson, J. (2008), *Retrofitting Suburbia: Urban Design Solutions for Redesigning Suburbs*, John Wiley & Sons, Hoboken, NJ.
49. Newton, P., Marchant, D., Mitchell, J., Plume, J., Seo, S. and Roggema, R. (2013), 'Performance Assessment of Urban Precinct Design: A Scoping Study', Co-operative Research Centre for Low Carbon Living, Sydney, Australia.
50. Murray, S., Bertram, N., Khor, L-A., Rowe, D., Meyer, B., Newton, P., Glackin, S., Alves, T. and McGauran, R. (2015), 'Processes for Developing Affordable and Sustainable Medium Density Housing Models for Greyfield Precincts', AHURI Final Report No. 236, Melbourne, Australia.
51. Trubka, R., Glackin, S., Lade, O. and Pettit, C. (2016), 'A web-based 3D visualisation and assessment system for urban precinct scenario modelling', *ISPRS Journal of Photogrammetry and Remote Sensing*, UN Division for Sustainable Development, 2015, Vol. 117, pp. 175-186. 'Transforming Our World: The 2030 Agenda for Sustainable Development', UN, New York.
52. Spiller, M. and Khong, D. (2014), 'Government Sponsored Urban Development Projects: What Can Australia Take from the US Experience?' (January), SGS Economics. Melbourne, Australia. Available from: http://www.sgsep.com.au/assets/Spiller-and-Khong-Occasional-Paper-January-2014-FINAL.pdf (last accessed 12th March, 2016).
53. CRC for Spatial Information (2016), 'Greening the Greyfields' [Internet], available at: http://www.crcsi.com.au/research/4-5-built-environment/4-55-greening-the-greyfields/ (accessed 1st February, 2016).
54. The Victorian Government (2015), 'Plan Melbourne Refresh. A Discussion Paper', available at: http://refresh.planmelbourne.vic.gov.au/plan-melbourne-refresh-discussion-paper (p. 57) (last accessed 12th March, 2016).

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Chapter 7: Sustainable Infill Development

The Context

This chapter show how infill development can be sustainable in a global and local sense. It does so by discussing sustainability in terms of urban systems in terms of energy, water, biodiversity and waste; and how an integrated approach to the design of these systems can drive efficiencies even further. Infill opportunities, especially at the larger precinct scale, present an excellent opportunity for enhancing city sustainability, so this chapter concludes by considering a range of sustainability elements in light of a recent Perth case study – WGV.

Global to Local Sustainability

Sustainability has local implications but the most pressing sustainability issues relate to global environmental issues. Human consumption patterns exceed planetary boundaries and are placing unsustainable stress upon the biosphere (Steffen et al. 2015; Rockström et al. 2009). In an attempt to rectify this imbalance the recent 'Paris Agreement' (COP21) and the Sustainable Development Goals (SDGs) represent major international efforts to develop unilateral policy directions to address sustainability in an equitable manner. However, the mechanisms to implement these goal-based agreements are yet to be determined. The solution may lie in cities. This is because the majority of the world's population now live in cities; and cities are centres of power, both governance and financial, making cities the central force driving global change. If refocussed to create sustainable outcomes cities could become the driving force to regenerate the planet (Fink 2013; Girardet 2010; Newman & Jennings 2008). But theoretical propositions such as this can only work if applied in practice. This means that thousands of decisions on the ground need to be aligned to a shared sustainability vision either through shared community values, or policy (e.g. Australian interpretations of the Paris Agreement or SDGs), or increasingly through the financial savings that sustainable living can offer. The purpose of this chapter will be to discuss some of these issues in relation to infill decisions in Perth, that when aggregated can go a long way to making a more sustainable, more liveable and more prosperous city.

The previous chapter on infill explains a number of reasons why infill is preferable to greenfield development in terms of resource use and sustainability. This chapter will discuss a number of additional sustainability overlays, which enable sustainability outcomes to go even further in terms of minimising resource use. But before it is possible to describe sustainable infill it is necessary to first define "sustainable". A simple definition will enable the degree of sustainability success to be measured against the intervention.

To help with this definition the next section distinguishes between three broad horizons of environmental impact in urban planning - green, sustainable and regenerative development (Thomson & Newman 2016; Living Building Challenge 2014; Cole 2012).

All too often developments branded as sustainable really only represent marginal improvements over conventional practice. Therefore, Figure 1 illustrates how “green” design is often simply just “less bad” than the minimum legal requirement of the building regulations, it represents relative improvements to the system (Braungart & McDonough 2009). On the contrary a regenerative development is designed to have a net positive environmental impact upon the biosphere (Mang & Reed 2012; Lyle 1996; Girardet 2010). Anything less than “net zero” impact is essentially unsustainable. Designing to meet the minimum building codes can be considered as “just legal” (Reed 2006), a regenerative mindset reframes the measure of success from meeting the minimum to seeing whether urban development can be designed to become net positive. Different aspects of a development may be regenerative for example biodiversity, creating more energy than is used or harvesting and reusing water on site. Therefore if cities were to become a driving force for the regeneration of degraded environments this would require the widespread adoption of net positive regenerative development.

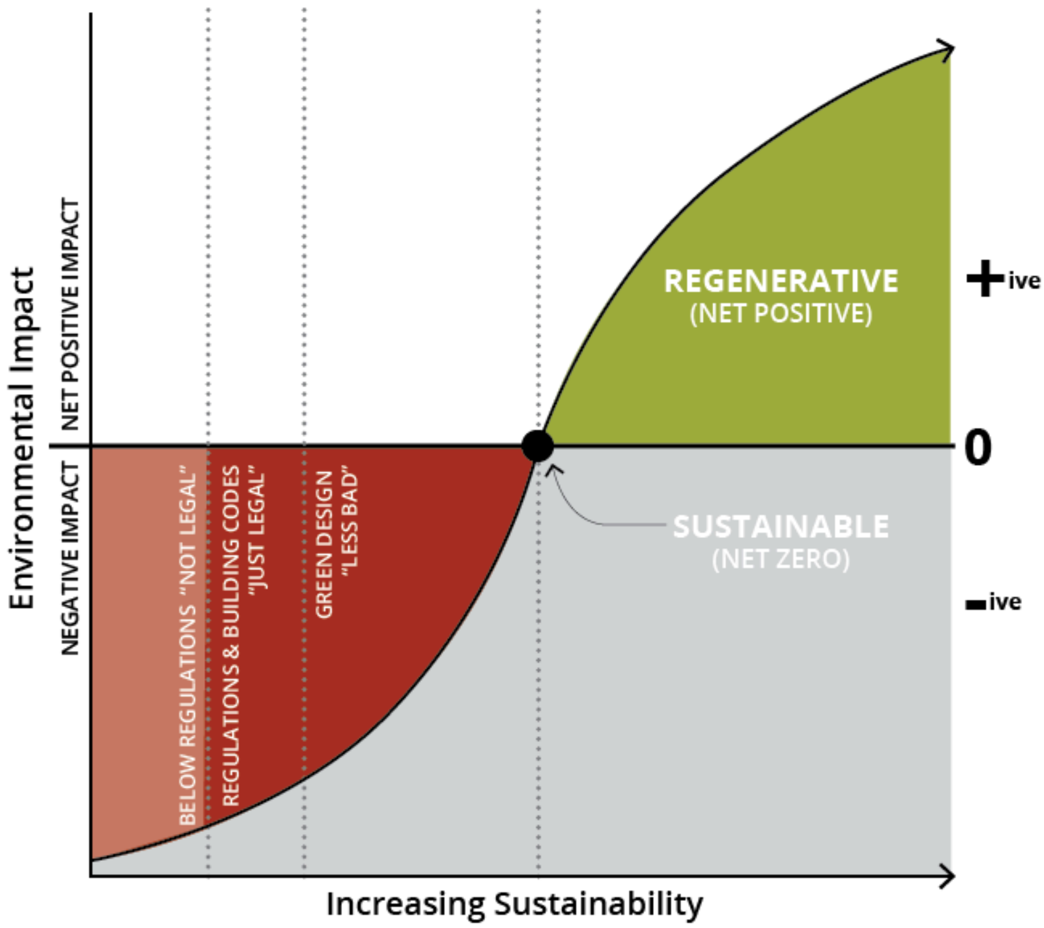

Figure 1: Net positive impact 'regenerative' design. Adapted from Living Building Challenge (2014)

Urban Metabolism

Modern cities have been generally designed as extractive engines drawing resources from natural systems, processing these resources to generate value, and producing wastes whose impacts are externalised. In the 1960s Wolman (1965) was the first to liken the input / output transactions of material flows through a city to the metabolism of an organism, by this notion of material flow accounting within human settlements is commonly referred to as 'urban metabolism'. The concept of urban metabolism has experienced a popular resurgence in recent years (Gandy 2004; Girardet 2010; Newman & Kenworthy 1999; Baccini & Brunner 2012) as systems scientists and urban practitioners, seek to better understand, measure and manage urban performance, growth and environmental impact.

Urban metabolism is a holistic way to understand the physical sustainability of cities. A genuinely smart urbanism is sustainable when it links development decisions to ecological impact. Urban metabolism therefore is an ideal tool for monitoring material flows to assist planners and designers optimise metabolic footprint (resource inputs and waste outputs) to reduce ecological impact, and in the process improve liveability.

Existing best practice technologies and design demonstrate that optimising urban metabolism can greatly enhance urban sustainability performance and reduce costs while producing life-affirming co-benefits to burgeoning cities. But to do so requires an integrated approach to planning, design and governance. Urban metabolism can, and should, be used as a design tool to inform sustainable urban design decisions (For a detailed example of an urban metabolism analysis of resource flows in Perth see the case study in Chapter 6).

Innovators in the built environment sector are already demonstrating how a regenerative urbanism can radically improve sustainability performance while maintaining or even enhancing liveability within cities (Newman et al. 2009; Newman & Kenworthy 2015; Beatley 2012; Beatley & Newman 2012). This approach represents a reframing of cities as a positive locus of sustainability action, as opposed to, a mechanistic site of consumption that externalises its environmental ills. The positive potential of sustainable urban environments to facilitate change is the premise behind the newly adopted UN Sustainable Development Goal 11 'to make cities inclusive, safe, resilient and sustainable'(United Nations General Assembly 2015). It is also the rationale for international organisations such as C40 Cities and ICLEI that have had a strong sustainable city agenda for some time.

So what does this mean for Australian cities?

Sustainable and liveable

Australian cities are renowned for the high quality of life afforded to citizens. According to the OECD better life index Australia ranks a close second after Norway for quality of life across eleven indicators (OECD 2016), while the Economist in 2015 ranked Melbourne the most liveable city in the world, with Adelaide [5th=], Sydney [7th] and Perth [8th](Economist Intelligence Unit 2015). However, research by Newton (2012) shows a clear correlation between higher city liveability to higher ecological footprint. Decoupling ecological footprint from the high consumption patterns currently associated with liveability will be one of the key challenges of the 21st century (Swilling et al. 2013; Gómez-Baggethun & Barton 2012; Steffen et al. 2015). However the challenge is not so much related to what to do, but rather how to do it at scale. Numerous exemplars can be found to demonstrate sustainable urban development but these are the exception not the rule.

Rapid urban growth in Australia is fuelled by high population growth, from both natural and immigration sources. To put this in context, Australia's population in the year to 31 December 2015 grew by 326,100 people consisting of:

- 148,900 people natural increase;

- 177,100 people of net overseas migration (ABS 2015).

This annual growth equates to nearly the population of Canberra, with the majority of that growth concentrated in the four major cities of Melbourne, Sydney, Perth and Brisbane.

In attempting to absorb this rapid population growth care must be taken to ensure Australian cities continue to perform at current levels. Whilst quality of life indicators are universally high there is some indication that performance is slipping. The Mercer *Quality of living survey* ranks Australian cities very highly but over time between 2004 and 2011 observes a slight reduction in quality of living in the four most populous and fastest growing cities (Commonwealth of Australia 2012, p.212), and notes that this trend is likely to become even more pronounced if population growth continues to outpace investment in lifestyle enhancing infrastructure (e.g. public transport). Chapter 6 provides more discussion around what infrastructure is needed where and how it might be funded better.

Liveability also includes the affordability of housing and the affordability of urban living. Australian cities have mostly created affordable housing on the urban fringe but increasingly this is not affordable living as the costs of transport are so high from the far flung suburbs (Rowley & Phibbs 2012)

The challenge for sustainable urban development is, therefore, two-fold:

- Firstly, the need to decouple liveability from high ecological footprint, and
- Secondly, to do so while accommodating urban growth through the provision of infrastructure and development in a way that creates liveability and sustainability.

Key to achieving this will be the mass implementation of low impact substitutes for delivering urban services (e.g. housing, transport, energy) that still deliver high quality of life outcomes (Newman & Jennings 2008; Newman & Kenworthy 1999). This chapter will discuss how sustainable, higher density infill, offers our best opportunity to achieve high sustainability and liveability.

Density, Design and Infill

Urban density is clearly the answer to the sustainability of our cities in preventing urban sprawl and creating opportunities for better transport options (Newman & Kenworthy 1999; Newman & Kenworthy 1989; Newman & Kenworthy 2015). However, the argument is more nuanced than this, not all density is equal. Density is a metric, most commonly referring to urban population, and by extension, building concentration. Good density is a product of good design (Llewelyn-Davies 2000). Design variations will make a big difference on how attractive the options are for liveability and sustainability.

Density targets, can also be applied to public realm outcomes such as green open space, canopy cover, water sensitive urban design interventions, solar panel penetration, this is uncommon, but would deliver more sustainable infill outcomes. Critically it is design quality that matters and how these disparate urban elements work together as an integrated whole (Fraker 2013). Dense urban infill should aim not only to be dense in buildings but also dense in urban services, dense in canopy cover and green open spaces and other liveability enhancing urban elements.

When density is prescribed as a mandatory measure as is standard with infill development it is possible and quite common to get poorly performing urban outcomes (Newton, Newman, et al. 2012). More useful is the application of performance criteria and form based codes that can better incorporate design considerations. This chapter describes various urban elements such as energy, water, waste, biodiversity and canopy cover and how decisions around infill interact with these elements to create more (or less) sustainable environments.

Sustainable buildings and sustainable neighbourhoods

Individual buildings can be designed to be highly autonomous structures with very efficient operating performance. However, larger sites present additional advantages over plot scale infill. Planning at the precinct or neighbourhood scale allows greater scope to integrate sustainability enabling infrastructure, for example public transport, public open space, social amenities, water catchments, underground power, biodiversity corridors, social housing and/or aged housing. Well-planned infill will better integrate these urban elements and in so doing will deliver more sustainable outcomes that also better provide for residents thus making these places more desirable to live in.

Case Study - WGV

To help explain the application of some of the concepts in a Western Australian context the chapter links initiatives to one of the most recent and best known sustainable infill precincts in Perth, WGV (named for its location in the Fremantle suburb of White Gum Valley). WGV consists of over 80 dwellings on a 2 hectare site, three kilometres from Fremantle. It is the first Western Australian project to be awarded the One Planet Community[1] sustainability accreditation and the second only in Australia (after WestWyck ecovillage in Melbourne).

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1 For more on One Planet Communities see http://bioregional.com.au/oneplanetliving/oneplanetcommunities/

The development is currently under construction offering a wide housing mix (including villas, townhouses and apartments) and is around three times as dense as the surround 1950s housing stock on big blocks (see Figure 2). WGV has a range of community amenities including some social housing, water sensitive urban design, and is seeking to be zero carbon (through solar and batteries) as well as the other goals set by One Planet Living.

Figure 2: Artist rendering of WGV. Source LandCorp

Part of the reason this development has been able to deliver so much can be related to strong leadership and complementary partnerships. The project was developed by the Western Australian land and infrastructure agency, LandCorp as an Innovation through Demonstration project, but has shared support from the local authority, the City of Fremantle. Instead of a NIMBY reaction from the community many local people have requested to shift into the development as it enables down-sizing as well as community-based amenity.

The delivery of sustainable infill precincts requires a combination of the right urban fabric, infrastructure integration, and technology (Girardet 2015; Newman et al. 2012). Integration will need to address each of the following components – energy, water, biodiversity and waste - to collectively work toward the delivery of a sustainable, or potentially regenerative, city.

Each of these is discussed below with reference to WGV where appropriate.

Energy

Energy use can be greatly reduced through demand management, for example through highly energy efficient buildings. While, relatively rare in Australia the super insulated, high performance, Passivhaus standard building envelopes are almost airtight, requiring only the smallest amount of energy to heat or cool the space (Passive House Australia 2014). Building an energy efficient building and supplementing this with renewables (either on-site or off-site) can deliver a zero carbon building, Figure 3 illustrates the Australian Sustainable Built Environment Council (ASBEC) recommendation for an Australian standard zero carbon building definition (Reidy et al. 2011).

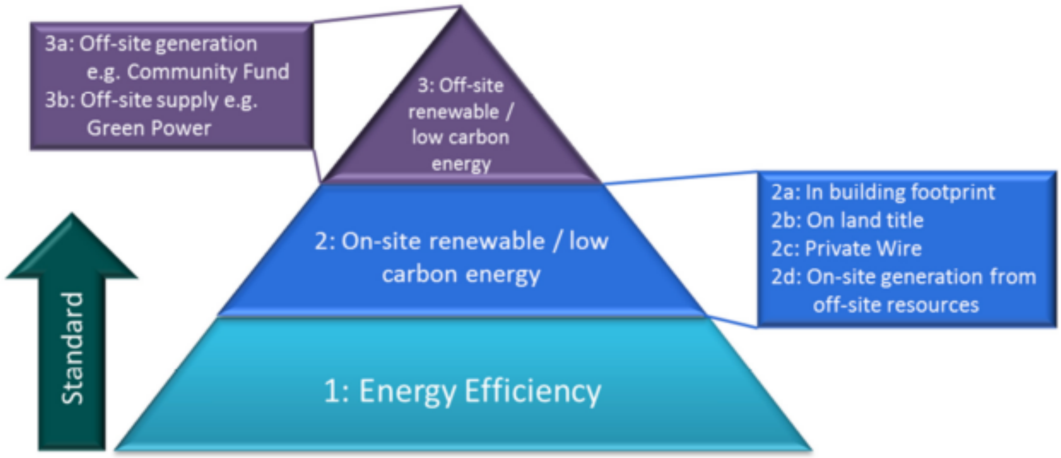

Figure 3: Recommendation for Australian Standard zero carbon building definition. Source Reidy et al. 2011.

It is even possible to create an energy plus precinct (i.e. one that creates more energy than it uses) by providing renewable energy generation at all available sites from sun, wind and geothermal sources.

Uptake of solar in Perth has been rapid, to the point that aggregate rooftop solar is now effectively "the largest power station in the state", with 200,000 arrays covering 20% of rooftops (Clover 2016). However the majority of solar is found on the rooftops of single owner detached villas (Newton & Newman 2013). To date uptake of solar has been much slower in strata buildings given the business and governance difficulties related to multiple ownership. Given that around a third of Australian dwellings are strata titled and this number is growing due to infill this presents a major barrier to solar uptake.

In the WGV case study, energy demand reduction and renewables aim to reduce grid energy consumption by 60 per cent across the development as a whole, and 100 per cent (zero net annual energy) in dwellings which take advantage of the WGV Sustainability Rebate Package.

One of the most innovative aspects of the WGV demonstration is a trial for the use of solar PV and storage where power bills come to individual tenants, not from an electricity company, but from the body corporate. The model will reduce carbon, provide electricity cost savings to the resident and repay the upfront capital costs for the PV infrastructure (Parkinson 2016). This is of particular relevance to infill because it presents a mechanism to unlock current barriers for the easy application of solar within strata developments. This is not only allows more residents access to ethical power but also financially helpful as recent research has found that in Perth a combination of solar PV and batteries that can enable any development to be zero carbon at lower cost than coal-fired power (Green, Byrne and Newman, 2015).

Integrating higher density, mixed-use urban areas, with public transport will reduce transport energy needs due to, shorter distances between locations, and the efficiencies of mass transit (Kenworthy & Laube 2001; Newman & Kenworthy 2011). Mass transit can be supplemented by car share schemes for longer journeys and good cycling and walking networks to make local trips more pleasant and safer. Where the fuel used to build and operate buildings and build and run transport, is renewable, an oversupply of energy can be harvested and used to help power and fuel the surrounding bioregion. This is likely to be renewably-powered electric systems in buildings and transport as well as renewably-powered gas (Newman & Kenworthy 2015).

Water

Potable water demand can be greatly reduced through water efficiency measures as well as water harvesting from rainwater and storm water collection, and recycling wastewater. Water can be fully collected at source within a city, as well as being recycled from grey water and black water and used to help regenerate aquifers and water bodies in the bioregion.

WGV demonstrates several initiatives to improve water consumption and maximise water harvesting. The water goal for the development is a 70 per cent reduction on typical mains water consumption. This will be achieved through the use of large shared underground (strata owned) rainwater tanks, a community bore, greywater recycling, irrigation meters, sensors and a distribution network for non-potable irrigation water via “purple pipes”. Excess water will infiltrate on site to recharge local groundwater through the existing on-site sump that has been revegetated to doubles as an accessible landscape feature. All houses will be dual metered for mains water and purple pipe water. Because much of this work is innovative metering will be conducted to determine the benefits of these approaches for application to other developments (Josh Byrne & Associates 2016).

Privately owned on-plot rainwater tanks are most efficient in areas where there is relatively constant annual rainfall to continually recharge what are typically small storage volumes in most domestic tanks. The climate in much of southern Australia is cool and wet winters, with long, hot, dry summers, meaning small rainwater tanks can be quickly exhausted. A complementary measure capable of storing much larger volumes of water is Aquifer Storage and Recovery (ASR). ASR is a large-scale process that can be used wherever the underlying stratigraphy permits. ASR has been used with considerable success in Playford, South Australia, where water is channelled through the street network to the Munno Parra urban wetland. The wetland reduces the nutrient content of the water, the clean water is then actively injected into the aquifer during periods of high rainfall, and recovered from the aquifer during periods of low rainfall (City of Playford 2015). The geomorphology of some cities is less suited to ASR, for example Perth's Quaternary sands are not suitable, but deeper stratigraphy may have potential. A 2013 study by the CSIRO demonstrated the technical feasibility for aquifer storage and recovery in the Leederville aquifer (Prommer et al. 2013).

Biodiversity and canopy cover

Given that much of southern Australia is a hot and heating environment the maintenance of vegetation cover, particularly taller tree canopies, is critical, not only for biodiversity but also for climate change resilience and urban comfort in periods of hot weather.

The warming impact of decreased canopy cover is called the "urban heat island effect" and the impact is greater than thermal comfort alone, as increased hot weather is also associated with adverse health impacts and it is closely correlated to increased mortality (Norton et al. 2015), and higher energy costs required for active cooling by air conditioning. Recent research by the Nature Conservancy and C40 Cities also demonstrated that leafy trees are the only cost effective solution for addressing both air quality and rising urban temperatures (McDonald et al. 2016). Yet, strangely, the benefits of urban greenery and the ecosystems services they provide are often overlooked as areas are redeveloped with infill.

A 2016 study by the City of Canning in Perth found on a hot day that the land surface temperature differential could be greater than 10 degrees Celsius dependant upon the underlying land use (see Figure 4).

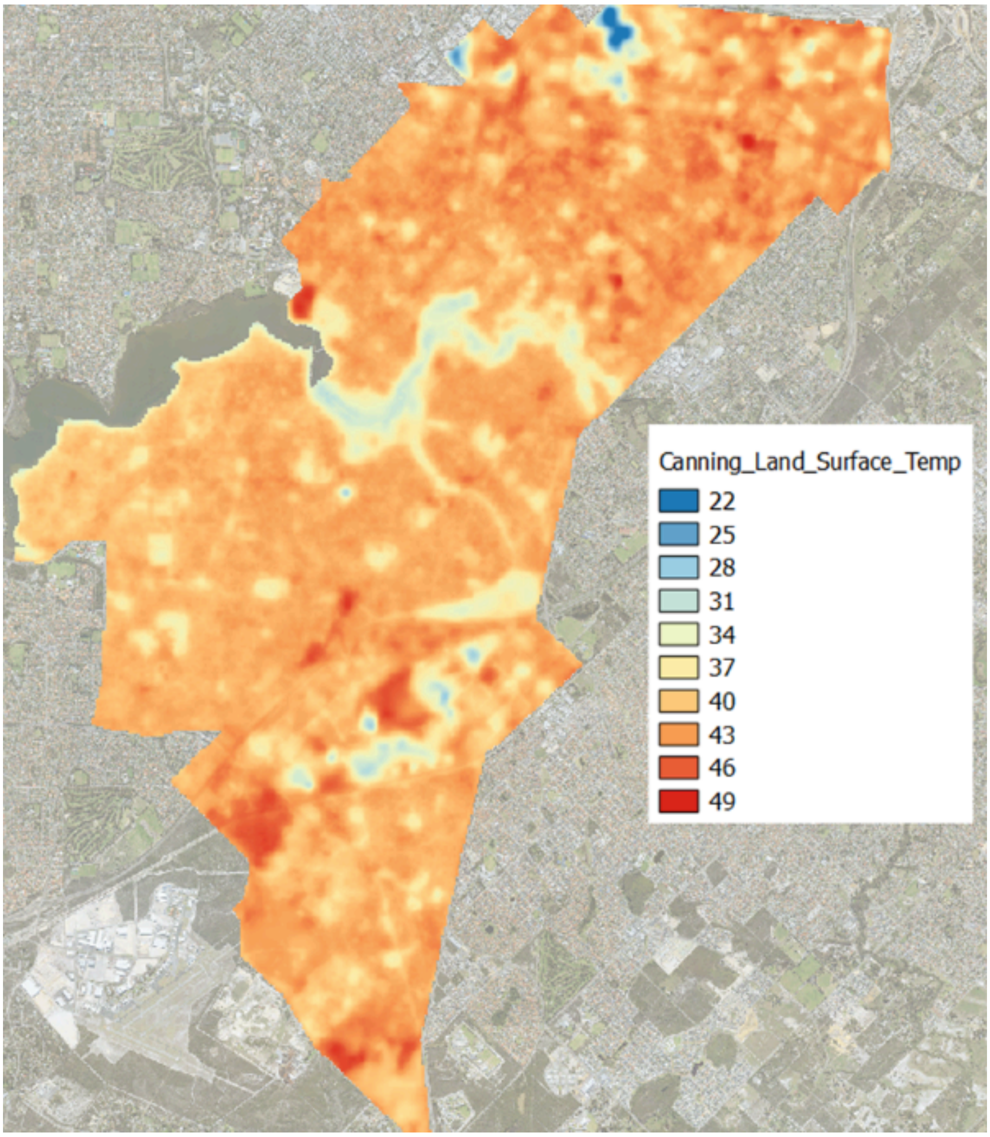

Figure 4: City of Canning land surface temperature map. Source City of Canning 2016.

Comparisons of land cover temperature correlations within the City show that the median variation across a plot will see buildings and non-vegetated land 5-6 degrees Celsius warmer than land covered by trees (see Figure 5). Conventional infill tends to neglect urban greenery, therefore, in April 2016, the City committed to investigate a range of policy measures that will allow infill to occur while increasing canopy density.

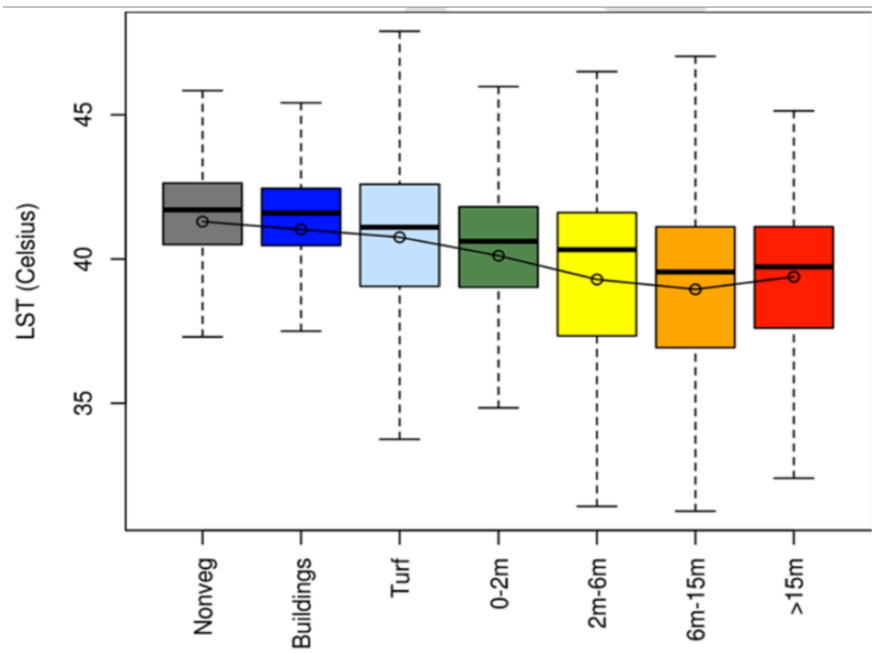

Figure 5: Land cover temperature correlation. Source Canning City Council 2016

The findings at Canning reflect the situation in many other councils (Hall 2007). In Perth, the City of Stirling is rapidly losing canopy cover to infill development. In 2014, the Council set a target of increasing canopy cover to 18% from 12.7%. In 2013, the council lost 22 hectares of canopy cover and predicts that without a mandate to protect trees it will lose 45% of all trees on private development sites over the next 15 years to infill development (leaving only 5% of residential areas shaded by trees) (Young 2016).

Similarly the City of Fremantle with only around 10% canopy cover is well behind the average national suburban canopy cover of 39% (Jacbos et al. 2014). In recognition of this limitation in 2015 Fremantle Council introduced an ambitious target of 20% canopy cover by 2040. This will be achieved by increasing plant cover in the public realm but as this is insufficient to meet the target, the Council committed in August 2016 to explore measures aimed to reduce canopy loss on private land, including the requirement for planning permission to remove larger trees (Emery 2016).

Even the most urban areas have considerable opportunity to increase greenery, for example, an *Urban Forest Strategy* has been prepared for both the City of Melbourne, which aims to increase canopy cover from 22% to 40% by 2040 (City of Melbourne 2012), and the City of Sydney which aims to increase from 15.5% to 23.25% by 2030 and then 27.15% by 2050 (City of Sydney 2013). Both these urban forest strategies increased canopy cover but also increased species diversity, community education and improved urban ecology.

Trees can be integrated into urban infill and given the liveability and health risk of canopy loss, higher vegetation density within redevelopment areas is critical. Sydney, which has seen the greatest amount of infill of all Australian cities, has used the *State Environmental Planning Policy 65 – Design Quality of Residential Apartment Development* (SEPP65) to mandate minimum areas for "deep soil zones" since 2004. The requirement stipulates minimum areas suitable for tree growth within all apartment building developments of three storeys or more with four or more dwellings (New South Wales Government 2015). The Victorian Government's *Draft Better Apartments Design Standards* introduced similar requirements when it was released for comment in May 2016 (see: Government 2016). Provision of minimum deep soil zones enables deep-rooted vegetation space in which to grow even in the densest of infill areas and is a measure that would be wisely adopted in other planning jurisdictions.

It is difficult to control urban canopy cover on private land but increasingly sophisticated remote sensing can cost effectively track canopy cover and be used as a planning tool to incentivise tree growth or retention and potentially penalise canopy cover loss.

In degraded urban environments with minimal endemic habitat there may be numerous opportunities for revegetation. Table 1 summarises the canopy cover of inner city areas in Australia's major capital cities from a 2014 benchmarking exercise by the Sydney based Institute for Sustainable Futures. It also and indicates the potential within each capital city to increase canopy cover (Jacbos et al. 2014).

Table 1: Capital City Land Cover (%). Source Jacobs et al. (2014)

Area	**Trees**	**Shrubs**	**Grass / Bare ground**	**Hard Surface**
City of Melbourne	12.9%	1.8%	22.3%	63%
City of Sydney	15.2%	2.5%	13.2%	69.1%
City of Adelaide	20.3%	1.3%	31.9%	46.5%
City of Perth	26.1%	3.3%	23.8%	46.8%
Inner Brisbane	16.3%	3.9%	20.1%	59.7%
City of Hobart	58.6%	8.5%	14.2%	18.7%

The table shows that just over a quarter of the City of Perth (i.e. Central Perth) is covered by trees (this includes Kings Park and other reserves) yet there is an almost equal amount of grass and bare ground totalling nearly 3km^2. Even a moderate replanting program on grassed and bare surfaces could add considerable canopy cover. Similarly there is the potential for the conversion of hard surfaces. Councils regularly insert new tree planting in footpaths using concrete cutting equipment. Car parks and roads can incorporate trees and swales and potentially biodiversity can be built into every part of the urban fabric, including green roofs and green walls. Bioregional needs in biodiversity can be facilitated by local councils in partnership with civic groups such as the metropolitan Natural Resource Management regions who in combination are best positioned to co-ordinate planting of different structural habitats and managing and motivating intensive human power (e.g. urban agriculture, and urban biodiversity conservation) (see: Newman & Jennings 2008; Newman & Matan 2013; Newman 2014). The introduction of such biophilic urbanism strategies that enable green roofs, green walls and water sensitive design can transform degraded urban environments into habitat rich ecosystems and in some instances create more habitat opportunities than existed on the site before it was built on (Beatley 2009).

By way of example at WGV tree canopy cover on the site will be restored to 30% site coverage. In addition 30% of the street trees will be planted as edible fruiting species to support local food production.

Waste

Waste can be reduced to very small amounts through urban industrial ecology approaches whereby waste are reframed as resources (Ellen MacArthur Foundation 2015; Broto et al. 2012). For example, sewerage may be “mined” for a variety of products including, water, biogas (methane), and elements such as carbon, phosphorus, nitrogen and other trace elements (Newman & Jennings 2008). Many councils are bulk composting green garden waste rather than burying it, and utilise this resource on public land as mulch. The City of Adelaide at their Green Waste Recycling and Mulch Centre has created a small green enterprise by charging non-City residents for dumping green waste and selling mulch and compost to the community.

Recycling within domestic waste is common and increasing in most council areas. In Perth, the largest waste stream by volume is construction and demolition material. The Western Australian Local Government Association (WALGA) estimates that this stream contributes around 50% of waste by volume (WALGA 2016).

Construction materials can be significantly reduced if new technologies and construction techniques (such as modular) can be used and recycling is optimised (Sanchez et al. 2015), however, thermodynamic limits mean that productive material outputs can never be greater than material inputs unlike water and energy (Gardner & Newman 2013). Manufactured buildings are well suited to infill locations (as described in Chapter 5) and enables high performance building envelopes to offer sustainability and operational cost benefits to the occupants. They also greatly reduce construction waste volumes offering sustainability and cost benefits to developers and waste management authorities.

Integration

Collectively, consideration of these sustainability elements creates numerous opportunities for infill to be delivered in a more sustainable, or even regenerative, manner. The planning of new developments should seek infrastructure synergies at the energy, water and waste nexus (GIZ and ICLEI 2014); such integration of utilities can optimise efficiency between each through an industrial ecology (Kennedy et al. 2007) and the circular metabolism of a regenerative city (Girardet 2015; Gardner & Newman 2013).

However, this cannot be done unless the economic and social generators from the site are simultaneously being achieved. The articulation of a sustainable city vision will also require commitment to high quality of life provision, affordability and new green enterprises to replace jobs that may be lost from a sustainability transition.

Many of these sustainability measures work best where there are higher densities. This is because higher densities reduce per capita costs for any shared infrastructure. Where the provider of sustainability infrastructure is government (e.g. public realm and WSUD) costs can recouped through rates, and where the provider is private industry (e.g. car share) the higher density of residents offers a larger market to pay for services.

Mainstreaming sustainable urbanism

Several elements will accelerate sustainable urbanism mainstreaming including:

- Leadership to establish and drive a clear vision,
- Accreditation and auditing to ensure the outcomes planned are the outcomes delivered;
- Digital tools (the subject of Chapter 5) and evidence based design to optimising production processes and operational performance,
- A planning framework that supports and facilitates integrated development outcomes and maximise community input and buy-in,
- Unlocking previously developed, low-density land (brownfields and greyfields) for redevelopment.

These key areas are discussed in greater detail below.

Setting the Vision

Vision and commitment to sustainable urbanism is essential, because business as usual approaches are not sustainable (Planning Institute of Australia 2016; Australian State of the Environment Committee 2011). Setting a sustainability vision for new development requires commitment to evidence based approaches such as urban metabolism analysis, which may require a systemic rethink of development approaches. A sustainability vision will need to be as specific as possible, it is not enough to state a development will be sustainable, measures of sustainability must be outlined in detail. Certain aspects of a vision may be standardised but a well-crafted vision will contain variation based upon its local conditions including neighbourhood characteristics, climate zones and community composition. The best visions tend to be community driven (e.g., participatory and deliberative) and supported by robust principles and metrics (cf. targets, goals).

As discussed in Chapter 6 the type of urban fabric will impact urban sustainability performance. Generally speaking higher density infill is the most efficient and lends itself to other sustainability infrastructure e.g. transit and trigeneration that only become economically viable with a higher population density or rate base.

Accreditation

To assist with measuring project sustainability a range of accreditation tools can be used for shaping an action plan or describing quality standards. Just as performance optimisation processes within business adopt the mantra 'what gets measured gets managed' - this is equally true for sustainable built environment leadership. Several sustainability accreditation tools and processes exist including the industry standards established by the Green Building Council of Australia, GreenStar for buildings, and GreenStar Communities for precincts. However a number of sustainability accreditation schemes with origins outside of Australia are entering the Australian market, notably, One Planet Communities, Living Building Challenge and PassivHaus. Some accreditation programs award ratings on "as designed" rather than "as built" outcome, however research shows that there are often significant differences between the two measures (Gupta & Dantsiou 2013). Post construction audits may be useful in the identification of faults that have a major impact upon overall building performance.

Supportive planning framework and sustainable infill taskforce

A supportive planning framework is critical, without it policy may well impede sustainable infill and facilitate suboptimal outcomes that compromise urban performance. Getting infill right is essential. There have been calls for new taskforces to facilitate good infill requirements (Newton et al. 2011; Kelly et al. 2012), this might involve design review to assist with independent quality control. Squandering redevelopment opportunities may result in lock in of poor development outcomes because once redevelopment occurs the higher densities and multiple ownership make future redevelopment increasingly difficult (Geels 2002; Smith et al. 2010).

New models for sustainable urban regeneration will require clever design and ongoing performance monitoring. In addition to a possible "sustainable infill taskforce" new forms of governance may also be required to monitor and manage increasingly distributed and localised infrastructure and services (Thomson & Rauland 2014). Planning frameworks may consider the use of standardised reporting metrics that can roll up to meet national reporting structures capable of feeding into sustainability metrics for state, national goals and international agreements such as the Paris Agreement and SDGs.

Unlocking land development

Infill by definition falls into established urban areas, but much of this land is locked up in existing uses. In the 1980s and 1990s most major infill sites in Australian cities were "brownfield" that is former industrial sites that were no longer required. Brownfield sites are becoming increasingly rare, especially in the inner city. The focus of attention has turned more recently to "greyfield" sites (Newton 2014; Newton, Newman, et al. 2012), these are underutilised residential precincts comprising low density, detached dwellings on single lots, well located in the inner and middle suburbs (Newton et al. 2011). For an extensive treatment of greyfield development see Newton (Newton, Murray, et al. 2012).

Rezoning of land is one mechanism commonly used to promote redevelopment of greyfield land. But to achieve the benefits that come with precinct scale development, land assembly of greyfield sites will be necessary otherwise inferior *ad hoc* infill, resulting in suboptimal piecemeal development, will occur (Thomson et al. 2016). For this reason density bonuses for larger redevelopment lots may be used as a policy incentive to encourage the assembly of smaller lots into bigger parcels (Legacy & Leshinsky 2015; Newton, Newman, et al. 2012).

However a more recent model has been proposed for the joint sale of allotments if certain conditions are met and the sale is agreed to by the majority of owners (Kelly et al. 2012). The entrepreneur rail model (discussed in Chapter 6) describes a mechanism for public private partnerships to deliver sustainable infill around rail corridors using private capital (Newman et al. 2016).

Conclusions

Across all tiers of government from local, state, national and international (Paris Agreement and SDGs etc.) there is policy direction to improve the sustainability performance of our cities. This chapter demonstrates the importance of sustainable planning and technology to help achieve this. The very fabric of our urban environment has a strong influence on urban performance, including both the location of density (e.g. adjacent transit or in activity centres) and the composition of density (as discussed in Chapter 6). In addition incorporating sustainability overlays such as energy, water, waste and biodiversity as outlined in this chapter can push sustainability performance further.

As infill becomes increasingly common in Australian cities highly sustainable redevelopments such as WGV demonstrate what is possible when an integrated approach to urban design, energy, water, waste and biodiversity occurs. The sustainability advantages are obvious however there are also financial benefits to residents with projected cost saving of up to $1,200 per year when compared to utility bills of a typical Perth home. It is upon templates such as this that Perth and other Australian cities need to build to help reduce Australia's disproportionately high per capita ecological footprint while also providing liveability and financial benefits to citizens.

An urban metabolism approach supported by material flow analysis provides a powerful evidence-based tool for monitoring the sustainability of urban populations, it can be used both to measure operational performance and particularly when used in conjunction with design tools such as Precinct Information Models (see the account of PIM in Chapter 5) may be used to design highly sustainable, or even regenerative developments.

Whole of city targets can be set for infill sites to encourage new development to meet or exceed these goals; this will potentially require new governance mechanisms and authorities. Prescription of additional standards may be resisted by some as "green tape". However the public good benefits, through better performing cities; and to individuals, through the provision of homes that are more comfortable and more affordable (to operate) present a powerful case for striving to achieve sustainable infill development.

References

ABS, 2015. *3101.0 - Australian Demographic Statistics, Dec 2015*, Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0 [Accessed August 25, 2016].

Australian State of the Environment Committee, 2011. State of the Environment 2011 (SoE 2011) - Built Environment, Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Available at: http://www.environment.gov.au/soe/2011/report/built-environment/index.html.

Baccini, P. & Brunner, P.H., 2012. *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*, MIT Press.

Beatley, T., 2009. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into our Lives. *William & Mary Environmental Law & Policy Review*, 34(1), pp.209–238.

Beatley, T., 2012. *Green Urbanism: Learning From European Cities*, Island Press.

Beatley, T. & Newman, P., 2012. *Green Urbanism Down Under: Learning from Sustainable Communities in Australia*, Island Press.

Braungart, M. & McDonough, W., 2009. *Cradle to Cradle*, Random House.

Broto, V.C., Allen, A. & Rapoport, E., 2012. Interdisciplinary Perspectives on Urban Metabolism. *Journal of Industrial Ecology*, 16(6), pp.851–861.

City of Melbourne, 2012. Urban Forest Strategy: Making a great city greener 2012-2032. , p.68. Available at: https://www.melbourne.vic.gov.au/Sustainability/UrbanForest/Documents/Urban_Forest_Strategy.pdf.

City of Playford, 2015. Waterproofing Playford Wetlands & Aquifer Storage Recovery Processes - Fact sheet.

City of Sydney, 2013. City of Sydney Urban Forest Strategy 2013. , pp.1–80.

Clover, I., 2016. Western Australia's rooftop solar now state's "biggest power station." *Reneweconomy*. Available at: http://reneweconomy.com.au/western-australias-rooftop-solar-now-states-biggest-power-station-27206/.

Cole, R.J., 2012. Transitioning from green to regenerative design. *Building Research & Information*, 40(1), pp.39–53.

Commonwealth of Australia, 2012. *State of Australian Cities 2012*, Australian Government, Department of Infrastructure and Transport, Major Cities Unit.

Economist Intelligence Unit, 2015. Daily chart: The world's most "liveable" cities | The Economist. Available at: http://www.economist.com/blogs/graphicdetail/2015/08/daily-chart-5 [Accessed August 22, 2016].

Ellen MacArthur Foundation, 2015. Open Source Circular Economy. In Perth: Creative Commons.

Emery, K., 2016. Fremantle council ban on cutting down mature trees. *The West Australian*.

Fink, J.H., 2013. Geoengineering cities to stabilise climate. *Proceedings of the ICE - Engineering Sustainability*, 166(5), pp.242–248. Available at: http://www.icevirtuallibrary.com/content/article/10.1680/ensu.13.00002.

Fraker, H., 2013. *The Hidden Potential of Sustainable Neighborhoods: Lessons from Low-Carbon Communities*, Washington, D.C.: Island Press.

Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. *City*, 8(3), pp.363–379.

Gardner, H. & Newman, P., 2013. *Reducing the materials and resource intensity of the built form in the Perth and Peel regions*, Perth, Australia.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), pp.1257–1274. Available at: http://www.sciencedirect.com/science/article/pii/S0048733302000628.

Girardet, H., 2015. *Creating Regenerative Cities*, Routledge.

Girardet, H., 2010. Regenerative cities. , p.20. Available at: www.worldfuturecouncil.org.

GIZ and ICLEI, 2014. *Operationalizing the Urban NEXUS: towards resource efficient and integrated cities and metripolitan regions*, Eschborn, Germany.

Gómez-Baggethun, E. & Barton, D.N., 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, pp.235–245. Available at: http://dx.doi.org/10.1016/j.ecolecon.2012.08.019.

Government, V.S., 2016. Better Apartments Consultation Draft. Available at: http://haveyoursay.delwp.vic.gov.au/better-apartments [Accessed August 25, 2016].

Gupta, R. & Dantsiou, D., 2013. Understanding the Gap between `as Designed' and `as Built' Performance of a New Low Carbon Housing Development in UK. In A. Hakansson et al., eds. *Sustainability in Energy and Buildings: Proceedings of the 4th International Conference in Sustainability in Energy and Buildings (SEB{\textasciiacute}12)*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 567–580.

Hall, T., 2007. *Where Have All the Gardens Gone? An Investigation into the Disappearance of Back Yards in the Newer Australian Suburb. Urban Research Program, Research Paper 13*, Brisbane, Australia.

Jacbos, B., Mikhailovich, N. & Delaney, C., 2014. *Benchmarking Australia's Urban Tree Canopy: An i-Tree Assessment, Final Report 2014*, Sydney, Australia.

Josh Byrne & Associates, 2016. *WGV Waterwise Development Exemplar 2015 / 16 Partner Update*, Fremantle, Australia.

Kelly, J. et al., 2012. *Tomorrow's suburbs.*, Grattan Institute.

Kennedy, C., Cuddihy, J. & Engel-yan, J., 2007. The Changing Metabolism of Cities. *Journal of Industrial Ecology*, 11(2).

Kenworthy, J. & Laube, F., 2001. *Millenium Cities Database for Sustainable Transport*,

Legacy, C. & Leshinsky, R., 2015. Regenerating Cities: Creating the Opportunity for Greyfield Precinct Infill Development. In *Instruments of Planning: Tensions and challenges for delivering more equitable and sustainable cities*. London: Routledge.

Living Building Challenge, 2014. LIVING BUILDING A Visionary Path to a Regenerative Future. *Living Building Challenge 3.0. A Visionary Path to a Regenerative Future*. Available at: http://living-future.org/sites/default/files/reports/FINAL LBC 3_0_WebOptimized_low.pdf.

Llewelyn-Davies, 2000. *Urban Design Compendium*, London, UK: English Partnerships & The Housing Corporation, U.K.

Lyle, J.T., 1996. *Regenerative Design for Sustainable Development*, New York, NY: Wiley.

Mang, P. & Reed, B., 2012. Designing from place: a regenerative framework and methodology. *Building Research & Information*, 40(1), pp.23–38.

McDonald, R. et al., 2016. *Planting Healthy Air: A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat.*, Arlington, USA. Available at: www.nature.org/healthyair.

New South Wales Government, 2015. *State Environmental Planning Policy No 65—Design Quality of Residential Apartment Development*, Australia. Available at: http://www.legislation.nsw.gov.au/#/view/EPI/2002/530/whole.

Newman, P., 2014. Biophilic urbanism: a case study on Singapore. *Australian Planner*, 51(1), pp.47–65. Available at: http://www.tandfonline.com/doi/abs/10.1080/07293682.2013.790832.

Newman, P. et al., 2016. *Entrepreneur Rail Model*, Perth, Australia.

Newman, P., Beatley, T. & Boyer, H., 2009. *Resilient Cities: Responding to Peak Oil and Climate Change*, Island Press.

Newman, P. & Jennings, I., 2008. *Cities as Sustainable Ecosystems: Principles and Practices*, Island Press.

Newman, P. & Kenworthy, J., 1989. *Cities and Automobile Dependence: An International Sourcebook* Gower, ed., Aldershot, UK.

Newman, P. & Kenworthy, J., 2011. Peak Car Use: Understanding the Demise of Automobile Dependence. *World Transport Policy and Practice*, 17(2), pp.32–42.

Newman, P. & Kenworthy, J., 1999. *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press.

Newman, P. & Kenworthy, J., 2015. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*, Washington, D.C.: Island Press.

Newman, P., Mason, A. & Gardner, H., 2012. *Regenerative cities*, Perth, Australia.

Newman, P. & Matan, A., 2013. *Green Urbanism in Asia: The Emerging Green Tigers*, World Scientific.
Newton, P., Murray, S., et al., 2012. *AHURI Research & Policy Bulletin How do we regenerate middle suburban " greyfield " areas ?*,
Newton, P., Newman, P., et al., 2012. Greening the Greyfields : Unlocking the Redevelopment Potential of the Middle Suburbs in Australian Cities. *World Academy of Science, Engineering and Technology*, 71(11), pp.658–677.
Newton, P., 2014. Regeneration: Tackling the Greyfields. In T. Perinotto, ed. *Creating Sustainable Precincts*. Sydney, Australia: The Fifth Estate, pp. 106–111. Available at: http://evacoust.startlogic.com/TimeToyota.pdf.
Newton, P. et al., 2011. *Towards a new development model for housing regeneration in greyfield residential precincts*,
Newton, P. & Newman, P., 2013. The geography of solar photovoltaics (pv) and a new low carbon urban transition theory. *Sustainability (Switzerland)*, 5(6), pp.2537–2556.
Newton, P.W., 2012. Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities. *Journal of Urban Technology*, 19(1), pp.81–102. Available at: http://www.tandfonline.com/doi/abs/10.1080/10630732.2012.626703.
Norton, B.A. et al., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, pp.127–138. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204614002503.
OECD, 2016. OECD Better Life Index. Available at: http://www.oecdbetterlifeindex.org/#/55555555555 [Accessed August 17, 2016].
Parkinson, G., 2016. Citizen utility: Housing estate to offer solar, storage and EVs to residents. *One Step off the Grid*. Available at: https://onestepoffthegrid.com.au/citizen-utility-housing-estate-to-offer-solar-storage-and-evs-to-residents/ [Accessed November 29, 2016].
Passive House Australia, 2014. Passive House Australia. Available at: http://passivehouseaustralia.org/ [Accessed August 27, 2011].
Planning Institute of Australia, 2016. Through the lens : megatrends shaping our future.
Prommer, H. et al., 2013. *Aquifer storage and recovery of potable water in the Leederville Aquifer*, Perth, Australia.
Reed, B., 2006. *Trajectory of Environmentally Responsible Design*, Santa Fe, USA.
Reidy, C., Lederwasch, A. & Ison, N., 2011. *Defining zero emission buildings*, Surry Hills, Australia.
Rockström, J. et al., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity. , 14(2). Available at: http://pdxscholar.library.pdx.edu/iss_pub.
Rowley, S. & Phibbs, P., 2012. *Delivering diverse and affordable housing on infill development sites*, Melbourne, Australia.
Sanchez, A.., Hampson, K.. & Mohamed, S., 2015. *Driving Whole-of-life Efficiencies through BIM and Procurement*, Brisbane, Australia.
Smith, A., Voß, J.P. & Grin, J., 2010. Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy*, 39(4), pp.435–448.
Steffen, W. et al., 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), pp.736–747.
Swilling, M. et al., 2013. *City-Level Decoupling Urban resource flows Urban resource flows and the governance of infrastructure transitions. A Report of the Working Group on Cities of the International Resource Panel.*, Nairobi, Kenya: United Nations Environment Programme.
Thomson, G. & Newman, P.W.G., 2016. Geoengineering in the Anthropocene through Regenerative Urbanism. *Geosciences*, 6(4).
Thomson, G., Newton, P. & Newman, P., 2016. Urban Regeneration and Urban Fabrics in Australian Cities. *Urban Regeneration and Renewal*, 10(2).
Thomson, G. & Rauland, V., 2014. GRID: A new governance mechanism for financing eco-infrastruture at the district scale. In *7th International Urban Design Conference:*

Productive cities. Adelaide, Australia: Association for Sustainability in Business.
United Nations General Assembly, 2015. *Transforming our world: the 2030 Agenda for Sustainable Development. The Resolution adopted by the General Assembly on 25 September 2015*,
WALGA, 2016. Construction and Demolition Waste. *WasteNet*. Available at: http://www.wastenet.net.au/construction-and-demolition-waste.aspx [Accessed August 20, 2016].
Wolman, A., 1965. The Metabolism of Cities. *Scientific American*, 213(3), pp.179–190.
Young, E., 2016. Stirling's landmark tree protection attempt falters at finish line. *WAtoday*. Available at: www.watoday.com.au/wa-news/stirlings-landmark-tree-protection-attempt-falters-at-finish-line-20160320-gnmnpt.html.

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Material Flows, Information Flows and Sustainable Urbanism

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Material Flows, Information Flows and Sustainable Urbanism

ABSTRACT: *Urban metabolism is a holistic way to understand the physical sustainability of cities. A genuinely smart urbanism is sustainable when it links development decisions to ecological impact. Urban metabolism can be used as a tool to monitor material flows and optimise metabolic footprint (resource inputs and waste outputs) to reduce ecological impact, whilst improving liveability. Like organisms, different cities have different metabolisms. Analysis from a detailed case study in Perth shows that different parts of a city (walking, transit and automobile urban fabrics) also have different urban metabolisms. Urban metabolism analysis is essential for identifying urban design leverage points that will enable the transformation of Australian cities from some of the world's most resource intensive to sustainable cities. A smart city, therefore, is one that measures material flows, and makes this data widely available as information flows to those people who are able to influence urban outcomes. Urban metabolism can inform evidence-base policies to optimise sustainable urban designs.*

Keywords: *Urban metabolism, sustainability metrics, leverage points, urban fabrics, sustainable urban policy.*

Introduction

Human consumption patterns exceed planetary boundaries placing unsustainable stress upon the biosphere (Steffen et al. 2015; Rockström et al. 2009). The recent 'Paris Agreement' (COP21) (United Nations 2015) and the Sustainable Development Goals (SDGs) (United Nations General Assembly 2015) have been drafted as major international efforts to develop unilateral policy directions to equitably address global sustainability. However, the mechanisms to implement these goal-based agreements are yet to be determined. The solution may lie in cities.

This is because cities are concentrations of human activity and governance. Cities encourage ideas and solutions to spread quickly because of the proximity of people to one another, allowing for bottom-up ideas to flourish (Brugmann 2010; Rauland 2013; Glaeser 2011; Campbell 2011). Possibly more importantly cities are centres local and regional administration, allowing for stronger top-down governance and regulation (UN Habitat 2016; Mumford 1961).

Harnessing the enhanced human agency of cities offers a powerful force for driving sustainability transitions. If sustainability improvements go far enough, and are done at scale across the majority of cities, then cities could begin to regenerate planetary ecological imbalances (Fink 2013; Girardet 2010; Newman & Jennings 2008).

Objectives and method

This paper attempts to demonstrate the strategic relationship between:

- Urban metabolism (measured as *material flows*);
- The importance of *information flows* to make urban metabolism data available to urban policy makers; and,
- The importance of evidence-based urban policy for delivering *sustainable urbanism.*

This is achieved through a broad literature review and two case studies:

- An urban metabolism assessment of various urban fabrics in Perth by Gardner and Newman for the Western Australian Government (2013); and,
- An analysis by the Australian Bureau of Statistics (ABS) of the appropriateness of city indicators proposed by the Australian Government in 2010 in an attempt to develop a national cities research program (Government of South Australia 2012).

The first is an example of a material flow analysis, and the second is related to metrics and information flows.

The paper draws conclusions about the need for a new model of evidence based urban policy and makes suggestions for monitoring and delivering more sustainable urban form.

Material Flows

> *If you understand the dynamics (behavior over time) of stocks and flows, you understand a good deal about the behavior of complex systems.* (Meadows 2008)

Modern cities have been generally designed as extractive engines drawing resources from natural systems, processing these resources to generate value, and producing wastes the impacts of which are externalised. Determining environmental impact (negative or positive) of a large and complex system such as a city requires an understanding, through measurement, of the various urban sub-systems. In the 1960s Wolman (1965) was the first to liken the input / output transactions of material flows through a city to the metabolism of an organism. This notion of material flow accounting within human settlements is commonly referred to as 'urban metabolism'. The concept of urban metabolism has experienced a popular resurgence in recent years (Gandy 2004; Girardet 2010; Newman & Kenworthy 1999; Baccini & Brunner 2012; Kennedy et al. 2007) as systems scientists and urban practitioners, seek to better understand, measure and manage urban performance, growth and environmental impact (for a comprehensive discussion and comparison of approaches see Kennedy et al. (2007)).

Urban metabolism provides a holistic way to understand the physical sustainability of cities. A genuinely smart urbanism is sustainable when it links development decisions to ecological impact (Hajer & Dassen 2014). Urban metabolism therefore is an ideal tool for helping deliver sustainable urban design because it accounts for material stocks and flows allowing planners and designers to link decisions to impact, adjust policy and optimise ecological footprint (measured through resource inputs and waste outputs). Urban metabolism analysis offers a more holistic extension to the more common economic or quality of life monitoring that typically provide the evidence base for urban liveability policies.

Existing best practice technologies and design optimise urban metabolism, greatly enhancing urban sustainability performance, while reducing operational costs while and other life-affirming co-benefits to cities (Rauland 2013). But to do so requires an integrated approach to planning, design and governance. Urban metabolism can, and should, be used as a design tool to inform sustainable urban design decisions (Hajer & Dassen 2014), this would require “institutionalising” the approach into urban planning approaches (McDonald & Patterson 2007).

Ideally holistic monitoring of urban metabolism would occur in a nested (multi-scalar) model that allows monitoring that roll-up or roll-down through use of a consistent basket of indicators to ensure integration across geographic and governance scales (Seitzinger et al. 2012; Truffer & Coenen 2012). While many attempts have been made to develop urban sustainability indicators for urban development (e.g., Green Star Communities, LEED ND, One Planet Living, Living Community Challenge to name a few), most of these are voluntary rating systems and are only useful for if applied by the developer at project conception. For meaningful impact at scale it will be necessary to upscale from niche demonstration projects to mainstream practice embedded in culture and enshrined in policy.

Monitoring using consistent sustainability metrics at the development scale in a way that could roll-up into LGA, state and federal performance accounting would be a powerful tool for aiding urban sustainability transitions. Such an approach would permit an accurate snapshot of urban sustainability performance between tiers of government and across jurisdictions to allow comparison (e.g., national and international urban performance report cards), benchmarking, celebration of high performers, and identification of poor performers for assistance. The recently released ISO 37101:2016(E) – Sustainable development in communities (ISO 2016) is a good starting point as it offers an international standard covering many indicators including renewable resources, biodiversity, ecosystems services as well as more conventional economic and social indicators. However, the list of metrics could be greatly expanded to cover a broader range of sustainability considerations.

This information could be used to monitor compliance of sustainability performance minimums and ongoing monitoring would allow the tracking of sustainability progress. More importantly from an urban design perspective this information could help shape strategic planning direction and inform best practice.

Form follows function and sustainability follows form

The theory of urban fabrics suggest that there are three types of urban fabric in cities: walking fabric, transit fabric and automobile fabric (Newman, Kenworthy, et al. 2016; Newman & Kenworthy 2015). Most cities today have a mixture of all three urban fabrics. The fundamental problem with 20th century town planning has been the belief that there is only one type of city: the automobile city.

Data from Perth demonstrates how different urban development patterns have different urban metabolisms, this in turn can inform decision making around how to design genuinely smart, sustainable cities. Walking and transit fabrics have lower urban metabolisms due to their higher density, shorter distances between destinations for reduced energy and time spent on transport, and shorter infrastructure lengths with less embodied energy (Gardner & Newman 2013).

The Perth case study looked at various urban fabrics (fringe development, middle suburb, and dense infill) in terms of annual per capita *inputs* including:

- Fuel, Power and Gas,
- Water,
- Food,
- Land in metres squared,
- Basic raw materials (BRM) – sand, limestone, clay, rock

And *outputs* including:

- Greenhouse gas (fuel, power and gas),
- Waste heat,
- Sewage (including stormwater),
- Household waste.

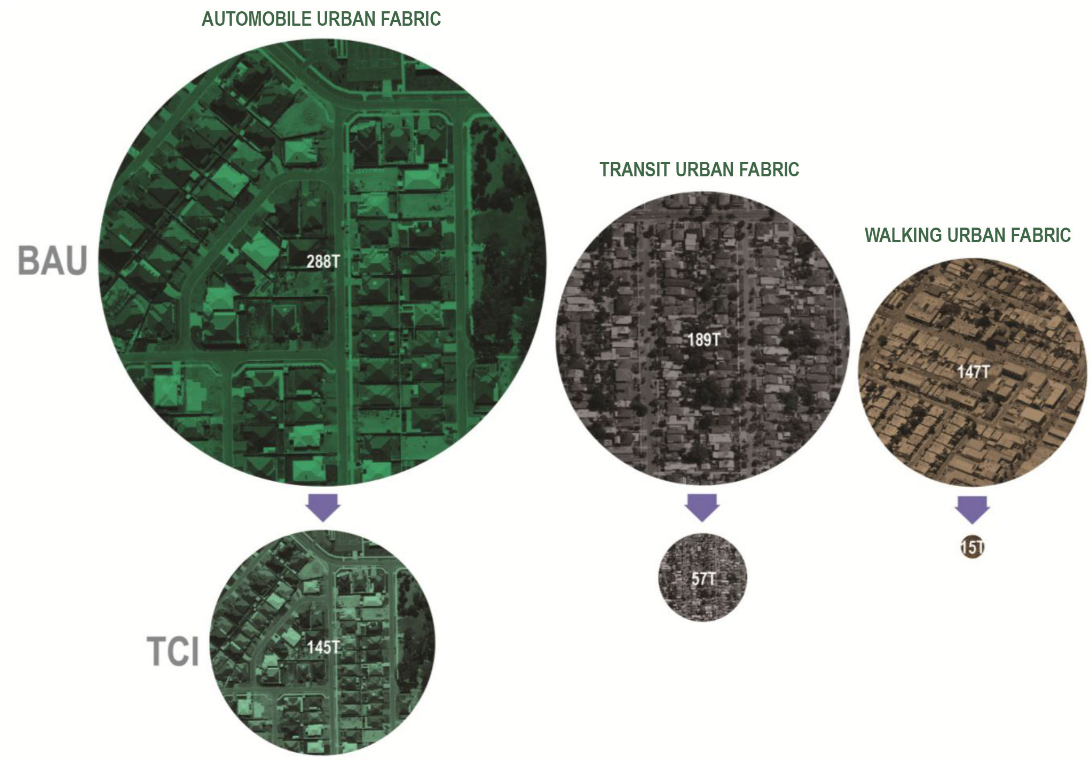
A key finding of the Gardner and Newman (2013) report was that the density and form of the underlying urban fabric played an important role in the urban sustainability performance of a city sub-region.

The study demonstrated that, in addition to the underlying fabric, aspects of the system could be optimised through technology and construction innovation (TCI). For example, the efficiencies of prefabricated construction result in considerable material savings. This combination of factors means that walking urban fabric with TCI can be nearly 30 times as efficient in material use (15t/person) than conventional automobile urban fabric (288t/person) (see Figure 1) (Gardner & Newman 2013). The business as usual (BAU) scenario for automobile urban fabric is so much higher because of several factors, primary amongst these are:

- Additional material used in low density dwellings, for example, the provision of a double garage,
- Large amounts of fill for 'benching', and construction of driveways and sealed surfaces on plot; and
- Additional length of infrastructure (e.g. roads or pipes) to service fewer dwellings (e.g. ten times the road length is required to service dwellings at 10 persons/ha (a common density for automobile fabrics) versus 100 person/ha (a common density for walking fabric) off the plot.

The inference from this study is that (re)designing urban areas as transit or walking fabric rather than automobile fabric, substantially reduces the development's urban metabolism.

Figure 1: Perth's basic raw material demand in terms of three urban fabrics (circles represent proportional volume of BRM). Source: Gardner & Newman (2013)



Just as the Perth case study shows the relative sustainability performance advantages of different urban fabrics, similar analysis has been done by others to assess the impact of urban design on urban performance at the smaller subdivision and neighbourhood level (see: Duckworth-Smith 2015; Fraker 2013).

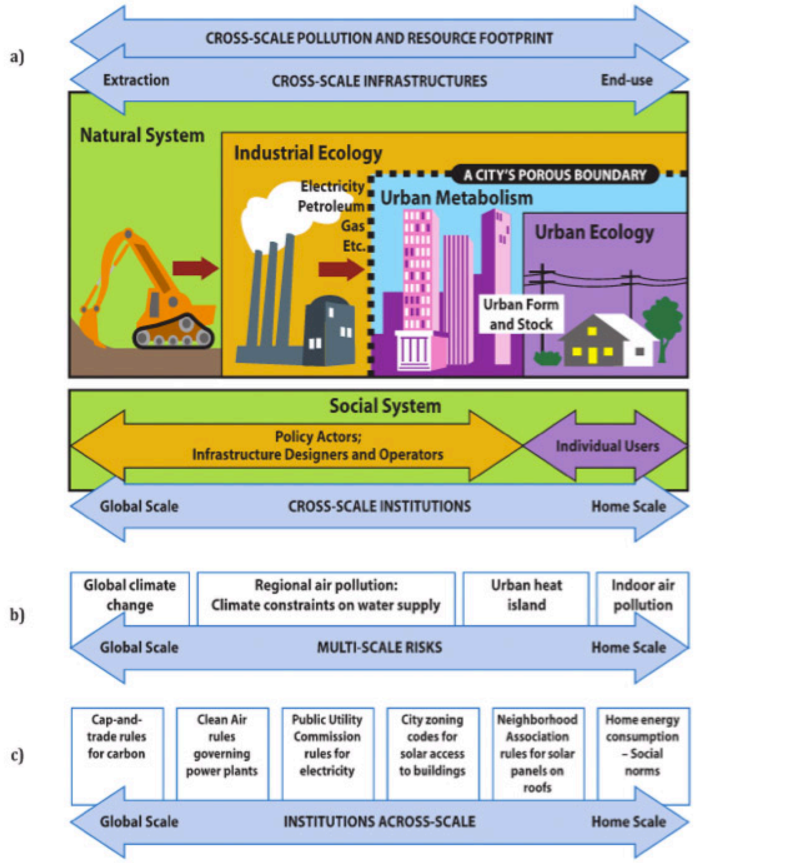
However, urban analysis alone is not sufficient to bring about change. Urban material resource and pollution flows are a function of the social system within which cities exist. Influencing urban material flow systems also requires understanding the underlying social conditions that shape metabolic flows. These interdependent systems are referred to Ramaswami et al. (2012) as socio-ecological-infrastructural systems. Ramaswami et al. explain:

> *Cities are embedded within larger-scale engineered infrastructures (e.g., electric power, water supply, and transportation networks) that convey natural resources over large distances for use by people in cities. The sustainability of city systems therefore depends upon complex, cross-scale*

interactions between the natural system, the transboundary engineered infrastructures, and the multiple social actors and institutions that govern these infrastructures.

This relationship is illustrated in Figure 2.

Figure 2: The social-ecological-infrastructural systems framework.
Source: Ramaswami et al. (2012)



Pictorial illustration of the social-ecological-infrastructural systems (SEIS) framework depicting: (a) integration across the spatial scale of infrastructures, urban metabolism, industrial ecology, and urban resource/pollution footprints with social actors and institutions; (b) multiple and multiscale risks posed to cities by infrastructure–environment interactions across scales; (c) select examples of institutions that shape energy use and greenhouse gas (GHG) emissions across scales.

As Figure 2 illustrates, the urban metabolism of cities is influenced multiple factors including the social actors and institutions that shape urban infrastructures. Urban metabolism analysis can show how a city system is performing and this information can be used to reveal to city makers opportunities for improvement.

Information Flows

An urban metabolism analysis is only useful to affect broader urban sustainability transitions if this information gets into the hands of the people who can influence change. In Figure 2 for example, the measurement of various material flows within natural and urban systems, would need to be fed in a timely manner to the policy actors, or individual users, in the social system. They would then need to be willing to act upon this information to optimise various elements or subsystems.

This seems simple enough, but in practice attempts to holistically monitor the sustainability of an urban system are relatively rare.

Some examples exist, for example the Western Australian Sustainability Strategy (Government of Western Australia 2003), and the Sydney State of the Environment Report (Newman et al. 1996) provide city scale urban metabolism studies. But these represent static snapshots of the environmental performance of the respective cities and not ongoing monitoring.

In 2010, the Australian Government through the State of Australian Cities (SAC) report (Commonwealth of Australia 2010) outlined a broad range of metrics to measure urban performance in terms of liveability, sustainability and productivity. These indicators were effectively a wish list of desirable metrics. The metrics were selected to represent a holistic basket of indicators at the city scale. To test their appropriateness at a sub-city scale the South Australian Integrated Design Strategy (IDS) (SA Department of the Premier and Cabinet) with the support of the Australian Bureau of Statistics (ABS) in 2012 conducted a study to see how these desirable (yet untested) metrics might be applied to an existing urban area. The area for the study was based upon the geography of inner Adelaide around 12 km^2 covering seven inner Adelaide councils.

The ABS assessed the suitability of the SAC indicators using the following criteria, "availability of data for the IDS-defined region data currency, frequency, time series capability and data quality scan accessibility; whether the data are free, at cost or somehow restricted availability of alternative measures (if known)" (Government of South Australia 2012).

The findings concluded that, "of the 81 SAC indicators, 28% (31 in number) were deemed as meeting the criteria for suitability. The remainder were considered either partially suitable or unsuitable as they did not meet the above criteria, most commonly due to data being unavailable for the (study area)" (ibid.). Not surprisingly the most complete metrics were demographic or economic in nature, while sustainability (and some social aspects) were not being systematically measured, and therefore were not being systematically managed. This will need to be addressed if we wish to monitor, report, respond to and improve the sustainability of cities.

Sustainable and liveable

Australian cities are renowned for the high quality of life afforded to citizens. According to the OECD better life index Australia ranks a close second after Norway for quality of life across eleven indicators (OECD 2016), while the Economist in 2015 ranked Melbourne the most liveable city in the world, with Adelaide [5th=], Sydney [7th] and Perth [8th](Economist Intelligence Unit 2015). However, research by Newton (2012) shows a clear correlation between higher city liveability to higher ecological footprint. Decoupling ecological footprint from the high consumption patterns currently associated with liveability will be one of the key challenges of the 21st century (Swilling et al. 2013; Gómez-Baggethun & Barton 2012; Steffen et al. 2015). However the challenge is not so much related to what to do, but rather how to do it at scale. Numerous exemplars can be found to demonstrate sustainable urban development but these are the exception not the rule. Australia needs to do better with its urban sustainability performance if it is to do its fair share of meeting the Paris Agreement or the Sustainable Development Goals.

Growth as a trigger for transformative change

Rapid urban growth in Australia is fuelled by high population growth, from both natural and immigration sources. To put this in context, Australia's population in the year to 31 December 2015 grew by 326,100 people consisting of:

- 148,900 people natural increase;
- 177,100 people of net overseas migration (ABS 2015).

This annual growth equates to nearly the population of Canberra, with the majority of that growth concentrated in the four major cities of Melbourne, Sydney, Perth and Brisbane.

In attempting to absorb this rapid population growth care must be taken to ensure Australian cities continue to offer high quality of life. Whilst quality of life indicators are universally high there is some indication that performance is slipping. The Mercer *Quality of living survey* ranks Australian cities very highly but over time between 2004 and 2011 observes a slight reduction in quality of living in the four most populous and fastest growing cities (Commonwealth of Australia 2012, p.212), and notes that this trend is likely to become even more pronounced if population growth continues to outpace investment in lifestyle enhancing infrastructure (e.g. public transport).

Liveability also includes the affordability of housing and the affordability of urban living. Australian cities have mostly created affordable housing on the urban fringe but increasingly this is not affordable living as the costs of transport are so high from the far flung suburbs (Rowley & Phibbs 2012).

The challenge for sustainable urban development is, therefore, two-fold:

- Firstly, the need to decouple liveability from high ecological footprint, and
- Secondly, to do so while accommodating urban growth through the provision of infrastructure and development in a way that creates liveability and sustainability.

Leverage points

Environmental impact can be reduced by simply consuming less, advocates promote a widespread cultural shift toward minimalist living or "the simpler way" (Trainer 2008). However, after four decades the approach has failed to interest people in at the scale required for a meaningful shift in consumption patterns. An alternative is the redesign of infrastructures that facilitate more sustainable lifestyles that maintain quality of life while also reducing environmental impact.

There are many places to intervene in a system as outlined by Meadows (1999) (Box 1.).

Box 1. Places to Intervene in a System (in increasing order of effectiveness) (source: Meadows 1999)

12. Constants, parameters, numbers (such as subsidies, taxes, standards)
11. The sizes of buffers and other stabilizing stocks, relative to their flows.
10. The structure of material stocks and flows (such as transport networks, population age structures)
9. The lengths of delays, relative to the rate of system change
8. The strength of negative feedback loops, relative to the impacts they are trying to correct against
7. The gain around driving positive feedback loops
6. The structure of information flows (who does and does not have access to what kinds of information)
5. The rules of the system (such as incentives, punishments, constraints)
4. The power to add, change, evolve, or self- organize system structure
3. The goals of the system
2. The mindset or paradigm out of which the system—its goals, structure, rules, delays, parameters—arises
1. The power to transcend paradigms

Meadows prioritises these places to intervene in terms of effectiveness, the lower the number the more effective but more difficult the strategy.

So far this paper has addressed the following:

- 10. Material stocks and flows (urban metabolism)
- 8. Feedback loops
- 6. Information flows

In the following sections this paper will address the following

- 5. The rules of the system (i.e., planning policy)
- 3. The goals of the system (e.g., performance targets)
- 2. The mindset or paradigm of the system.

Sustainable urban policy

Automobile urban fabric has been the conventional urban form in the cities of Australia, New Zealand, North America and other developed nations since the mid-Twentieth Century. But automobile urban fabric delivers suboptimal urban form, which becomes increasingly apparent as city size increases. Suboptimal urban form risks lock-in because costs of retrofitting once built are very high. The structure of the urban fabric is shaped by planning policies, which are shaped by the underlying assumptions about how our cities should be. With automobile fabric the cultural assumption is the need to design in vehicle infrastructure, efficient road capacity (at the expense of pedestrians and other transport modes), and minimum on-plot parking requirements. Inflexibility in the dominant automobile dependent (Newman & Kenworthy 1999; Newman & Kenworthy 1989) paradigm leads to,

> *… negative path dependency, becoming too narrowly specialised, having unsuitable governance arrangements…experiencing lock in due to unfavourable spatial patterns and transport development choices* (Moir et al. 2014, p.4).

The dominance of hydrocarbon fuelled cars as a transportation mode impacts on energy consumption and carbon dioxide emissions (Kenworthy 2014). The technical substitution of hydrocarbon fuelled motors by renewable energy powered electric motors may reduce the impact of vehicle emissions, but, even with the substitution of fuel sources conventional practice will continue to deliver automobile urban fabric with its reduced sustainability performance.

In Perth, suboptimal urban form results from infill that promotes car dependence, yet this is mandated by the current planning policy that requires at least one car park per dwelling even in location near good public transport (Western Australian Planning Commission 2015). Compare this approach to the inner Melbourne co-housing development “the Commons”, constructed in 2014 and comprising 24 two-bedroom apartments in a 5-storey block. The apartments have no car parking, no air conditioning and no second toilet, but, has won 13 major architecture and sustainability awards including the Frederick Romberg Awards for Residential Architecture - Multiple Housing at the 2014 National Architecture Awards (Chua 2014). Living simply, combined with good design at the right location (adjacent a railway station) has created a highly liveable, highly desirable and highly sustainable outcome. Fortunately, some planning policies, like the recently revised NSW State Environmental Planning Policy 65 (New South Wales Government 2015) are beginning to incorporate concessions to permit reduced car parking requirements at key locations (e.g., railway stations, activity centres) to make apartments more sustainable, more affordable and allow more space for non-vehicle infrastructure uses. Successful bottom up models such as the Commons, combined with top-down planning policy that mandates the integration of transport (especially transit) and land use, are just beginning to reshape Australian cities.

Urban change is constant, but urban fabrics are more persistent. Considerable effort will be needed to displace the dominance of automobile fabric both physically and culturally. To bring about widespread change it is necessary to find leverage points in the system where changes have the greatest transformative potential. But the urban fabric study in Perth showed that transforming urban fabric is a powerful sustainability transition, because (re)designing the underlying urban infrastructure walking and transit fabrics will result in much lower environmental impact than conventional automobile fabric. This is true even if we integrate similar additional sustainability measures (e.g. renewable energy, prefabrication) because of the reduced embodied energy in urban fabric itself (Gardner & Newman 2013).

Emerging models such as the Entrepreneur Rail Model (Newman, Jones, et al. 2016) demonstrates both financial incentives (through rezoning and value capture to fund new rail infrastructure), and policy incentives (through meeting planning objectives such as more compact and vibrant urban form) to encourage city makers to pursue infrastructure driven urban regeneration.

Returning again to Perth, it's projected population is expected to double some time mid to late this century (ABS 2013). To accommodate this population growth and improve sustainability will be difficult. A planning response could be to continue to release fringe land and disperse population to the urban periphery, but this results in less sustainable outcomes (Gardner & Newman 2013), increases infrastructure and service provision costs (Hajer & Dassen 2014; Trubka et al. 2008), and increases costs of living (Dodson & Sipe 2006). Alternatives are offered in Figure 3, which shows the comparative areas (to scale) of accommodating 2 million people at the average population density of each urban fabric, whereby:

- Label A illustrates 100% automobile fabric at 12 persons per urban hectare (i.e., developed urban land) requiring around 166 km^2

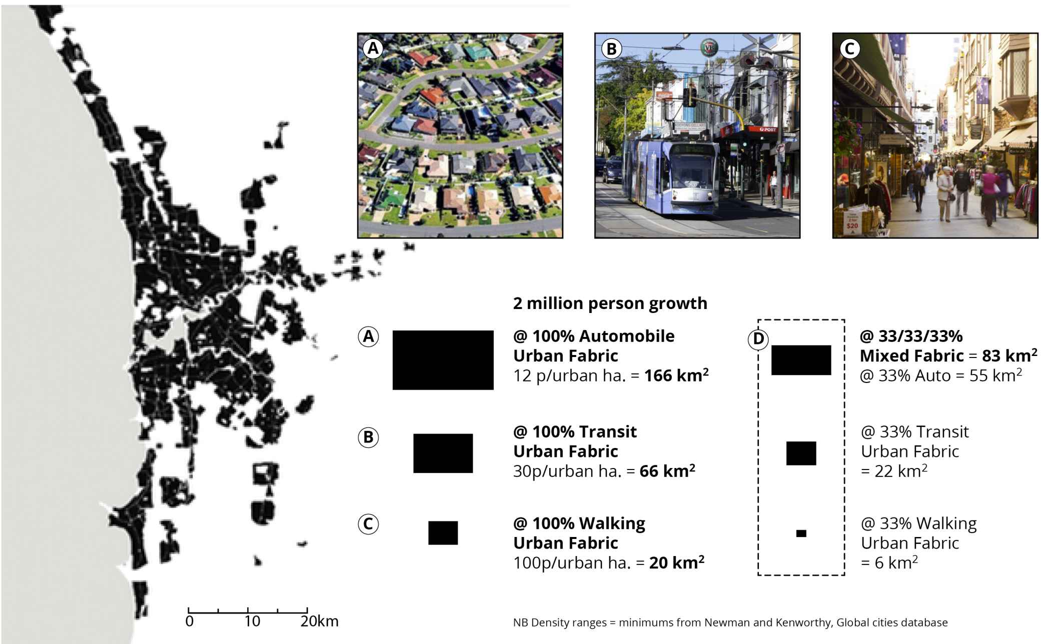
- Label B illustrates 100% transit fabric at 30 persons per urban hectare requiring around 66 km^2
- Label C illustrates 100% walking fabric at 100 persons per urban ha requiring around 20 km^2.

Typical development models are skewed in favour of delivering the automobile fabric, but label D shows a three way split between each major urban fabric. This would result in half the development footprint of a scenario that was 100% automobile fabric and it would accommodate two thirds of the population in the less resource intense and more vibrant walking and transit urban fabrics.

Shifts in urban fabric are likely to be gradual unless leverage points can be found in the system to accelerate change, for example:

- Government led models such as land use and transit policy,
- Public private partnerships such as the Entrepreneur Rail Model (Newman, Jones, et al. 2016), or,
- Bottom-up community projects, e.g. co-housing (such as the Commons), delivered at scale.

Figure 3: Areas required to accommodate 2 million people in Perth by urban fabric



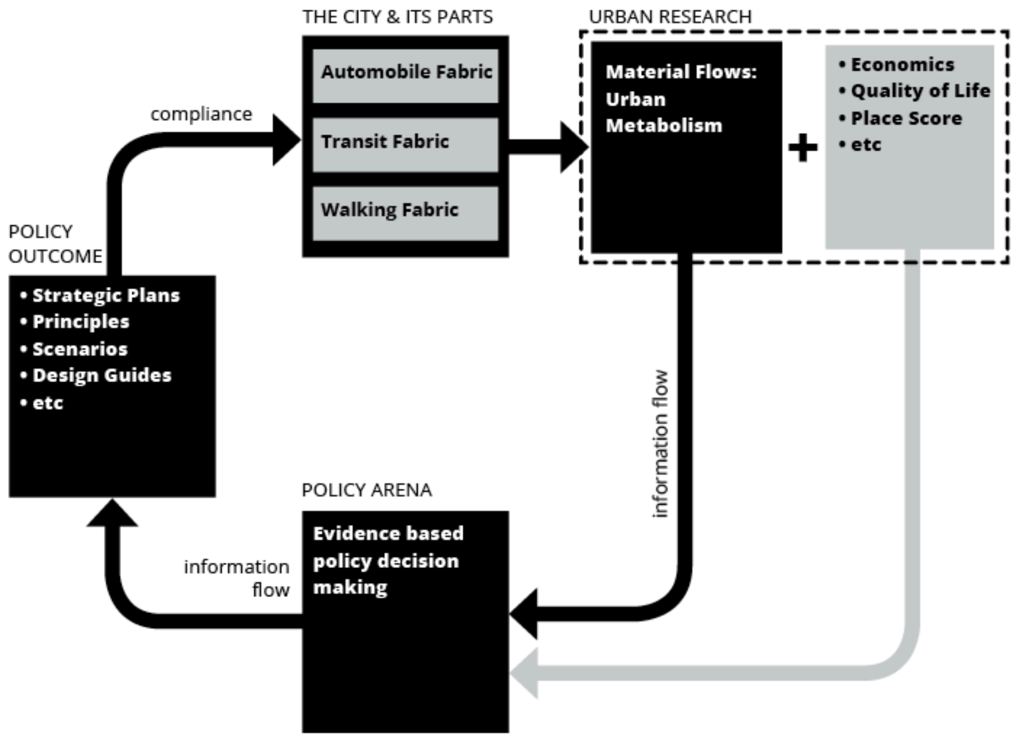
Material flows, Information flows and Sustainable Urbanism

To bring about meaningful and widespread urban sustainability transitions is complicated and requires a number of factors to align. Figure 4 illustrates an ideal scenario whereby:

- The city and its parts are actively monitored through *material flow* analysis that reveals the urban metabolism of an area,
- A system of *information flows* make urban research available in a useful form and timely manner as an evidence base for decision makers,
- The process itself is an iterative *feedback* loop to continually strive for genuine transformative change that drives sustainable urbanism.

Where any one of these elements is missing fully informed decision-making will be hindered, the *status quo* will prevail and urban form and urban sustainability will likely suffer. As the ABS study (Government of South Australia 2012) into the proposed State of Australian Cities indicators demonstrated, even in major cities many useful indicators are either not being measured, or the information flow does not exist, so that policy and design decisions are made with an incomplete understanding of the urban system.

Figure 4: Diagram illustrating an ideal relationship between material flows, information flows and urban outcomes



Conclusion

A new paradigm is needed to help shift behaviours and policies that shape our cities to deal with their ecological impacts. A smart city is ideally a sustainable city. Delivering a sustainable city requires a sustainable urbanism that is cognisant of urban fabric, urban sustainability performance and quality of life. But a genuinely sustainable urbanism represents a radical departure from conventional practice and is hindered by barriers such as:

- Resistance from those who have advantages of staying with the old systems and path dependant lock-in (Geels 2010),
- The mismatch between electoral short termism of business cycles and electoral cycles versus the long term horizons of city planning and sustainability (Roggema 2012), and
- The perceived sustainability cost premium (Thomson et al. 2013; Sustainability Victoria 2011).

A genuinely sustainable urbanism will involve a paradigm shift. As Meadows explains in *Places to Intervene in Systems* (1999), a paradigm shift is the most effective way for change but it is also very difficult to engender. This is because urban performance is not just about infrastructure but more significantly (and less visible) it is about the social systems that perpetuate poor urban performance and associated environmental problems.

However, the narratives emerging around international commitments such as the Paris Agreement or the SDGs may create momentum for the collective culture change required for a paradigm shift to drive an urban sustainability transition. If this can occur there will be a need for a model such as that suggested in this paper - an iterative policy feedback loop. One that incorporates urban sustainability performance measurements (material flows) and makes this data available as information flows to inform decision-making.

References

ABS, 2015. *3101.0 - Australian Demographic Statistics, Dec 2015*, Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0 [Accessed August 25, 2016].

ABS, 2013. *3222.0 - Population Projections, Australia, 2012 (base) to 2101*,

Baccini, P. & Brunner, P.H., 2012. *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*, MIT Press.

Brugmann, J., 2010. *Welcome to the Urban Revolution: How Cities Are Changing the World*, New York, NY: Bloomsbury Press.

Campbell, K., 2011. *Massive Small: The Operating Programme for Smart Urbanism*, London, UK: Urban Exchange.

Chua, G., 2014. The Commons by Breathe Architecture named Best of the Best at 2014 Sustainability Awards | Architecture And Design. *Architecture&Design*. Available at: http://www.architectureanddesign.com.au/awards-1/2014-winners/the-commons-by-breathe-architecture-named-best-of [Accessed August 26, 2016].

Commonwealth of Australia, 2010. *State of Australian Cities 2010*, Australian Government, Department of Infrastructure and Transport, Major Cities Unit.

Commonwealth of Australia, 2012. *State of Australian Cities 2012*, Australian Government, Department of Infrastructure and Transport, Major Cities Unit.

Dodson, J. & Sipe, N., 2006. Suburban shocks : Assessing locational vulnerability to rising household fuel and mortgage interest costs. In *29th Australasian Transportation Research Forum*. Gold Coast, Queensland.

Duckworth-Smith, A., 2015. Backyard bonanza: improving the quality of "popular" suburban infill. *Australian Planner*, 52(4), pp.297–313. Available at: http://www.tandfonline.com/doi/full/10.1080/07293682.2015.1086808.

Economist Intelligence Unit, 2015. Daily chart: The world's most "liveable" cities | The Economist. Available at: http://www.economist.com/blogs/graphicdetail/2015/08/daily-chart-5 [Accessed August 22, 2016].

Fink, J.H., 2013. Geoengineering cities to stabilise climate. *Proceedings of the ICE - Engineering Sustainability*, 166(5), pp.242–248. Available at: http://www.icevirtuallibrary.com/content/article/10.1680/ensu.13.00002.

Fraker, H., 2013. *The Hidden Potential of Sustainable Neighborhoods: Lessons from Low-Carbon Communities*, Washington, D.C.: Island Press.

Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. *City*, 8(3), pp.363–379.

Gardner, H. & Newman, P., 2013. *Reducing the materials and resource intensity of the built form in the Perth and Peel regions*, Perth, Australia.

Geels, F.W., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, 39(4), pp.495–510. Available at: http://dx.doi.org/10.1016/j.respol.2010.01.022.

Girardet, H., 2010. Regenerative cities. , p.20. Available at: www.worldfuturecouncil.org.

Glaeser, E., 2011. *Triumph of the City*, Pan Macmillan UK.

Gómez-Baggethun, E. & Barton, D.N., 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, pp.235–245. Available at: http://dx.doi.org/10.1016/j.ecolecon.2012.08.019.

Government of South Australia, 2012. *ABS Inner Adelaide Snapshot*, Adelaide, Australia.

Government of Western Australia, 2003. *Hope for the future: The Western Australian State Sustainability Strategy*, Perth, Australia.

Hajer, M. & Dassen, T., 2014. *Smart about Cities*, Rotterdam, The Netherlands: Nai010 Publishers.

ISO, 2016. *INTERNATIONAL STANDARD Sustainable development in communities — Management system for sustainable development*, Switzerland.

Kennedy, C., Cuddihy, J. & Engel-yan, J., 2007. The Changing Metabolism of Cities. *Journal of Industrial Ecology*, 11(2).

Kenworthy, J., 2014. Total daily mobility patterns and their implications for forty-three global cities in 1995 and 2005. *World Transport Policy and Practice*, 20(1), pp.41–55.

McDonald, G.W. & Patterson, M.G., 2007. Bridging the divide in urban sustainability: From human exemptionalism to the new ecological paradigm. *Urban Ecosystems*, 10(2), pp.169–192.

Meadows, D.H., 1999. *Places to Intervene in a System*, Hartland, Vermont.

Meadows, D.H., 2008. *Thinking in Systems: A Primer*, Chelsea Green Publishing.

Moir, E., Moonen, T. & Clark, G., 2014. The future of cities: what is the global agenda? , p.60.

Mumford, L., 1961. *The City in History: Its Origins, Its Transformations, and Its Prospects*, Harcourt, Brace & World.

New South Wales Government, 2015. *State Environmental Planning Policy No 65—Design Quality of Residential Apartment Development*, Australia. Available at: http://www.legislation.nsw.gov.au/#/view/EPI/2002/530/whole.

Newman, P., Jones, E., et al., 2016. *Entrepreneur Rail Model*, Perth, Australia.

Newman, P. et al., 1996. Human Settlements. In R. Taylor, ed. *Australia State of the Environment*. Collingwood, Victoria: CSIRO Publishing.

Newman, P. & Jennings, I., 2008. *Cities as Sustainable Ecosystems: Principles and Practices*, Island Press.

Newman, P. & Kenworthy, J., 1989. *Cities and Automobile Dependence: An International Sourcebook* Gower, ed., Aldershot, UK.

Newman, P. & Kenworthy, J., 1999. *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press.

Newman, P. & Kenworthy, J., 2015. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*, Washington, D.C.: Island Press.

Newman, P., Kenworthy, J. & Kosonen, L., 2016. The Theory of Urban Fabrics: Planning the Walking, Transit and Automobile Cities for Reduced Automobile Dependence. *Town Planning Reviews*, 87(4).

Newton, P.W., 2012. Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities. *Journal of Urban Technology*, 19(1), pp.81–102. Available at: http://www.tandfonline.com/doi/abs/10.1080/10630732.2012.626703.

OECD, 2016. OECD Better Life Index. Available at: http://www.oecdbetterlifeindex.org/#/55555555555 [Accessed August 17, 2016].

Ramaswami, A. et al., 2012. A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems: An Integrative Curriculum Across Seven Major Disciplines. *Journal of Industrial Ecology*, 16(6), pp.801–813.

Rauland, V., 2013. *Decarbonising Cities : Certifying Carbon Reduction in Urban Development*. Curtin University.

Rockström, J. et al., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity. , 14(2). Available at: http://pdxscholar.library.pdx.edu/iss_pub.

Roggema, R., 2012. *Swarming Landscapes: The Art of Designing For Climate Adaptation*, Springer Netherlands.

Rowley, S. & Phibbs, P., 2012. *Delivering diverse and affordable housing on infill development sites*, Melbourne, Australia.

Seitzinger, S. et al., 2012. Planetary Stewardship in an Urbanizing World: Beyond City Limits. *Ambio*, 41, pp.789–794.

Steffen, W. et al., 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), pp.736–747.

Sustainability Victoria, 2011. *Business models for enabling sustainable precincts*, Melbourne, Australia.

Swilling, M. et al., 2013. *City-Level Decoupling Urban resource flows Urban resource flows and the governance of infrastructure transitions. A Report of the Working Group on Cities of the International Resource Panel.*, Nairobi, Kenya: United Nations Environment Programme.

Thomson, G., Matan, A. & Newman, P., 2013. A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia. In *SOAC National Conference Proceedings, Nov 26-29 2013. Sydney, NSW: State of Australian Cities Research Network*. Sydney, Australia.

Trainer, T., 2008. Transitions: Pathways Towards Sustainable Urban Development in Australia. In P. Newton, ed. Melbourne, Australia: CSIRO Publishing.

Trubka, R., Newman, P. & Bilsborough, D., 2008. *Assessing the costs of alternative development paths in Australian cities*, Fremantle, Australia. Available at: http://www.earthsharing.org.au/wp-content/uploads/Curtin_Sustainability_Paper_0209.pdf.

Truffer, B. & Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies. *Regional Studies*, 46(1), pp.1–21. Available at: http://www.tandfonline.com/doi/abs/10.1080/00343404.2012.646164.

UN Habitat, 2016. *Urbanization and Development Emerging Futures. World Cities Report 2016*, Nairobi, Kenya: United Nations Human Settlements Programme.

United Nations, 2015. *Adoption of the Paris Agreement*, Paris, France. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

United Nations General Assembly, 2015. *Transforming our world: The 2030 agenda for sustainable development*, NY.

Western Australian Planning Commission, 2015. *R-Codes Amendments 2015*,

Wolman, A., 1965. The Metabolism of Cities. *Scientific American*, 213(3), pp.179–190.

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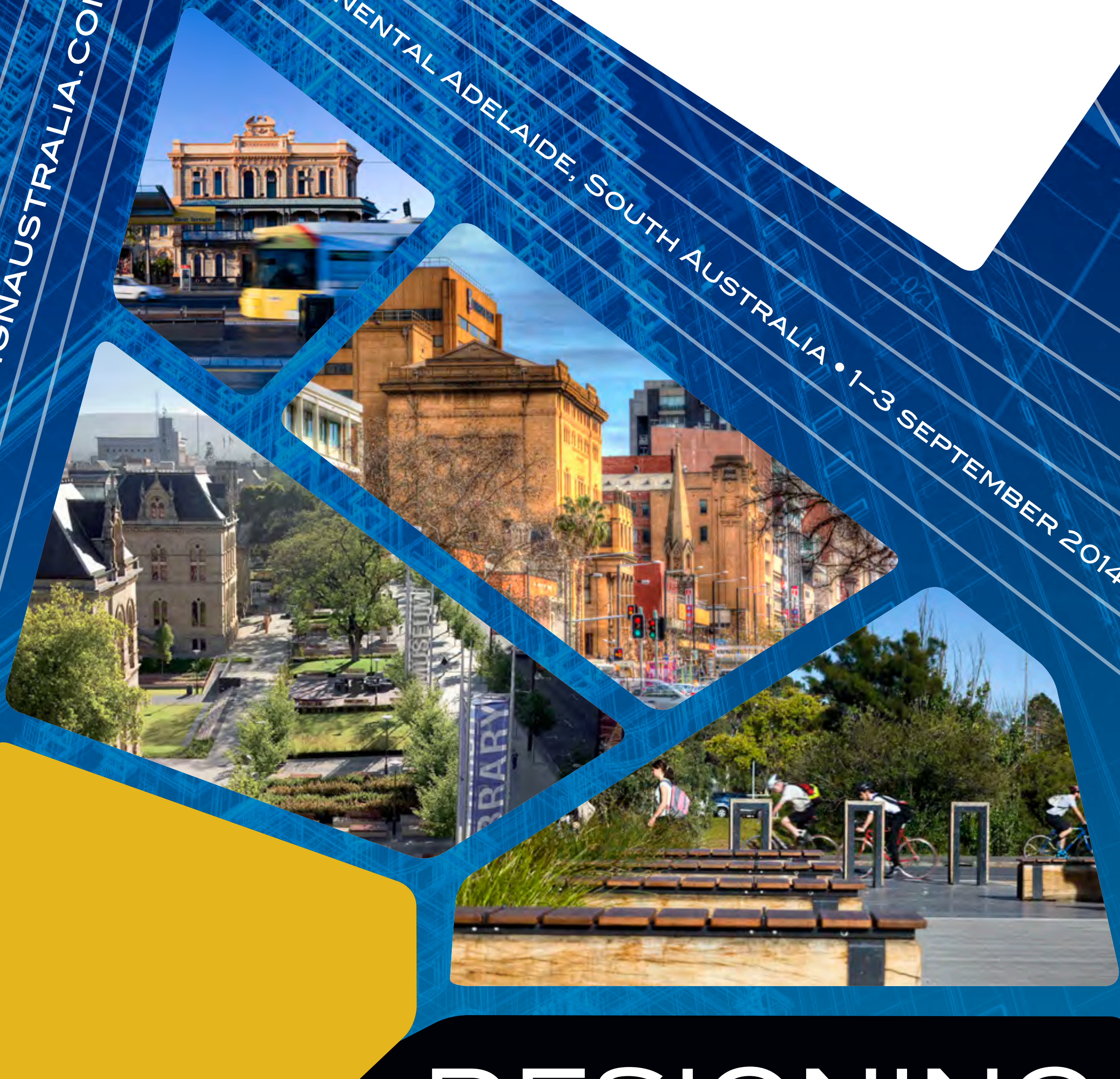

DESIGNING PRODUCTIVE CITIES

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Peer Review Papers

GRID: A new governance mechanism for financing eco-infrastructure at the district scale.

Giles Thomson and Vanessa Rauland
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ABSTRACT

The combined challenges of climate change, finite resources, population growth and aging infrastructure demand a shift toward more resource-efficient, low-carbon sustainable cities. This may be achieved through new forms of eco-infrastructure delivered at the district scale. Despite considerable success in numerous demonstration projects globally, such development has not yet become mainstream. Finance remains a key obstacle preventing wide-spread implementation.

This paper suggests that new funding models are needed that can help spread the costs of the infrastructure over a longer time period and across different land titles. It highlights a range of possible funding options and introduces the concept of Green Regenerative Improvement Districts, or 'GRID', as a possible new governance mechanism that could assist with financing and managing precinct scale eco-infrastructure.

Keywords: Sustainable urbanism, infrastructure financing, eco-infrastructure, precincts, funding models.

INTRODUCTION

Key findings from the latest IPCC Assessment Report (AR5) stress the vulnerability of cities to climate change and highlight the need to build greater resilience and adaptive capacity within cities through improved infrastructure provision, (van Staden, 2014; IPCC 2014).

In the Australian context, aging infrastructure and insufficient investment in upgrades (Pickering 2014) is creating an 'infrastructure deficit' (Kohler 2014). New resource efficient, low carbon eco-infrastructure is urgently required within Australian cities to reduce consumption, while maintaining or improving the liveability and resilience of our cities (Girardet 1992, Newman and Kenworthy, 1999).

Despite the existence of many promising demonstration projects, uptake of sustainable development remains slow and is far from mainstream. While there are various reasons for this, the authors suggest that key inhibitors include a lack of financing and governance processes that promote sustainability.

Given competing budgetary demands at higher levels of government, innovative governance and financing at the local level may be able to unlock the potential delivery of district scale eco-infrastructure to help transform the built environment in Australia.

This paper begins by describing why the precinct or neighbourhood district is the optimal level for implementing eco-infrastructure, before exploring a range of existing and emerging funding models and mechanisms that could assist in its delivery. Many of these funding options may require additional governance structures to facilitate and manage the process over time and tenure.

WHAT IS A DISTRICT OR PRECINCT?

The terms district, precinct and neighbourhood are used interchangeably within this paper and are defined as a collection of buildings that use shared infrastructure, such as roads, energy, water and waste management systems. It can be a new development or a re-development and, while it can be purely residential or commercial, ideally it will incorporate mixed uses, thus providing a hub or agglomeration of activities and multiple stakeholders.

WHY DISTRICT-SCALE ECO-INFRASTRUCTURE?

The authors define eco-infrastructure as being alternative options for delivering urban services to help achieve sustainable outcomes and reduce a city's carbon footprint (Rauland 2013). While this includes biological infrastructure, it also incorporates alternative sustainable infrastructure options for supplying power, water, and waste services. Delivering these services at a local, decentralised scale, can help provide greater integration between technologies, systems and planning. It also provides economic and environmental benefits and efficiencies that can be "an order of magnitude greater than when they are pursued in isolation" (The Climate Group, 2010, p. 9) by being small enough to innovate quickly yet big enough to have a meaningful impact (EcoDistricts Protocol, 2014).

EXAMPLES OF LOW CARBON, ECO-DISTRICTS

Globally, many well-known eco-cities, districts and low carbon communities, such as BedZED (UK), Vauban (Germany), Hammerby Sjostad and Bo01 (Sweden), and Masdar City (UAE) have demonstrated various elements of precinct-scale carbon reduction (Ewing et al., 2008; Joss, 2011; Newman et al., 2009; Roseland, 2012; Williams 2012). It is important to note, however, that, most of these have received some form of subsidy or assistance (Thomson, Matan, Newman 2013), indicating that in many cases this type of development is not yet commercially viable.

Regulatory and financial barriers, in particular, have inhibited greater adoption of low carbon and energy efficiency built environment development (more information on barriers can be found in Rauland 2013).

EXISTING FUNDING MODELS

Various funding models have emerged in recent years to deal with barriers to widespread sustainable development such as high upfront capital costs and split incentives[1] Some of these funding solutions have been tailored to assist sustainable investment in single ownership buildings, however, many of these could potentially be expanded to enable district-scale eco-infrastructure delivery. To do so effectively is likely to require new governance processes. A range of existing funding options, and a potential new governance model to manage development at the precinct scale (GRID), are discussed briefly below.

VALUE CAPTURE

Value capture has traditionally been used to finance transport infrastructure. The model essentially captures a percentage of the land value uplift resulting from adjacent public transit infrastructure construction. The mechanism for collection is typically some form of land tax (cf. Tax Increment Financing [TIF]), which is then put toward paying off the infrastructure over a set time period (eg. 25 years).

McIntosh (2011) observes that long-term trend analysis in Brisbane demonstrates a 22% increase in property value in suburbs with high transit amenity. The value capture model could be repurposed to pay for other types of eco-infrastructure where the additional infrastructure can be demonstrated to increase

1 'Split incentives' refers to a situation where property developers/owners are reluctant to invest in sustainability improvements that primarily benefit building occupants and provide little or no financial return on their investment, while building occupants are reluctant to invest in upgrades that increase the value of the property for the owner.

value (e.g. by reducing living and business operation costs through improved energy, water and waste management).

ENERGY SERVICE COMPANY

An Energy Service Company (ESCo) can be used to implement energy efficiency upgrades to buildings or precincts, as well as providing decentralised renewable or low carbon energy generation projects. It is particularly useful in dealing with the high upfront capital costs associated with energy-related projects by removing the risk associated with uncertain energy payback periods.

ESCos function predominantly at the small, decentralised level and can often offer lower cost energy generation options as they avoid many of the charges associated with large-scale operations. The ESCo model is particularly appealing at the precinct scale and could be used in combination with a variety of other measures and models.

LEASING ARRANGEMENTS

Leasing arrangements function similarly to an ESCo in that they require no upfront capital, as lease repayments are usually covered by the energy savings. While the company leasing the equipment do not usually own it (unlike with some ESCos), the leasing arrangement allows the company to regularly upgrade to the most efficient equipment. An example was Low Carbon Australia[2], an independent public company funded by the Federal Government, who joined together with Alleasing in 2010 to develop a unique leasing arrangement for energy efficient equipment called E3 Lease.

In addition, various new leasing arrangements for solar panels, are transforming the solar market by eliminating the upfront capital costs associated with solar panels while offering a fixed lower electricity price for customers over a set time period.

COMMUNITY-OWNED RENEWABLE ENERGY

Community-owned renewable energy projects have become increasingly common in recent years, and countless projects now exist which use a variety of technologies including solar, wind, small scale hydro, biodiesel and biomass. Numerous studies have documented the barriers, opportunities and importance of community-owned energy (Rae & Bradley 2012; Bunning 2014; Walker 2008; Middlemiss & Parish 2009). Key advantages of community ownership include: creating a secure and reliable source of local energy; increasing local autonomy and control; lowering long term energy costs; creating a local income stream; demonstrating

[2] Low Carbon Australia was absorbed by the Clean Energy Finance Corporation in 2013.

environmental commitments and ethical considerations; increasing local resilience and avoiding costly infrastructure upgrades (Walker 2008; Li et al 2013).

While there are currently only a handful of community-owned energy projects in Australia (such as Hepburn Wind and Denmark Community Wind), there is significant potential and scope for expansion. If the current barriers can be overcome, community-owned low carbon energy generation could assist significantly with eco-infrastructure delivery at the district level (Bunning 2014). Brixton Energy Company in London presents a useful urban model for the integration of community owned solar in medium to high-density inner city environments.[3]

PROPERTY ASSESSED CLEAN ENERGY

In 2008 the City of Berkley, California, introduced the Property Assessed Clean Energy (PACE) model, an innovative financing tool that assists building owners to fund sustainability measures (e.g. energy efficiency or integrated renewables) (City of Berkley, 2008). PACE loans are repaid via a local government or state property tax tied to the property over a specified period (e.g. 20 years). This model gives building owners access to funds to meet the large upfront costs associated with sustainable technology investment (e.g. PV cells or trigeneration) that can be repaid over a longer time period. The financial savings from reduced energy costs can also be directed toward loan repayments.

PACE allows the building owner to pass on the costs associated with their upgrade to the next buyer if the loan has not been fully repaid by the time of sale. This helps to remove the risk associated with expensive upgrades with long-term returns on investment.

ON-BILL REPAYMENT

While PACE works well for single owner-occupied buildings, is not so useful for rental and multi-family buildings. A 2013 pilot project overcomes the split incentive barrier through On-Bill Repayments (OBR), which allows owners to recoup sustainability investments through monthly utilities bills (Kim et al. 2012).

ENVIRONMENTAL UPGRADE AGREEMENTS

EUA’s are a recent Australian adaptation of the PACE financing mechanism, however, EUAs focus on commercial buildings. They are currently available in Sydney and Melbourne, and are being discussed in Perth.

3 For more on Brixton Energy Company see: https://brixtonenergy.co.uk/

While, PACE, EUA and OBR models were all aimed for individual buildings, the concepts provide useful financial templates that lend themselves to a next generation model that could be expanded to the precinct scale.

GREEN BONDS

Green Bonds were first established in 2007 by Skandinaviska Enskilda Banken (SEB) together the World Bank (SEB 2014). The bonds were initially developed to meet an increasing demand for climate friendly investment opportunities, though they are now used to fund a range of environmental and sustainable, as well as climate related projects. The triple-A rated-fixed bonds are comparable to other World Bank bonds (World Bank 2014).

Green Bonds were only introduced to the Australian market in April 2014, though have been readily embraced by various superannuation funds, asset managers, insurance companies and banks (The Australian 2014), thus highlighting the demand for such products in the Australian context. This opens up funding opportunities, helping to unlock investment in precinct-scale eco-infrastructure projects.

BUSINESS IMPROVEMENT DISTRICTS

Business Improvement Districts (BIDs) are organisations created and funded by local businesses and property owners within a defined district of a city, to manage the improvement of that district. They are generally funded by an increase in tax or a levy applied to businesses and property owners within the specified BID area (Levy 2001).

The role and function of BIDs vary considerably between different districts, cities and countries, depending on the needs of the local area. Various BIDs currently exist in Australia (e.g. Brisbane SCIPs, City of Fremantle and Gosford city).

BIDs are thus an alternative, privately funded, independent and participatory governance mechanism that allows stakeholders help to develop the BID plan and decide how funds will be managed. To date BIDs have not focused specifically on environmental improvements, however, using the concept of a BID to facilitate the implementation of green eco-infrastructure at a precinct level is discussed below.

A NEW MODEL – GRIDSs

Rauland (2013) identifies a GRID or 'Greening, Revitalisation and Improvement District', as 'a mechanism that helps to deliver the basic green urban infrastructure needed at the local precinct level.

A GRID could be established in a similar manner to a BID but with a mandate to ensure the provision of sustainability improvements. A GRID plan would need to be developed with goals and objectives, including environmental targets, identification of suitable options for eco-infrastructure provision and on-going maintenance.

Each GRID would develop it's own business case for projects to determine costs, benefits and levy amount and how it will be collected and administered.

Once established a GRID would increase value through:

- Environmental efficiencies to reduce operating costs for owners and tenants, and;
- Placemaking and liveability improvements that attract people to use and spend in the area.

Prior to establishment, community buy-in and regulatory amendments in some jurisdictions would be required. However, once established, a GRID would ideally pick and choose from a range of financial mechanisms such as those discussed in this paper. For example a GRID may acquire a precinct scale PACE style loan and recoup costs via an OBR type scheme. Technical maintenance of specialist eco-infrastructure such as District energy or Water Sensitive Urban Design (WSUD), could be managed by an ESCO or leasing agent with funding provided through a GRID levy, or for larger projects, value capture.

CONCLUSION

This paper has discussed the need for, and potential opportunities available to create, new financing arrangements that can enable low carbon, green infrastructure to be implemented at the precinct scale. However, this is likely to require new forms of governance. The concept of a GRID was proposed, which would function as a formal governance structure, to facilitate precinct-scale eco-infrastructure financing and ongoing management of the precinct. Spreading the cost over multiple properties and over longer payback periods, through a GRID governance structure, would reduce the often-prohibitive burden of high upfront costs associated with this type infrastructure, thus helping to mainstream precinct-scale low carbon and sustainability improvements within the built environment.

REFERENCES

Bunning, J. (2014). Governance for regenerative and decarbonised eco-city regions. *Renewable Energy*, 67, 73-79.

City of Berkley (2008) Financing I*nitiative for Renewable and Solar Technology*. Retrieved from: http://www.ci.berkeley.ca.us/berkeleyfirst/

EcoDistricts (2014) *EcoDistricts Protocol*, Portland.

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2008). *Growing Cooler: The Evidence on Urban Development and Climate Change*. Washington, DC: Urban Land Institute.

Feldman, K.A. 1971. Using the work of others: Some observations on reviewing and integrating. *Sociology of Education*. 4:86-102. Girardet, H (1992) *The GAIA Atlas of Cities: New directions for sustainable urban living.* GAIA books. London.

IPCC 2013 The Fifth Assessment Report. Intergovernmental Panel on Climate Change

Joss, S., Tomozeiu, D., & Cowley, R. (2011). Eco-Cities - A Global Survey 2011: Eco-city Profiles *International Eco-Cities Initiative*: University of Westminster.

Kim, C., O'Connor, R., Bodden, K., Hochman, S., Liang, W., Pauker, S. & Zimmermann, S. (2012) *Innovation and Opportunities in Energy Efficiency Finance*, White Paper, Wilson Sonsini Coodrich & Rosati, NY. May 2012, second edition.

Kohler (2014) *Infrastructure deficit puts us on a road to nowhere*. Retrieved from http://www.abc.net.au/news/2014-01-29/kohler-infrastructure-emergency/5224586

Levy, P. R. (2001). Paying for the Public Life. *Economic Development Quarterly, 15*(124-131).

Li, W, L., Birmelea, J., Schaicha, H,. & Konold, W.(2013). Transitioning to community-owned renewable energy: Lessons from Germany. *Procedia Environmental Sciences,* 17, 719–728

Middlemiss, L. & Parish, B. (2010). Building capacity for low-carbon communities: The role of grassroots initiatives. *Energy policy*, 38, 7559–7566.

Newman, P. & Kenworthy, J. (1999). *Sustainability and Cities: Overcoming Automobile Dependence.* Washington DC: Island Press.

Newman, P., Beatley, T., & Boyer, H. (2009). *Resilient Cities: Responding to Peak Oil and Climate Change.* Washington DC: Island Press.

Pickering, C (2014) Abbott's infrastructure projects must have a solid foundation. *Climate Spectator*. Retrieved from http://www.businessspectator.com.au/article/2014/7/18/australian-news/abbotts-infrastructure-projects-must-have-solid-foundation

Rae, C., & Bradley, f. (2012). Energy autonomy in sustainable communities—A review of key issues. *Renewable and Sustainable Energy Reviews,* 16, 6497–6506

Rauland, V. (2013). Decarbonising cities: certifying carbon reduction in urban development. PhD Thesis. Curtin University. Retrieved from http://espace.library.curtin.edu.au/R?func=dbin-jump-full&local_base=gen01-era02&object_id=194386

Roseland, M. (2012). *Toward Sustainable Communities: Solutions for Citizens and Their Governments* (4th ed.). Gabriola Island, BC: New Society Publishers.

SEB (2014) *Achieving fiduciary risk/return whilst improving environmental performance.* Retrieved from
http://sebgroup.com/greenbonds

The Australian (2014, 17 April) *Australian Standard-green bond launched*. Retrieved from http://www.theaustralian.com.au/business/latest/australian-standard-green-bond-launched/story-e6frg90f-1226888510814

The Climate Group. (2010). Climate Smart Precincts: Opportunities Report to the First Ministers The Climate Group.

Thomson, G., Matan, A., Newman, P. (2013) A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia. Proceedings for the State of Australian Cities conference, Sydney, November 2013

Van Staden, R. (2014). *Climate Change: Implications for Cities. Key Findings from the Intergovermental Panel on Climate Change* Fifth Assessment Report. University of Cambridge.Walker, G. (2008). What are the barriers and incentives for community-owned means of energy production and use? *Energy Policy*, 36, 4401-4405.

Williams, J. (2012). *Zero Carbon Homes: A Road Map*. New York: Earthscan.

World Bank (n.d.) *About World Bank Green Bonds* http://treasury.worldbank.org/cmd/htm/WorldBankGreenBonds.html (accessed August 2014)

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A Review of International Low Carbon Precincts to Identify Pathways for Mainstreaming Sustainable Urbanism in Australia.

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Abstract
Urban environments, once built, are slow to change, therefore the neighbourhoods we build today, will ideally be designed to meet our future needs. The combined challenges of climate change, population growth and finite resources demand we rapidly decarbonise our cities. Failing to provide the necessary infrastructure to decarbonise Australian cities today will place a social, environmental and economic burden upon future generations of Australian society.

At a high strategic level this imperative is acknowledged but in practice government planning agencies have typically placed greater emphasis upon maintaining land supply and housing affordability over effectively fostering a culture of sustainable urbanism. The absence of a strong sustainability culture within the built environment sector, has seen barriers, such as the 'sustainability cost premium' and the political 'short termism' of a three year electoral cycle, impede more rapid transition to a widespread culture of sustainable urbanism practice.

This paper describes six international 'low carbon precinct' case studies to show how they were able to overcome some of these barriers. The case studies employ a diverse range of strategies including demonstration project trials, integrated eco-services, and innovative funding models to deliver low carbon precincts. It shows how political, skill and market barriers can be overcome through the use of different delivery models, and how these models may provide useful lessons to help develop pathways to decarbonise urban development in Australian cities.

Introduction
Urban environments, once built, are slow to change, therefore the neighbourhoods we build today, ideally, need to meet the social, environmental and economic needs of the future. The combined challenges of climate change, population growth and finite resources demand decarbonising our cities. Failing to provide the necessary infrastructure to decarbonise Australian cities today will place a social, environmental and economic burden upon future generations of Australian society.

This paper discusses common barriers to sustainable urbanism, including lack of skilled labour to deliver sustainable projects, the 'sustainability cost premium' and the 'short termism' of a three year political electoral cycle. These barriers have been overcome by a number of international 'low carbon precincts' presented here as six case studies.

This paper focuses on precinct scale development as precincts may provide the best opportunity for incrementally decarbonising Australian cities during the transition from unsustainable conventional practice to widespread sustainable urbanism. Precinct scale initiatives can help trial and test subdivision/neighbourhood wide urban eco-services that would not be possible at the individual building scale. Low carbon precincts are the ideal places to trial innovative processes and technologies that can inform urban policies or institutionalise financial incentives to ultimately mainstream the type of sustainable urbanism needed to decarbonise Australian cities.

Approach

A range of low carbon exemplars were identified through a literature review and six were selected for inclusion in this paper where they were able to demonstrate innovative delivery mechanisms that allowed one or more of the sustainable urbanism barriers (as described in detail below) to be overcome.

The low carbon precincts presented are BedZED (UK), One Brighton (UK), Peterborough Carbon Challenge (UK), Hammarby Sjostad (Sweden), Vauban (Germany) and the City of Berkley PACE scheme (USA). These case studies are all proven exemplars of sustainable urbanism and demonstrate a diverse range of strategies including demonstration project trials, integrated eco-services, and innovative funding models to deliver low carbon precincts. The paper discusses the key sustainability initiatives associated with each project and the processes used by stakeholders to deliver them. A range of 'lessons' are outlined in the concluding section to offer a possible processes that may assist in 'mainstreaming' low carbon precincts in an Australian context.

Understanding the problem

Australia's greenhouse gas emissions

Per capita Australia produces more carbon pollution than any other developed nation. The building sector is a major contributor to Australia's greenhouse gas emissions with residential energy use alone accounting for around 12% of carbon dioxide (CO_2) emissions (Australian Government, 2013a). Australia's international commitment to an 80% CO_2 emission level reduction (below 2000) by 2050 is ambitious (Australian Government, Department for Climate Change). In response to this target, Climateworks Australia (2013) recommend that a low emissions built environment is a key goal for success (Denis et al. 2013). But achieving this target will require a radical shift in the building sector away from business as usual towards mainstreaming sustainable urbanism practice. The logistics of the challenge are likely to be exacerbated as a result of high population growth which is projected to be around 50-100% (30-42 million people) by the mid 2050s (ABS, 2008) this growth will make per capita emission targets even more onerous to meet.

The knowledge to deliver low emission built environments exists, but the challenge will be to find market-acceptable, cost-effective models for implementation. At present major structural and financial barriers are impeding the rapid transition from business as usual towards a sustainable urbanism.

Barriers to delivery of sustainable urbanism

Barriers to sustainable urbanism mainly relate to the inherent inertia of the high cost, risk adverse construction, engineering and development sectors. The irony is that while long term economics necessitate a transition to sustainable urbanism, short term economics are inhibiting change (Generation, 2012; Cole, 2012). Our urban fabric is currently being delivered through systems that have well established supply chains that are geared toward lower construction cost with little sustainability consideration. More sustainable options (that may prove cheaper over the product life cycle) are uncommon due to the additional cost and risk associated with sustainability innovation, in addition current regulations do not necessarily support the delivery of sustainable urban form and in many instances may even prohibit delivery (Newman, Bachels and Scheurer, 2010).

Our ability to shift towards low carbon, sustainable cities and lifestyles requires a sustainable (sub)urban infrastructure capable of maintaining liveability standards while helping minimise difficulties/resistance during a transitioning toward resource consumption reduction (Newton, 2012). The challenge will be to overcome the existing skills, political/policy and market barriers.

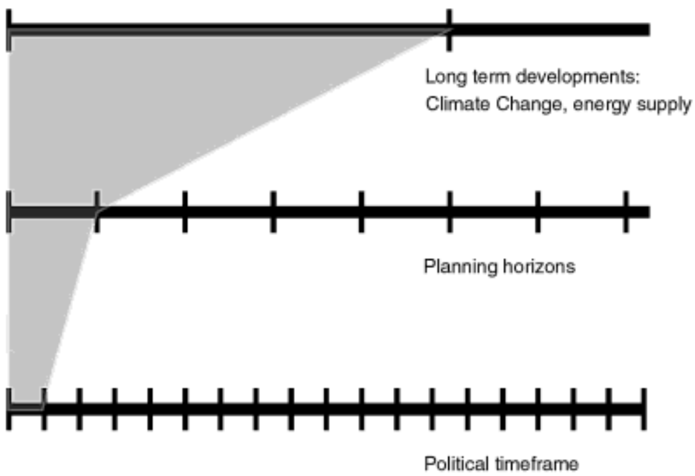
Skills Barrier – knowledge and workforce

Shifting from business as usual will require retraining of the work force at all stages of development delivery including design, planning and construction as well as streamlining material supply chains and services to facilitate sustainable outcomes. The skills to deliver sustainable communities exist but 'best practice' is not the norm. Initiatives in Australia such as the Council of Australian Government (COAG) endorsed Green Skills Agreement aim to address this issue and state that, '*existing jobs will need to be redesigned through upskilling or re-skilling, to meet the skills needs of individual firms and entire industries in the move towards a more sustainable future'* (COAG, 2009).

In the European Union (EU), where some of the most stringent sustainable building requirements exist, the shortfall in sustainable building skills as a barrier to green building uptake is well documented. The EU International Labour Office suggest that the major gaps in the EU construction sector included poor quality installation and health and safety issues (International Labour Organization, 2011). Similar skills gaps could be expected in Australia. For example, the ambitious but ultimately flawed, Australian Government sponsored Home Insulation Programme that commenced in July 2009 before being ungraciously cancelled in February 2010 following much negative publicity. The Programme provided subsidies for building insulation and was touted to reduce household energy bills by 40%, but a skills deficient caused issues which according to *The Australian* newspaper 'has been linked to four deaths of installers, 120 house fires and up to 1000 electrified roofs' (Kelly, 2010). This example demonstrates that good programmes poorly executed due to a skill gap can result in failure.

Political Barrier – the short termism of a three year electoral cycle
The challenge that short term electoral cycles place upon the creation of meaningful climate change policy relates to the different time scale and the opportunistic nature of populist politics as Figure 1 illustrates (Roggema, 2012).

Figure 1: The different timeframes of politics, planning and climate change.
Source: 'Connection of long and short term' Roggema and Van den Dobbelsteen, 2008, cited in Roggema 2012



The visionary long term leadership required for sustainable development policy can be difficult because politicians are inherently reluctant to commit to policies that have no simple solution, no clear end point, that are likely to cost a lot with few short term benefits and that (most significantly) will not show clear results until well after the proponent's political career has ended (Roggema, 2012). Policy to support a sustainable low carbon future will remain sluggish while it is impeded by 'political party rivalry' and 'the politics of fear' (Carter, Pisaniello and Burritt, 2010) as witnessed in the political controversy and ongoing tussle around the *Clean Energy Act* (2011) (referred to as the 'Carbon tax') in Australia. Until issues such as climate change have stronger political consensus in Australia there will be a need for strong leadership from within industry and the community to ensure the built environment sector keeps pace with longer term scientific and policy targets.

Market Barrier - the 'sustainability cost premium' in Australia

Industry leadership to deliver 'best practice' sustainable urbanism requires developers to deviate from conventional practice, often resulting in additional risk associated with innovation or new technology, this risk usually translates into a financial disincentive, the so-called 'sustainability cost premium' (Sustainability Victoria, 2011). Without a sponsor willing to pay a premium above market value to subsidise costs, the sustainability cost premium impedes sustainable urbanism. Most of the sustainable low carbon precinct case studies discussed in the next section of this paper have a sponsor (often government) willing to offer financial support to absorb risk and encourage a demonstration project. Subsidised demonstration projects, while performing a useful educational and marketing role, typically result in 'flagship' developments that represent an exception to the rule rather than common practice. Newton suggests that we need to move beyond this toward low-cost,

> *eco-efficient urban infrastructure, that is, infrastructure capable of delivering key services such as water, energy, housing, and mobility with reduced EFs* (ecological footprints) (Newton 2012, p.9).

Achieving this requires overcoming the market barriers associated with additional costs. These market barriers are further compounded by the well established notion of 'split incentives' whereby those making the capital investment decisions (the developer or landlord) are not the same entity as those responsible for paying energy bills (the property purchaser or tenant) (Australian Government, 2013b). Mainstreaming sustainable urbanism will only occur if market barriers and split incentives can be overcome, this paper identifies some novel ways in which this has been achieved in a number of case studies.

Case Studies

Effective pathways for delivery must overcome the combined skills, policy and market barriers if sustainable urbanism is to be mainstreamed. One way sustainable urbanism may be delivered is through a piecemeal approach of semi-autonomous precincts that incrementally deliver a more sustainable city. Six low carbon case studies are discussed, they all result from comprehensive development approach at the subdivision/precinct scale or local government sustainability initiatives. Table 1 provides a brief overview of the six case studies.

Table 1: Case Study overview

PROJECT	COUNTRY	DELIVERY MECHANISM	DESCRIPTION	PREVIOUS SITE CONDITION
BedZED	UK	Public private partnership	1.6ha Residential mixed use, 82 dwellings	Greenfield site (council owned)
One Brighton	UK	Market driven, developer initiative	Residential Mixed use with supermarket, 172 dwellings	Greyfield site (former surface car park)
Peterborough Carbon Challenge	UK	Public private partnership (government led and heavily subsidised)	Residential mixed use, 7ha 285 dwellings	Brownfield site (former industrial land)
Vauban, Freiburg	Germany	Market driven, community led	Urban neighbourhood 5000 residents + 600 jobs	Brownfield and greenfield site (former army barracks)
Hammarby Sjostad	Sweden	Public private partnership, government led	11,000 residential units for just over 25,000 people and a total of about 35,000 people will live and work in the area by 2015	Brownfield site (former naval yard)
City of Berkley	USA	Property Assessed Clean Energy (PACE)	Voluntary clean energy financing incentive for local residents	Greyfield (City policy for retrofitting existing buildings)

BedZED, UK

Beddington Zero Energy Development (BedZED) is a suburban, mixed-use development of 82 dwellings and 2500m^2 of commercial or live/work space in South London; completed in

2002 this important low carbon precinct pioneer is now a mature low carbon development providing many lessons, particularly around overcoming skill barriers but also market barriers.

In 1997 the UK charity BioRegional, seeking new office space to house their growing environmental social enterprise, decided that instead of renting a conventional commercial space they would 'express their commitment and ideas by building a green office' (Desai, 2010). This resulted in the BedZED development.

BedZED was developed using a strong sustainability vision referred to as the 'One Planet Living Principles' (developed collaboratively by BioRegional and the World Wildlife Fund). These principles have since been promoted and adopted as a benchmark for other 'One Planet' sustainable developments. The ten principles relate to carbon, waste, transport, materials, food, water, biodiversity, culture, economy and happiness, and effectively function as a reference point for decision making throughout the development process.

The BedZED 'urban eco-village' includes a low energy, medium density urban development (approximately 50 dw/ha) on a subdivision oriented to maximise passive solar design . The super insulated buildings resulted in a 75% improvement upon UK building regulations (Desai, 2010, p.33), while renewable energy production in the form of PVs and biomass fueled trigeneration (supplemented by natural gas) resulted in an average 45% reduction in energy consumption (and 81% heating reduction) when compared to neighbouring, conventional developments. The development also included other innovations such as green roofs (accessible as private open space), rainwater harvesting, on-site 'enhanced reed bed system' for sewerage treatment and approximately 15% of total building material was derived from reclaimed or recycled sources (Desai, 2010).

Although the project was not a success financially, BioRegional cite two primary factors that helped off-set the 'sustainability cost premium'. These factors were the use of a 'planning gain mechanism' and the property value premium the green designs attracted.The planning gain mechanism involved trading green innovation for additional development area, in this instance the production of a 'green transport plan' allowed the developer to seek permission for a reduction in car parking provision and road space which was transferred to additional development space that in turn translated to additional returns (estimated to be in the region of £3.7 million additional development value) (BioRegional, 2009). The market appeal of the innovative product "*achieved premium values some 17-20% above the conventional new homes in the area. Buyers paid extra for the innovative design and the "green" credentials"* (BioRegional, 2009, p.8).

Having a strong environmental vision at the outset of the project and a steward or 'sustainability integrator' (Desai, 2010) ensured the sustainability vision (One Planet Principles) were not compromised at any stage of the process from concept, through detailed design, construction and post occupancy management.

Based upon their BedZED experience, BioRegional have partnered with, or acted as consultants for, developers on additional low carbon sustainable projects including One Planet Brighton, discussed next, to help disseminate their knowledge and increase the skills base for delivery of low carbon communities.

One Brighton, UK

One Brighton is a 172 unit, commercially viable follow-up to BedZED completed in 2010. It applies the One Planet Principles to a high density inner city development adjacent the Brighton Train Station. One Planet Brighton is a high density, mixed-use infill development built on a former surface car park in the city of Brighton on England's South Coast. The development includes a major commitment to social housing (30%) operated by an external housing association. The market driven development by BioRegional Quintain was a joint venture with builder partners Crest Nicholson (Desai, 2010).

The vacant site was initially bought by a supermarket chain to be developed as a typical 'big-box' supermarket with surface car parking, however community opposition to the proposal led to the local government requiring a comprehensive Master Plan that sought to incorporate the supermarket as one component of a mixed-use development that incorporated residential, retail and community space.

The purpose was to demonstrate that sustainable urbanism could overcome typical market barriers to be commercially viable and compete with conventional, unsustainable development.

The sustainability narrative did not dominate the sales pitch instead a 21st century lifestyle was pitched along with the idea of ‘five minute living’ – having shops, work, school, theatres and public transport all within five minutes of home. These collective messages allowed this development to outperform the major UK house builders sales rates in a difficult post Global Financial Crisis economy (50% improvement on industry benchmarks) (Desai, 2010).

The development sought very few concessions with the exception that negotiations were made with the council to reduce private vehicle parking requirements to zero on-site car parking with the exception of disabled and car club parking. This permitted increased site yield (‘a planning gain mechanism’). The sustainability cost premium was partly absorbed by the higher yield on the small site resulting in an increase the number of apartments from a permissible 80 to 172 units (internal rate of return was approximately 15%) (Sustainability Victoria, 2011).

The developer (Bioregional Quintain) also introduced the role of ‘sustainability integrator’ to ensure the sustainability principles were ‘integrated seamlessly from design through construction to estate management’. A ‘long term estates management strategy’ was developed to manage the integrated environmental systems post-sales at which point the sustainability integrator handed over to a site caretaker to continue to ensure the smooth running of the long term estates management strategy. Given the use of unconventional sustainability technologies in most low carbon precincts, ongoing maintenance is critical for long term success.

To help monitor suitable products BioRegional also developed a not for profit service called ‘One Planet Products’ that assesses products and suppliers against the One Planet Principles to catalogue a ‘green’ supply chain permitting efficient selection of the most appropriate products and suppliers (see http://www.oneplanetproducts.com/). The service helps spread knowledge within the construction industry and increases sales and market penetration for green products (hopefully also reducing costs of green products over time as an economy of scale).

Assembling the right team was essential to the success of One Brighton. The developer and builder consortium were value-driven and include some of the UK’s most sustainable practices.
The development was almost entirely funded through private finance (with minor renewable energy grant subsidies). By aligning project objectives with the consent authorities high level sustainability objectives the proponent was able to submit a non-complying scheme and argue for merit based planning gain to make the sustainable scheme financially viable.

Vauban, Germany

The 38 hectare Vauban neighbourhood completed in 2006 is the greenest quarter of Germany’s ‘ecological capital’ – Frieburg. The City of Freiburg helped facilitate and empower residents through an interesting model of community participation through a community engagement platform, Forum Vauban. Forum Vauban, working in collaboration with the City of Freiburg, developed a community vision that sought to balance environmental, social and economic goals to guide future development (Forum Vauban, 2004). The city council set requirements, boundaries and incentives such as reduced tax on land acquisition, to help implement the vision.

As a result of this process the neighbourhood includes a range of sustainability measures including high density and mixed use services concentrated along the tram route and bus corridors, a comprehensive cycle and pedestrian network (in addition to low trafficked streets) and high performance building requirements.

A key element enabling the cost effective implementation of this vision was the establishment of ‘construction communities’ (owner-developer collectives of 3-21 households in size) based on the co-housing concept where a group of individuals with a common vision for living formed a co-operative to develop apartment buildings on their terms. Because construction communities are owner occupiers a number of these developments exceeded the high building standards required by the council, with a 100 dwellings built to the PassivHaus standard and 59 dwellings that exceed this to add energy back to the grid as ‘plus energy houses’ (Forum Vauban, 2004).

By cutting out conventional developers driven by a profit motive, collectives of several households with a common vision work together to build apartments or a city block to their own specifications. Similarly, community funded decentralised energy allowed residents to simultaneously invest in their local community and receive income as dividends from energy sales.

Community and owner-occupier investment has the advantage of removing much of the financial burden from government while allowing the local government approval processes to ensure developments to meet minimum criteria relating to sustainability performance and social responsibility based upon the values that emerged from the community engagement. Funds that might ordinarily have been absorbed by the developer’s profit margin are able to be invested in sustainable technology overcoming some of the sustainability cost premium.

Peterborough Carbon Challenge, UK

The Carbon Challenge was a UK government initiative that saw the public sector working with private developers to ‘accelerate innovation’ (English Partnerships, 2007). Peterborough was the larger of the two Carbon Challenge projects ultimately realised. Both projects were supported by heavy government subsidies and led by the English Government’s national regeneration agency English Partnerships. English Partnerships maintained that the projects were necessary:

> *…in order to develop the skills and technologies in the house building industry that are necessary to deliver new zero carbon homes at Level 6 of the Code for Sustainable Homes. The Carbon Challenge will make house builders and their suppliers better prepared to meet the Government’s goal that all new homes will be zero carbon by 2016.* English Partnerships, *Carbon Challenge Standard Brief* (August 2007)

The Peterborough Carbon Challenge project consists of 295 dwellings (including a 40% affordable housing), a centrally located office and community space within a seven hectare brownfield site is in the historic city of Peterborough (Opportunity Peterborough, 2011). This public private partnership was led by English Partnerships in conjunction with development authority ‘Opportunity Peterborough’ and other government stakeholders. A competitive tender process resulted in the winning team being awarded subsidised land sale to absorb the additional risk and costs associated with innovative sustainability measures.

Currently under construction, Peterborough Carbon Challenge, will be the UK’s largest zero-carbon, mixed-use development when completed (Peterborough City Council, 2011). The Carbon Challenge benefits industry and government by testing the policy and highlighting opportunities and weaknesses that need to be addressed. It also enables the community to understand what a ‘zero-carbon’ community can look like (Department of Homes and Communities, 2011).

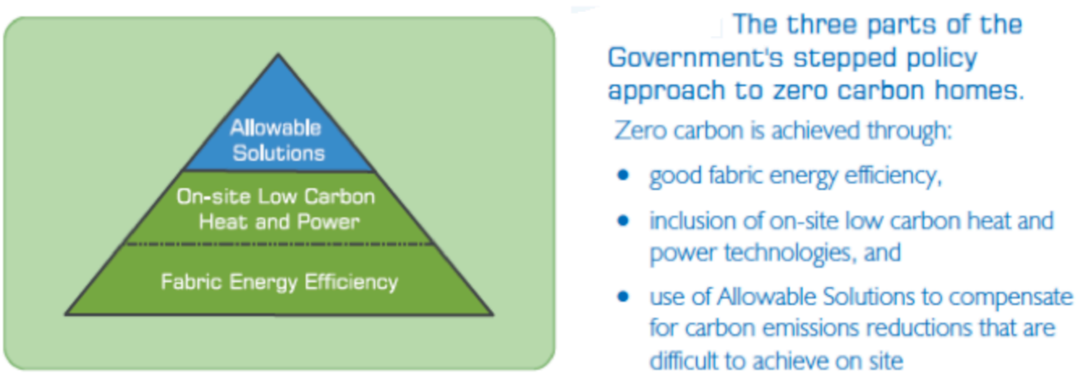
The driver for government involvement in the project was the *Code for Sustainable Homes* (CSH) released in response to the ‘Stern Review’ recommendation for the government to take early and strong action on climate change to minimise future social and economic disruption. When the code was released in 2006, however, no existing housing development could satisfy the aspirational future code requirements therefore the Carbon Challenge was developed as a pilot program to demonstrate that zero-carbon housing was possible, to showcase excellence in sustainable urban development and initiatives and also to test and monitor new ideas.

The winning scheme included highly insulated buildings (reaching PassivHaus standard), combined heat and power plant, water sensitive urban design and integration of urban ecology on a constrained site, on-site food production including small orchard plantings and allotments and a community café that will sell locally produced goods (RUDI, 2008; Department of Homes and Communities, 2011).

Lessons from the Carbon Challenge have lead to a modification from the initial prohibitively expensive requirement for all energy to be produced on site, to a more cost-effective approach that ensures new development delivers high building fabric energy efficiency with more lenient 'on-site' energy requirements (see Figure 2) with any further carbon emission reduction requirements able to be compensated by 'allowable solutions' (off-site).

Figure 2: The three parts of the UK Government's stepped policy approach to zero carbon homes.

Source: *Zero Carbon Strategies*, Zero Carbon Hub (2013)



The 'carbon challenge' was a useful process for the UK government, providing demonstration projects to showcase new technology and 'accelerating innovation' within the private sector to help meet national emission reduction objectives. More importantly, however, it allowed rapid prototyping and testing of policy outcomes, ultimately leading to the revision of an onerous and costly burden upon the developer to meet all their renewable energy needs 'on-site'. The amended policy shifted the emphasis toward the creation of highly efficient building envelopes to reduce energy demand from housing stock. The generation of on-site renewables while encouraged, may also be met be 'allowable solutions' off-site (Zero Carbon Hub, 2011).

Lessons learnt from the Carbon Challenge process and subsequent research have been collated and maintained in a central repository – the 'Zero Carbon Hub' – a public private partnership 'established to take day-to-day operational responsibility for coordinating delivery of low and zero carbon new homes' with the strategic objectives to: create confidence during change, reduce risk and clear obstacles, disseminate practical guidance (Zero Carbon Hub, 2008). This knowledge sharing portal helps disseminate lessons to government, industry and community accelerating uptake of knowledge relating to the building sector and helping to overcome the skills barrier.

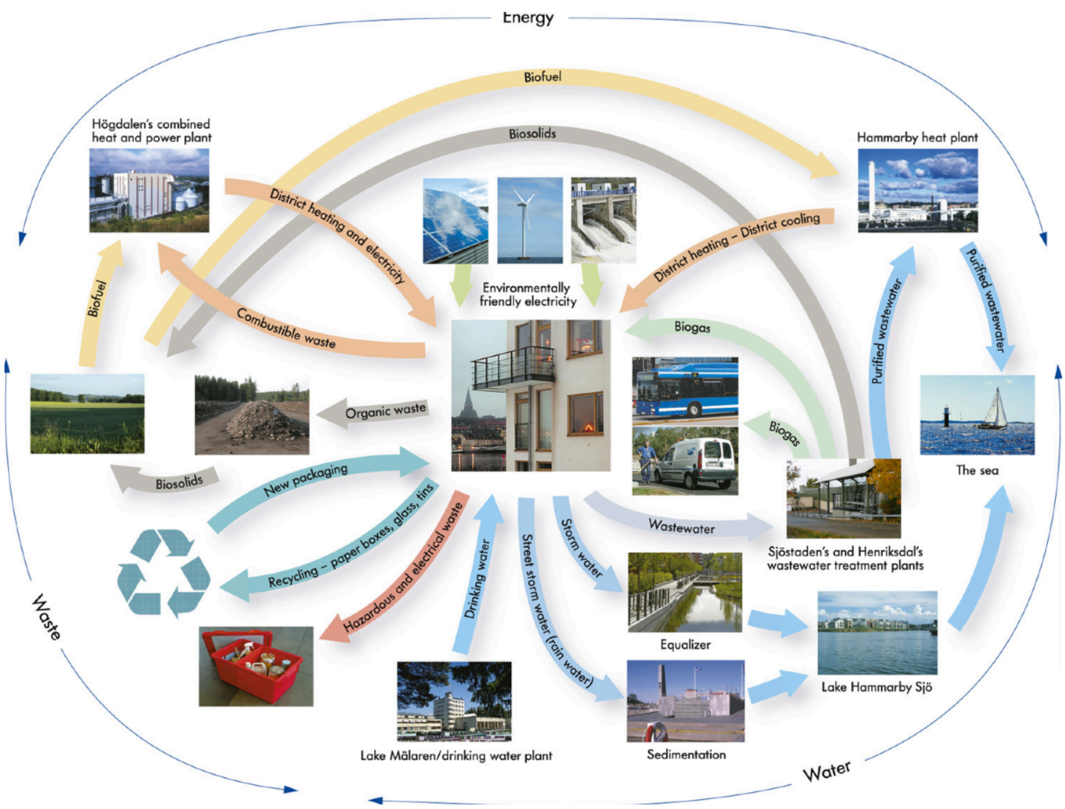
Hammarby Sjostad, Sweden

Hammarby Sjostad is a 200 hectare medium to high density neighbourhood in central Stockholm that is the result of a public private partnership to redevelop a former naval yard into a showcase sustainable neighbourhood. The project, catalyzed by the unsuccessful 2004 Stockholm Olympic bid, when complete in 2016 will include a mix of land uses including 10,000 dwellings, office, retail and community space. A special feature of the redevelopment is the high quality public realm which maximises the existing site assets and includes a long water frontage activated by harbourside walks fronted by restaurants and cafes (Energy Cities n.d.).

The development aims to achieve a 50% reduction in emissions and waste from a 1990s baseline established by surrounding communities through a series of ‘integrated sustainable systems’. The series of integrated sustainable systems are summarised in the ‘Hammaby (metabolic) model’ (shown in Figure 3) (GlashusEtt, 2007). This is a holistic approach to urban services that increases efficiency by taking advantage of interdependencies between energy, waste and water management cycles.

The Hammarby model recognises that ‘everybody who lives in Hammarby Sjostad is part of an eco-cycle’ that includes energy, waste, sewerage and water for both housing and offices (City of Stockholm, 2013). Development of the model required close collaboration between the various government agencies to close these loops as much as possible such that waste is not treated as pollution but rather as a resource. An example of the Hammarby Model eco-cycle is the incineration of combustible waste to produce both electricity and district heating in the precinct wide district heating network (GlashusEtt, 2007).

Figure 3: ‘The Hammarby Model’.
Source: GlashusEtt (2007)



Hammarby Sjostad is exceptional in that it not only demonstrates innovation in project delivery but it also showcases innovation regarding integrated public services. Service agencies usually function within their own ‘silo’ largely a result of discrete funding streams that bring about a disregard, disinterest or disempowerment to engage with other agencies. What we see at Hammarby is public agencies being provided a mandate to work together to seek mutually beneficial synergies that result in resource efficient industrial ecology – the ‘Hammarby Model’. This model serves to reinterpret waste streams as resources to largely close the neighbourhood’s urban ‘metabolic loop’ at the precinct scale.

City of Berkley PACE, USA

In 2008 the City of Berkley, California, introduced an innovative financing tool that allows property owners to receive full funding to retrofit homes with sustainable measures thus overcoming the split incentive through the Property Assessed Clean Energy (PACE) model (City of Berkley, 2008). PACE loans are repaid via a local government or state property tax tied to the property over a specified period (e.g. 20 years) (cf. Environmental Upgrade Agreements (EUA) Sustainable Melbourne Fund). This model allows households to overcome the 'split incentive barrier' that sees the developer without incentive to invest in sustainable technologies because the benefits are passed onto the new occupant. Conversely the new building owner is often not in a financial position to meet the large upfront investment in sustainable technology (e.g. PV cells) despite the likelihood that such an investment may save them money in the long term. PACE allows this barrier to be overcome and with the reduced utility costs can save the occupant money over time. The Berkley model has been widely replicated across the US and is now in use in 31 US states (PACE Now, 2013).

PACE works well for single owner occupied buildings but another split incentive barrier exists for rental and multi-family buildings where the owners may be reluctant to pay for sustainability improvements they can not recoup from tenants. A 2013 pilot project overcomes this through On-Bill Repayment (OBR) which allows owners to repay loans through monthly utilities bills (Kim et al. 2012).

Both the PACE and OBR models are aimed for individual buildings but it would be a small step widen this to the precinct scale to encourage decentralised energy systems particularly for regeneration or new build projects. A Greening, Revitalisation and Improvement District (GRID) concept has been proposed by Rauland (2013) as a model for funding precinct scale eco-infrastructure and the PACE and OBR models may provide the financial template for this to occur.

Conclusions

A holistic approach to urban environments (be they greenfield, brownfield or greyfield sites) at the precinct scale provides the opportunity for eco-infrastructure development at a scale of efficiency not able to be achieved at the individual building level. Precinct scale development may provide the best opportunity for incrementally decarbonising Australian cities short of comprehensive policy change or institutionalised financial incentives at a national level.

Political, skill and market barriers exist that inhibit sustainable urbanism. Lessons from the international low carbon precinct case studies presented here may help develop pathways to overcome these barriers as Australia transitions toward low carbon sustainable urbanism practices.

The UK government, by coupling policy (*the Code for Sustainable Homes*) with funding for demonstration projects (the Carbon Challenge), were able to overcome the time lag usually associated with incremental policy through 'rapid prototyping' of a end state (the Carbon Challenge demonstration projects). The Carbon Challenge was good for public relations gaining industry and public attention but it also served to accelerate innovation in the UK built environment sector by expanding the building sector's knowledge and skills base. Feedback from the demonstration projects led to policy review and also knowledge dissemination through monitoring and recording of lessons with a repository of information being managed online through the 'zero carbon hub'. The zero carbon hub acts as a one-stop knowledge bank increasing accessibility to technical information thereby quickly reskilling the UK building sector to deliver energy efficient buildings and low carbon decentralised energy in the built environment.

Government can also restructure agencies to overcome a siloed approach to services that lead to inefficient resource use in favour of processes that permit agencies to work in an integrated manner by encouraging waste reuse to reduce the 'metabolism loop' of urban processes as seen successfully applied in the 'Hammarby Model'.

An entrepreneurial approach to the planning system as demonstrated by BioRegional's developments BedZED, and in particular, One Brighton, saw the developer apply 'the planning gain mechanism' to great effect negotiating development floor area bonuses from consent authorities as a result of project merit. The sale of the additional floor area translated into greater development returns to offset the ‘sustainability cost premium’ to make sustainable development competitive in a conventional market place.

The sustainability cost premium can be overcome by an informed and proactive community such as in Vauban where community involvement in Forum Vauban allowed collaboration with city authorities to deliver innovation in new development. Owner-developer co-operatives allowed like-minded individuals to take on the role of property developer and cut out the developer profit margin (usually 5-15% of total project costs) with this budgetary saving reallocated toward sustainability or liveability measures to benefit home owners and broader community.

For retrofit projects or where other initiative are not feasible the introduction of PACE and OBR schemes can be used to overcome split incentives to finance clean energy and other sustainability initiatives.

A consistent factor of all the discussed case studies was a strong and clear sustainability vision described at the outset along with commitment to see the vision through to project delivery. Invariably this involved dedicated stewardship, although the form of the steward varied and included development authorities (Peterborough), ‘sustainability integrators’ (One Planet – BedZED, One Brighton), local councils (Hammarby Stojstad, Berkley PACE) or community groups (Vauban).

Ultimately visionary leadership, stewardship and integration between stakeholders will be required to decarbonise Australian cities particularly when faced with political, financial and skill based barriers to sustainability innovation within the built environment. As cities seek to transition toward low carbon communities, precinct scale development provides opportunities for experimentation by being large enough to allow integrated eco-infrastructure and service provision efficiencies, yet, small enough to permit effective local governance that ensures sustainability stewardship. The examples of precinct scale sustainable development presented here offer ways to overcome some of the political, skill and market barriers that currently exist in Australia and are inhibiting the uptake of sustainable urbanism.

References

Australian Bureau of Statistics (2008) *3222.0 - Population Projections, Australia, 2006 to 2101*

Australian Government (2013a) *State of Australian Cities.* Department of Infrastructure and Transport.

Australian Government (2013b) *Overcoming split incentives – factsheet*. Department of Industry September 2013.

Carter, A.J., Pisaniello, J.D. and Burritt, R.L. (2010), 'Government sustainability policy in Australia: moving from rhetoric to effective implementation', Centre for Accounting, *Governance and Sustainability Occasional Working Papers, No. 3*, October, University of South Australia, Adelaide.

COAG (2009) *Green Skills Agreement*. Department of Industry.

Cole, D (2012) 'Economic Growth or The Environment. Both: Sustainable Capitalism' *Metis*, Volume 3, 2012.

BioRegional (2009) *BedZED seven years on: The impact of the UK's best known eco-village and its residents.* BioRegional, London.

City of Stockholm (2013) http://www.hammarbysjostad.se/ (accessed July 2013).

City of Berkley (2008) http://www.ci.berkeley.ca.us/berkeleyfirst/ (accessed July 2013).

Creagh S, Denis A, Canadell P, Reidy C (2013) 'Greenhouse emissions stable over decade as GDP grew 31%' *The Conversation*, July 30 2013.

Denis, A. et al. (2013) Tracking Progress Towards a low carbon economy. National Progress Report. ClimateWorks Australia, July 2013.

Desai, P (2010) *One Planet Communities. A real-life guide to sustainable living*. John Wiley & Sons p.28.

Energy Cities (n.d.) 'Hammarby Sjostad' http://www.energy-cities.eu/IMG/pdf/Sustainable_Districts_ADEME1_Hammarby.pdf (accessed July, 2013)

International Labour Organization (2011) *Study of occupational and skill needs in green building: final report* / International labour office, Ilo Skills and Employability Department. Geneva: Ilo, 2011.

Forum Vauban (2004) http://www.forum-vauban.de/overview.shtml (accessed July, 2013).

Generation Investment Management LLP. *Sustainable Capitalism.* White Paper, London, UK: Generation Investment Management LLP, 2012.

Girardet, H (1992) *The GAIA Atlas of Cities: New directions for sustainable urban living.* GAIA books. London.

GlashusEtt (2007) *Hammarby Sjöstad – a unique environmental project in Stockholm*. City of Stockholm

Kelly, J (2010) 'Home insulation program flawed and risky, Hawke report finds'. *The Australian*. April 22, 2010.

Kim, C et al. (2012) *Innovation and Opportunities in Energy Efficiency Finance*, White Paper, Wilson Sonsini Coodrich & Rosati, NY. May 2012, second edition.

Opportunity Peterborough (2011) 'Future Plans' http://www.opportunitypeterborough.co.uk/invest/future-plans/ (accessed August, 2013)

Pace Now (2013) *Financing energy efficiency*. http://pacenow.org/pace-programs/ (accessed October, 2013).

Peterborough City Council (2011) 'Peterborough leads 'zero carbon' homes agenda as plans are approved 8 February 2011 (accessed July, 2013).

Newman, P. and Kenworthy J. (1999) *Sustainability and Cities: Overcoming Automobile Dependence* (Island Press, Washington DC).

Newman, P. Bachels, M and Scheurer, J. (2010) *The Knowledge Arc Light Rail: Sections F and G, Delivering TODS*, Curtin University Sustainable Policy Institute and Parsons Brinkerhoff.

Newton, P (2012) "Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities". *Journal of Urban Technology*, Routledge.

Rauland, V (2013) *Decarbonising Cities: Certifying Carbon Reduction in Urban Development*. Curtin University Sustainable Policy Institute, PhD Thesis.

Riedy, C., Lederwasch, A. and Ison, N. (2011) Defining zero emission buildings – Review and recommendations: Final Report. (Prepared for Sustainability Victoria by the Institute for Sustainable Futures, University of Technology, Sydney).

Rogema, R (2012) *Swarming Landscapes: The Art of Designing For Climate Adaptation*. Springer Science+Business Media Dortrecht.

RUDI (2008) 'Peterborough zero carbon community developer selected' http://www.rudi.net/node/20114 (accessed July, 2013).

Sanders, R. Milford, L. and Rittner, T. (2013) *Reduce Risk, Increase Clean Energy. How States and Cities are Using Old Finance Tools to Scale Up a New Industry.* Clean Energy and Bond Finance Initiative.

Sustainability Victoria (2011) *Business models for enabling sustainable precincts*. The Government of Victoria p.6.

Wilfred, C. Ramos, M. (2009) *Zero Carbon Compendium: Who's doing what worldwide.* NHBC Foundation.

UK Department of Homes and Communities (2011) http://www.homesandcommunities.co.uk/carbon_challenge

Zero Carbon Hub (2008*) http://www.zerocarbonhub.org/* (accessed July, 2013).

Zero Carbon Hub (2011) *Fabric Energy efficiency for zero carbon homes. A flexible performance standard for 2016.*

Zero Carbon Hub (2013) *Zero Carbon Strategies.*

Consolidated Bibliography

This bibliography consolidates the references from the exegesis and publications contained in this thesis.

A

Arup, 1999. *Smart cities*, Available at: http://publications.arup.com/Publications/S/Smart_Cities.aspx.

Australian Public Service Commission, 2007. *Tackling wicked problems: A public policy perspective*, Canberra, Australia: Commonwealth of Australia.

B

Baccini, P., 1997. A city's metabolism: Towards the sustainable development of urban systems. *Journal of Urban Technology*, 4(2), pp.27–39.

Baccini, P. & Brunner, P.H., 2012. *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*, London, UK: MIT Press.

Bai, X., Norman, B. & Edwards, P., 2016. Navigating through the Urban Age : Principles Navigating through the Urban Age : Principles and Innovations. *Solutions*, 7(May), pp.55–62.

Beatley, T., 2011. *Biophilic Cities: Integrating Nature Into Urban Design and Planning*, Washington, D.C.: Island Press.

Beatley, T., 2009. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into our Lives. *William & Mary Environmental Law & Policy Review*, 34(1), pp.209–238.

Beatley, T., 2012. *Green Urbanism: Learning From European Cities*, Washington, D.C.: Island Press.

Beatley, T. & Newman, P., 2012. *Green Urbanism Down Under: Learning from Sustainable Communities in Australia*, Washington, D.C.: Island Press.

Benne, B. & Mang, P., 2015. Working regeneratively across scales—insights from nature applied to the built environment. *Journal of Cleaner Production*, (109), pp.42–52. Available at: http://linkinghub.elsevier.com/retrieve/pii/S095965261500150X.

Biggs, C., Ryan, C. & Wiseman, J., 2010. *Distributed Systems: A design model for sustainable and resilient infrastructure*, Available at: http://www.ecoinnovationlab.com/uploads/attachments/305_VEIL.Resilient Systems Briefing Paper.pdf.

Bina, O. et al., 2016. The future imagined: Exploring fiction as a means of reflecting on today's Grand Societal Challenges and tomorrow's options. *Futures*. Available at: http://dx.doi.org/10.1016/j.futures.2016.05.009.

BioRegional, 2009. *BedZED : Toolkit Part II A practical guide to producing affordable carbon neutral developments*, London, UK.

Blood, D. & Partner, S., 2012. *Sustainable Capitalism*, London, UK. Available at: www.generationim.com.

Bostrom, N., 2002. Existential Risks: Analyzing Human Extinction Scenarios and Related Hazards. *Journal of Evolution and Technology*, 9(March).

Bringezu, S. et al., 2014. *Assessing Global Land Use : Balancing Consumption with Sustainable Supply. A Report of the Working Group on Land and Soils of the Interantional Resource Panel*, United Nations Environment Program. Available at: http://www.unep.org/resourcepanel/Portals/50244/publications/Full_Report-Assessing_Global_Land_UseEnglish_(PDF).pdf.

Broto, V.C., Allen, A. & Rapoport, E., 2012. Interdisciplinary Perspectives on Urban Metabolism. *Journal of Industrial Ecology*, 16(6), pp.851–861.

Browning, W., Ryan, C. & Clancy, J., 2014. 14 Patterns of Biophilic Design. *Terrapin Bright Green,LLC*, pp.1–60.

Brugmann, J., 2011. *Financing the resilient city: A demand driven approach to development, disaster risk reduction, and climate adaptation*, Bonn, Germany.

Bunning, J. et al., 2013. Low-Carbon Sustainable Precincts: An Australian Perspective. *Sustainability*, 5(6), pp.2305–2326. Available at: http://www.mdpi.com/2071-1050/5/6/2305/.

Burdett, R. & Sudjic, D., 2010. *The Endless City: The Urban Age Project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society*, Phaidon Press.

C

Calthorpe, P., 2010. *Urbanism in the Age of Climate Change*, Washington, D.C.: Island Press.

Campbell, 2016. Massive Small declaration. *Massive small*. Available at: http://www.massivesmall.com/declaration/ [Accessed November 25, 2016].

Campbell, K., 2011. *Massive Small: The Operating Programme for Smart Urbanism*, London, UK: Urban Exchange.

Carmona, M. et al., 2012. *Public Places - Urban Spaces*, London, UK: Taylor & Francis.

Chambers, N. et al., 2002. *City Limits: A resource flow and ecological footprint analysis of Greater London*, Oxford, UK. Available at: http://www.citylimitslondon.com/downloads/Complete report.pdf.

CIESIN, 2005. The Growing Urbanization of the World. GRUMP mapping project finds urban areas increasing in surprising ways. *Columbia University Earth Institute website*.

City of Melbourne, 2012. Urban Forest Strategy: Making a great city greener 2012-2032. , p.68. Available at: https://www.melbourne.vic.gov.au/Sustainability/UrbanForest/Documents/Urban_Forest_Strategy.pdf.

City of Sydney, 2013. City of Sydney Urban Forest Strategy 2013. , pp.1–80.

Clegg, P., 2012. A practitioner's view of the "Regenerative Paradigm." *Building Research & Information*, 40(3), pp.365–368. Available at: http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.663557.

Coglianese, C. & D'Ambrosio, J., 2008. Policymaking under Pressure: The Perils of Incremental Responses to Climate Change. *Connecticut Law Review*, 40(2007), p.1411.

Cole, R.J., 2012. Transitioning from green to regenerative design. *Building Research & Information*, 40(1), pp.39–53.

Cooper, I., 2012. Winning hearts and minds or evidence-driven: which trajectory for regenerative design? *Building Research & Information*, 40(3), pp.357–360. Available at:

http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.662388.
Costanza, R., 2008. Stewardship for a "full" world. *Current History*, 107(705), pp.30–35.
Cowan, R., 2005. *Dictionary of Urbanism*, London, UK: Streetwise Press.
Crutzen, P.J., 2002. Geology of mankind. *Nature*, 415(January), p.23.
Crutzen, P.J. & Stoermer, E.F., 2000. The Anthropocene. *Global Change Newsletter*, (41), pp.17–18.
Curtis, C. & Scheurer, J., 2010. Planning for sustainable accessibility: Developing tools to aid discussion and decision-making. *Progress in Planning*, 74(2), pp.53–106.

D

Davison, A. & Kirkpatrick, J., 2013. Re-inventing the Urban Forest: The Rise of Arboriculture in Australia. *Urban Policy and Research*, 32(2), pp.145–162. Available at: http://www.tandfonline.com/doi/abs/10.1080/08111146.2013.832669.
Diamandis, P.H. & Kotler, S., 2014. *Abundance: The Future Is Better Than You Think*, Free Press.
Dodson, J. & Sipe, N., 2006. Suburban shocks : Assessing locational vulnerability to rising household fuel and mortgage interest costs. In *29th Australasian Transportation Research Forum*. Gold Coast, Queensland.
Dramstad, W., Olson, J. & Forman, R., 1996. *Landscape Ecology Principles in Landscape Architecture*, Washington, D.C.: Harvard University Graduate School of Design, Island Press, American Institute of Landscape Architects.
Droege, P., 2012. *100% Renewable: Energy Autonomy in Action*, Routledge.
Droege, P., 2010. *100% Renewable Energy - and Beyond - for Cities*, Hamburg, Germany.
Droege, P., 2008. *Urban Energy Transition : An Introduction*, Elsevier Science.

E

EcoDistricts, 2016. *EcoDistricts Protocol Version 1.1*, Portland, Oregon. Available at: www. ecodistricts.org.
Ellen MacArthur Foundation, 2015. Open Source Circular Economy. In Perth: Creative Commons.
English Partnerships, 2007. *Carbon Challenge Standard Brief*, London, UK.
European Union, 2011a. *Greening of the building sector is held back by skill shortages. Skills-led strategies can drive green building forward*, Geneva, Switzerland.
European Union, 2011b. *Skills and Occupational Needs in Renewable Energy*, Geneva, Switzerland: International Labour Office.

F

Farr, D., 2012. *Sustainable Urbanism: Urban Design With Nature*, Wiley.
Ferguson, A., 2016. Law to Compel Low-Carbon Future. *Australian Financial Review*. Available at: http://afr.com.
Fink, J., 2011. The Case for an Urban Genome Project: A Shortcut to Global

Sustainability. *The Bridge, Linking Engineering and Society*, 41(1).
Fink, J.H., 2013. Geoengineering cities to stabilise climate. *Proceedings of the ICE - Engineering Sustainability*, 166(5), pp.242–248. Available at: http://www.icevirtuallibrary.com/content/article/10.1680/ensu.13.00002.
Flannery, T., 2015. *Atmosphere of Hope: Solutions to the Climate Crisis*, Penguin Books Limited.
Florida, R.L., 2002. *The Rise of the Creative Class: And how It's Transforming Work, Leisure, Community and Everyday Life*, Basic Books.
Forman, R.T.T. & Godron, M., 1986. *Landscape Ecology*, Wiley.
Forman, R.T.T. & Wu, J., 2016. Where to put the next billion people. *Nature*.

G

Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. *City*, 8(3), pp.363–379.
Garnaut, R., 2011. *The Garnaut Review 2011*, Available at: http://www.cambridge.edu.au/academic/marketing/files/2011/August/August_Kit_sm.pdf.
Geddes, P., 1949. *Cities in Evolution*, Williams & Norgate.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), pp.1257–1274. Available at: http://www.sciencedirect.com/science/article/pii/S0048733302000628.
Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, 1(1), pp.24–40. Available at: http://dx.doi.org/10.1016/j.eist.2011.02.002.
Geels, F.W. & Schot, J., 2007. Typology of sociotechnical transition pathways. *Research Policy*, 36(3), pp.399–417.
Girardet, H., 2000. Cities, People Planet. In *Schumacher Lectures April 2000*. Liverpool, UK: Schumacher Society.
Girardet, H., 2004. *Cities people planet: liveable cities for a sustainable world*, Wiley-Academy.
Girardet, H., 2015. *Creating Regenerative Cities*, Routledge.
Girardet, H., 2010. *Regenerative cities*, Hamburg, Germany. Available at: www.worldfuturecouncil.org.
Girardet, H., 1996. *The Gaia Atlas of Cities: New Directions for Sustainable Urban Living*, Gaia.
GIZ and ICLEI, 2014. *Operationalizing the Urban NEXUS: towards resource efficient and integrated cities and metripolitan regions*, Eschborn, Germany.
Glaeser, E., 2011. *Triumph of the City*, Pan Macmillan UK.
GlashusEtt, 2007. *Hammarby Sjöstad – a unique environmental project in Stockholm.*, Stockholm, Sweden.
Global Footprint Network, 2016. Global Footprint Network. Available at: http://www.footprintnetwork.org/ [Accessed October 1, 2016].
Gollagher, M. & Hartz-Karp, J., 2013. The role of deliberative collaborative governance in achieving sustainable cities. *Sustainability (Switzerland)*, 5(6), pp.2343–2366.
Gómez-Baggethun, E. & Barton, D.N., 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, pp.235–245. Available

at: http://dx.doi.org/10.1016/j.ecolecon.2012.08.019.
Graves, T., 2015. From Problem-space to Solution-space: Causal layered analysis and context-space mapping. In S. Inayatullah & I. Milojević, eds. *CLA 2.0 - Transformative Theory in Research and Practice*. Taipai, Taiwan: Tamkang University Press.

H

Hajer, M., 2011. *The energetic society*, The Hague, The Netherlands.
Hajer, M. & Dassen, T., 2014. *Smart about Cities*, Rotterdam, The Netherlands: Nai010 Publishers.
Hall, P., 1998. *Cities in Civilization: Culture, Innovation, and Urban Order*, London, UK: Pantheon.
Hall, P., 2013. *Good Cities, Better Lives: How Europe Discovered the Lost Art of Urbanism*, New York, NY: Routledge.
Hardin, G., 1968. The Tragedy of the Commons. *Science*, 162(3859), pp.1243–1248.
Hargroves, K. & Smith, M.H., 2005. *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, London, UK: Earthscan.
Hartz-karp, J., 2007. How and Why Deliberative Democracy Enables Co-Intelligence and Brings Wisdom to Governance How and Why Deliberative Democracy Enables Co-Intelligence and. *Journal of Public Deliberation*, 3(1). Available at: http://www.publicdeliberation.net/jpd/vol3/iss1/art6.
Hes, D. & du Plessis, C., 2014. *Designing for Hope: Pathways to Regenerative Sustainability*, New York, NY: Taylor & Francis.

I

Inayatullah, S., 2015. *What Works: Case Studies in the Practice of Foresight*, Tamsui, Taiwan: Tamkang University Press.
Inayatullah, S. & Milojević, I., 2015. *CLA 2.0 Transformative Research in Theory and Practice* S. Inayatullah & I. Milojević, eds., Taipai, Taiwan: Tamkang University Press.
ISO, 2016. *INTERNATIONAL STANDARD Sustainable development in communities — Management system for sustainable development*, Switzerland.

J

Jackson, T., 2009. *Prosperity without Growth. Economics for a Finite Planet*, New York, NY: Earthscan.
Jacobs, J., 1989. *The Death and Life of Great American Cities*, New York, NY: Vintage.
Jacobs, J., 1969. *The economy of cities*, New York, NY: Random House.
de Jong, M. et al., 2015. Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, pp.1–14. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652615001080.

K

Keirstead, J., Jennings, M. & Sivakumar, A., 2012. A review of urban energy system models: Approaches, challenges and opportunities. *Renewable and Sustainable Energy Reviews*, 16(6), pp.3847–3866. Available at: http://dx.doi.org/10.1016/j.rser.2012.02.047.
Keltanen, M., 2013. Why “lean data” beats big data. *The Guardian*.
Kennedy, C., Cuddihy, J. & Engel-yan, J., 2007. The Changing Metabolism of Cities. *Journal of Industrial Ecology*, 11(2).
Kennedy, C., Pincetl, S. & Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*, 159(8–9), pp.1965–1973. Available at: http://dx.doi.org/10.1016/j.envpol.2010.10.022.
Kenworthy, J., 2014. Total daily mobility patterns and their implications for forty-three global cities in 1995 and 2005. *World Transport Policy and Practice*, 20(1), pp.41–55.
Kenworthy, J. & Laube, F., 2001. *Millenium Cities Database for Sustainable Transport*,
Kitney, D., 2016. Leaders Heed Warning on Climate Risks. *The Australian Business Review*. Available at: http://www.theaustralian.com.au/business.
Kolbert, E., 2010. The Anthropocene Depate: Marking Humanity’s Impact. *Yale Environment 360*.
Kostof, S., Castillo, G. & Tobias, R., 1999. *The City Assembled: The Elements of Urban Form Through History*, London, UK: Thames and Hudson.
Kostof, S. & Tobias, R., 2004. *The City Shaped: Urban Patterns and Meanings Through History*, London, UK: Thames and Hudson.
Kreibich, N. & Obergassel, W., 2016. *Carbon Markets After Paris How to Account for the Transfer of Mitigation Results?*, Wuppertal, Germany.

L

Landry, C. & Burke, T., 2014. *The Fragile City and the Risk Nexus*, Stroud, UK: Comedia Publications Limited.
Lehmann, S., 2010. *The Principles of Green Urbanism: Transforming the City for Sustainability*, Earthscan.
Lenton, T.M. et al., 2008. Tipping elements in the Earth’s climate system. *Proceedings of the National Academy of Sciences*, 105(6).
Living Building Challenge, 2014. LIVING BUILDING A Visionary Path to a Regenerative Future. *Living Building Challenge 3.0. A Visionary Path to a Regenerative Future*. Available at: http://living-future.org/sites/default/files/reports/FINAL LBC 3_0_WebOptimized_low.pdf.
Loorbach, D., 2007. *Transition Management: NewMode of Governance for Sustainable Development*, Utrecht: International Books.
Loorbach, D.A., 2010. Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. *Governance, An International Journal of Policy, Administration, and Institutions.*, 23(1), pp.161–183. Available at: 10.1111/j.1468-0491.2009.01471.x.
Lovins, L.H., Lovins, A. & Hawken, P., 1999. *Natural Capitalism: The next industrial revolution*, Earthscan.
Lowe, I., 2015. Causal Layered Analysis, Climate Change and Limits to Growth. In S. Inayatullah & I. Milojević, eds. *CLA 2.0 - Transformative Theory in Research and Practice*. Taipei, Taiwan: Tamkang University Press, pp. 109–122.
Luck, M.A. et al., 2001. The Urban Funnel Model and the Spatially Heterogeneous

Ecological Footprint. *Ecosystems*, 4(8), pp.782–796.
Lyle, J., 1999. *Design for Human Ecosystems: Landscape, Land Use, and Natural Resources*, Washington, D.C.: Island Press.
Lyle, J.T., 1996. *Regenerative Design for Sustainable Development*, New York, NY: Wiley.

M

Mang, P. & Reed, B., 2012. Designing from place: a regenerative framework and methodology. *Building Research & Information*, 40(1), pp.23–38.
Marchetti, C., 1994. Anthropological Invariants in Travel Behavior. *Technological Forecasting and Social Change*, 47, pp.75–88.
Martinez-alier, J., 2007. Marxism, Social Metabolism, and Ecologically Unequal Exchange. In A. Hornborg, J. McNeill, & J. Martinez-alier, eds. *Rethinking Environmental History*. Plymouth, UK: AltaMira Press, pp. 19–22.
Maxwell, J. a, 2009. Designing a Qualitative Study. *The SAGE Handbook of Applied Social Research Methods*, pp.214–253. Available at: http://www.corwin.com/upm-data/23772_Ch7.pdf.
McDonough, W., Braungart, M. & Clinton, B., 2013. *The Upcycle: Beyond Sustainability--Designing for Abundance*, Farrar, Straus and Giroux.
McIntosh, J., Trubka, R. & Newman, P., 2014. Can value capture work in a car dependent city? Willingness to pay for transit access in Perth, Western Australia. *Transportation Research Part A: Policy and Practice*, 67, pp.320–339. Available at: http://www.sciencedirect.com/science/article/pii/S0965856414001736.
McPhearson, T. et al., 2016. Scientists must have a say in the future of cities. *Nature*, 538(7624), pp.165–166. Available at: http://www.nature.com/doifinder/10.1038/538165a.
Meadows, D.H., 1999. *Places to Intervene in a System*, Hartland, Vermont.
Meadows, D.H. et al., 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*, New York, NY: Universe Books.
Mittal, J., 2014. Self-financing land and urban development via land readjustment and value capture. *Habitat International*, 44, pp.314–323. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0197397514001155.
Moir, E., Moonen, T. & Clark, G., 2014. *The future of cities: what is the global agenda?*, London, UK.
Mostafavi, M., Doherty, G. & Design, H.U.G.S., 2016. *Ecological Urbanism*, Lars Muller Publishers.
Mumford, L., 1961. *The City in History: Its Origins, Its Transformations, and Its Prospects*, Harcourt, Brace & World.

N

Nair, S. et al., 2014. Water-energy-greenhouse gas nexus of urban water systems: Review of concepts, state-of-art and methods. *Resources, Conservation and Recycling*, 89, pp.1–10. Available at: http://dx.doi.org/10.1016/j.resconrec.2014.05.007.
New South Wales Government, 2013. *Factsheet Overcoming Split Incentives, Heating, Ventilation & Air Conditioning High Efficiency Systems Strategy*, Sydney, Australia.

Newman, P., 2014. Biophilic urbanism: a case study on Singapore. *Australian Planner*, 51(1), pp.47–65. Available at: http://www.tandfonline.com/doi/abs/10.1080/07293682.2013.790832.
Newman, P. et al., 2016. *Entrepreneur Rail Model*, Perth, Australia.
Newman, P., 2016. Perth as a “big” city: Reflections on urban growth. *Thesis Eleven*, 135(1), pp.139–151. Available at: http://the.sagepub.com/cgi/doi/10.1177/0725513616657906.
Newman, P., 1999. Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning*, 44(February), pp.219–226.
Newman, P., Beatley, T. & Boyer, H., 2009. *Resilient Cities: Responding to Peak Oil and Climate Change*, Washington, D.C.: Island Press.
Newman, P. & Jennings, I., 2008. *Cities as Sustainable Ecosystems: Principles and Practices*, Washington, D.C.: Island Press.
Newman, P. & Kenworthy, J., 1989. *Cities and Automobile Dependence: An International Sourcebook* Gower, ed., Aldershot, UK.
Newman, P. & Kenworthy, J., 2011. Peak Car Use: Understanding the Demise of Automobile Dependence. *World Transport Policy and Practice*, 17(2), pp.32–42.
Newman, P. & Kenworthy, J., 1999. *Sustainability and Cities: Overcoming Automobile Dependence*, Washington, D.C.: Island Press.
Newman, P. & Kenworthy, J., 2015. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*, Washington, D.C.: Island Press.
Newman, P., Kenworthy, J. & Glazebrook, G., 2013. Peak Car Use and the Rise of Global Rail: Why this is happening and what it means for large and small cities. *Journal of Transportation Technologies*, 3(4), pp.272–287.
Newman, P., Mason, A. & Gardner, H., 2012. *Regenerative cities*, Perth, Australia.
Newman, P. & Matan, A., 2013. *Green Urbanism in Asia: The Emerging Green Tigers*, Singapore: World Scientific Publishing.
Newton, P., Murray, S., et al., 2012. *AHURI Research & Policy Bulletin How do we regenerate middle suburban “ greyfield ” areas ?*, Melbourne, Australia.
Newton, P., 2010. Beyond Greenfields and Brownfields: The Challenge of Regenerating Australia’s Greyfield Suburbs. *Built Environment*, 36, pp.1–53.
Newton, P., Newman, P., et al., 2012. Greening the Greyfields : Unlocking the Redevelopment Potential of the Middle Suburbs in Australian Cities. *World Academy of Science, Engineering and Technology*, 71(11), pp.658–677.
Newton, P., 2014. Regeneration: Tackling the Greyfields. In T. Perinotto, ed. *Creating Sustainable Precincts*. Sydney, Australia: The Fifth Estate, pp. 106–111. Available at: http://evacoust.startlogic.com/TimeToyota.pdf.
Newton, P. et al., 2011. *Towards a new development model for housing regeneration in greyfield residential precincts*,
Newton, P.W., 2012. Liveable and Sustainable? Socio-Technical Challenges for Twenty-First-Century Cities. *Journal of Urban Technology*, 19(1), pp.81–102. Available at: http://www.tandfonline.com/doi/abs/10.1080/10630732.2012.626703.
Newton, P.W., 2014. Low Carbon Precincts for Low Carbon Living. *Carbon Management*.
Newton, P.W., 2008. *Transitions: Pathways Towards Sustainable Urban Development in Australia*, Springer Netherlands.
Norman, B., 2010. *A low carbon and resilient urban future: An integrated approach to planning for climate change*, Canberra, Australia: Commonwealth of Australia.

Norman, B., 2009. Principles for an intergovernmental agreement for coastal planning and climate change in Australia. *Habitat International*, 33(3), pp.293–299. Available at: http://dx.doi.org/10.1016/j.habitatint.2008.10.002.
Norman, B., 2016. Urban Sustainability : Joining the Dots Between Planning, Science, and Community. *Solutions*, (May-June), pp.46–54.
Norman, B. & Reid, J., 2016. In Quito, the world meets to discuss the future of cities. *The Conversation*, (October), pp.1–4. Available at: https://theconversation.com/in-quito-the-world-meets-to-discuss-the-future-of-cities-67125.

O

Ostrom, B.E., 2010. Beyond Markets and States : Polycentric Governance of Complex Economic Systems. , 100(June), pp.1–33.

P

Pauli, G.A., 2010. *The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs*, Toas, New Mexico: Paradigm Publications.
Pickett, S.T. a et al., 2011. Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management*, 92(3), pp.331–362. Available at: http://dx.doi.org/10.1016/j.jenvman.2010.08.022.
Pincetl, S., Bunje, P. & Holmes, T., 2012. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning*, 107(3), pp.193–202. Available at: http://dx.doi.org/10.1016/j.landurbplan.2012.06.006.
du Plessis, C., 2012. Towards a regenerative paradigm for the built environment. *Building Research & Information*, 40(1), pp.7–22.

R

Ramaswami, A. et al., 2012. A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems: An Integrative Curriculum Across Seven Major Disciplines. *Journal of Industrial Ecology*, 16(6), pp.801–813.
Rauland, V., 2013. *Decarbonising Cities : Certifying Carbon Reduction in Urban Development*. Curtin University.
Rauland, V. & Newman, P., 2015. *Decarbonising Cities: Mainstreaming Low Carbon Urban Development*, Springer International Publishing.
Rawnsley, T. & Spiller, M., 2012. Housing and Urban Form: A New Productivity Agenda. In R. Tomlinson, ed. *Australia's Unintended Cities*. Collingwood, Victoria: CSIRO Publishing.
Rees, W. & Wackernagel, M., 2008. Urban ecological footprints: Why cities cannot be sustainable-and why they are a key to sustainability. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*, 16, pp.537–555.
Ritchie, A. & Thomas, R., 2013. *Sustainable Urban Design: An Environmental Approach*, Taylor & Francis.
Rittel, H.W.J. & Webber, M.M., 1973. Dilemnas in a general theory of planning.

Policy Sciences, 4(December 1969), pp.155–169.
Robèrt, K. et al., 2002. Strategic sustainable development - selection, design and sysnergies of applied tools. *Journal of Cleaner Production*, 10, pp.197–214. Available at: http://www.sciencedirect.com/science/article/pii/S0959652601000610.
Robèrt, K.-H. et al., 2012. *Sustainability Handbook*, Lund, Sweden: Studentlitteratur.
Robèrt, K.-H., Broman, G.I. & Basile, G., 2013. Analyzing the Concept of Planetary Boundaries from a Strategic Sustainability Perspective: How Does Humanity Avoid Tipping the Planet? , 18(2). Available at: http://dx.doi.org/10.5751/ES-05336-180205.
Rockström, J., 2009. A safe operating space for humanity. *Nature*, 461(24), pp.472–475.
Rockström, J. et al., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity. , 14(2). Available at: http://pdxscholar.library.pdx.edu/iss_pub.
Roggema, R. & van Dobbelsteen, A., 2008. Building Resilience: Responding to a Turbulent World. In *UK Systems Society International Conference*. Oxford, UK.
Rohe, W.M., 2009. From Local to Global: One Hundred Years of Neighborhood Planning. *Journal of the American Planning Association*, 75(2), pp.209–230.
Roorda, C. et al., 2014. Transition Management in the Urban Context: Guidance Manual. , p.49.
Ruddiman, W.F. et al., 2015. Defining the epoch we live in. Is a formally designated “Anthropocene” a good idea? *Science*, 348(6230), pp.38–39.
Russell, J.M. & Gurevich, H., 2013. *Thrivability: Breaking Through to a World That Works*, Triarchy Press.

S

Sanders, R.G., Milford, L. & Rittner, T., 2013. Reduce Risk, Increase Clean Energy: How States and Cities are Using Old Finance Tools to Scale Up a New Industry. , (August), p.34.
Sarantakos, S., 1998. *Social Research* 2nd ed., Melbourne, Australia: Macmillan.
Schellnhuber, H.J. & Martin, M., 2014. *Climate-System Tipping Points*, Vatican City.
Schellnhuber, H.J., Rahmstorf, S. & Winkelmann, R., 2016. Why the right climate target was agreed in Paris. *Nature Clim. Change*, 6(7), pp.649–653. Available at: http://dx.doi.org/10.1038/nclimate3013%5Cnhttp://10.1038/nclimate3013.
Schepelmann, P., Goossens, Y. & Makipaa, A., 2010. *Towards Sustainable Development: Alternatives to GDP for measuring progress*, Wuppertal, Germany: Wuppertal Institute for Climate, Environment and Energy.
Scheurer, J. & Curtis, C., 2008. *Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure*, Perth, Australia.
Scruggs, G., 2016. UN-Cities? Rumoured proposal gains steam. *Citiscope*.
Seitzinger, S. et al., 2012. Planetary Stewardship in an Urbanizing World: Beyond City Limits. *Ambio*, 41, pp.789–794.
Selzter, E. et al., 2010. *Making EcoDistricts: Concepts and Methods for Advancing Sustainability in Neighbourhoods*, Portland.
Seto, K. et al., 2014. *Human Settlements, Infrastructure, and Spatial Planning* O.

Edenhofer et al., eds., Cambridge, UK and New York, NY, USA: Cambridge University Press.
Seto, K.C., Güneralp, B. & Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, 109(40), pp.16083–16088.
Seyfang, G. et al., 2014. A grassroots sustainable energy niche? Reflections on community energy in the UK. *Environmental Innovation and Societal Transitions*, 13, pp.21–44. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2210422414000227.
Sharifi, A. & Murayama, A., 2013. A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review*, 38, pp.73–87.
Smith, N., 2002. New globalism, new urbanism: gentrification as global urban strategy. *Antipode*, 34(3), pp.427–450.
Soderlund, J. & Newman, P., 2015. Biophilic architecture: a review of the rationale and outcomes. *AIMS Environmental Science*, 2(4), pp.950–969. Available at: http://www.aimspress.com/article/10.3934/environsci.2015.4.950.
Steffen, W., Richardson, K., et al., 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), pp.736–747.
Steffen, W. et al., 2011. The Anthropocene : From Global Change to Planetary Stewardship. *Ambio*, 40(7), pp.739–761.
Steffen, W., Broadgate, W., et al., 2015. The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*, 2(1), pp.81–98.
Steffen, W., Crutzen, J. & McNeill, J., 2007. The Anthropocene: are humans now overwhelming the great forces of Nature? *Ambio*, 36(8), pp.614–621.
Stern, N., 2006. The Stern Review on the Economic Effects of climate change. *Population and Development Review*, 32(December), pp.793–798.
Svane, Ö., 2007. Hammarby Sjöstad and the Process of Environmental Management. , 30(7), pp.1–10.

T

Talen, E. ed., 2013. *Charter of the New Urbanism, 2nd Edition*, McGraw-Hill Education.
Taylor, N., 2007. *Urban Planning Theory since 1945*, London, UK: Sage.
Thackara, J., 2005. *In the Bubble: Designing in a Complex World*, London, UK: MIT Press.
The Council of Economic Advisers, 2014. The cost of delaying action to stem climate change. , (July), pp.0–32. Available at: https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.
The U.S. Green Building Council, 2013. *The Business Case for Green Building*, Available at: http://www.worldgbc.org/activities/business-case/.
Thompson, H. & Waugh, A., 2009. *A Process Revealed*, FUEL Publ.
Thompson, S. & Maginn, P. eds., 2012. *Planning Australia. An overview of urban and regional planning* 2nd ed., Melbourne, Australia: Cambridge University Press.
Trainer, T., 2008. Transitions: Pathways Towards Sustainable Urban Development in Australia. In P. Newton, ed. Melbourne, Australia: CSIRO Publishing.
TriMet, 2015. *45 Years Making History and Transit in the Portland Region*, Portland,

Oregon.
Truffer, B. & Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies. *Regional Studies*, 46(1), pp.1–21. Available at: http://www.tandfonline.com/doi/abs/10.1080/00343404.2012.646164.

U

UK GBCA & Zero Carbon Hub, 2010. *Sustainable Community Infrastructure*, London, UK.
UN-Habitat, 2013. *The Future we Want, the City we Need*, Nairobi.
UN DESA, 2011. *The Great Green Technological Transformation*, New York: United Nations Department of Economic and Social Affairs.
UN Habitat, 2016. *Urbanization and Development Emerging Futures. World Cities Report 2016*, Nairobi, Kenya: United Nations Human Settlements Programme.
UN System Task Team on the Post-2015 UN Development Agenda, 2012. *Realizing the Future we Want for All*, New York, NY.
UNEP, 2013. *City-Level Decoupling Urban resource flows Urban resource flows and the governance of infrastructure transitions. A Report of the Working Group on Cities of the International Resource Panel. A Report of the Working Group on Cities of the International Res*, United Nations Environment Programme.
UNEP, 2011. *Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel.Fischer-Kowalski, M., Swilling, M. von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Kra*,
UNFPA, 2007. *The state of the world population 2007: unleashing the potential of urban growth.*,
United Nations, 2013. *A New Global Partnership : Eradicate Poverty and Transform economies through Sustainable Development: The Report of the High-Level Panel of Eminent Persons on the Post-2015 Development Agenda*, New York.
United Nations, 2015a. *Adoption of the Paris Agreement*, Paris, France. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.
United Nations, 2016. *Habitat III New Urban Agenda. Draft outcome document for adoption in Quito, October 2016*,
United Nations, 1987. *Our Common Future - Brundtland Report*, New York, NY: Oxford University Press.
United Nations, 2015b. *World Population Prospects*,
United Nations, 2014. *World Urbanization Prospects: The 2014 Revision, Highlights*, Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.
United Nations General Assembly, 2015. *Transforming our world: The 2030 agenda for sustainable development*, NY.
University of Leicester, 2016. Media note: Anthropocene Working Group (AWG). Available at: http://www2.le.ac.uk/offices/press/press-releases/2016/august/media-note-anthropocene-working-group-awg [Accessed September 22, 2016].

V

VisionPDX, 2007. *Portland 2030: a vision for the future*, Portland, Oregon. Available at: http://www.portlandonline.com/bds/index.cfm?a=195005&c=46936.

Vollan, B. & Ostrom, E., 2010. Cooperation and the Commons. *Science*, 330(6006), pp.923–924.

W

Wackernagel, M. & Rees, W., 1998. *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers.
Wackernagel, M. & Rees, W.E., 1997. Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective. *Ecological Economics*, 20(1), pp.3–24. Available at: http://www.sciencedirect.com/science/article/pii/S0921800996000778.
Waldheim, C., 2012. *The Landscape Urbanism Reader*, Princeton Architectural Press.
Walker, D. & Swartz, J., 2016. *Carbon Pricing the Paris Agreement's Key Ingredient*,
Waters, C.N. et al., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science*, 351(6269), pp.137–147.
Von Weizsäcker, E. et al., 2009. *Factor Five: Transforming the global economy through 80% improvements in resource productivity.* Earthscan, ed., London, UK.
Weymouth, R. & Hartz-Karp, J., 2015. Deliberative Collaborative Governance as a Democratic Reform to Resolve Wicked Problems and Improve Trust. *Journal of Economic and Social Policy*, 17(1), pp.1–32.
Whitmee, S. et al., 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet*, 6736(15), pp.1973–2028. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0140673615609011.
Williams, K., 2012. Regenerative design as a force for change: thoughtful, optimistic and evolving ideas. *Building Research & Information*, 40(3), pp.361–364. Available at: http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.662389.
Wittmayer, J., Roorda, C. & Steenbergen, F. Van, 2014. Governing Urban Sustainability Transitions – Inspiring examples. , (September).
Wolman, A., 1965. The Metabolism of Cities. *Scientific American*, 213(3), pp.179–190.
Woo, F., 2014. *Regenerative Urban Development*, Hamburg, Germany.
World Future Council, Nordic Folkecenter & Climate Service Center (CSC), 2013. From vision to action: A workshop report on 100% Renewable Energies in European Regions.

Y

Yin, R.K., 2006. Case study methods. In J. L. Green, G. Camilli, & P. B. Elmore, eds. *Handbook of Complementary Methods in Education Research*. American Education Research Association, pp. 111–122.
Yin, R.K., 1994. *Case Study Reserach - Design and Methods* 2nd ed., London, UK: Sage Publications.

Z

Zalasiewicz, J. et al., 2010. The New World of the Anthropocene. *Environmental Science & Technology*, 44(7), pp.2228–2231.
Zero Carbon Hub, 2009. *Defining a fabric energy efficiency standard for zero carbon homes*, Milton Keynes, UK.
Zhang, X. et al., 2015. Regenerative sustainability for the built environment – from vision to reality: an introductory chapter. *Journal of Cleaner Production*, pp.1–10. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652615013815.
Zvelebil, M., 2009. *Hunters in Transition: Mesolithic Societies of Temperate Eurasia and Their Transition to Farming*, Cambridge University Press.

Appendix A Co-author’s statements

Appendix A Co-author's Statements

Publication 1: Co-Author Statements

Thomson, G., Newman, P. (2016) Geoengineering in the Anthropocene through Regenerative Urbanism. *Geosciences*. *6,* 46; doi:10.3390/geosciences6040046

(Peer reviewed journal, Published Paper)

Thomson, G (80% Contribution)

Preparation and completion of manuscript, establishment of theoretical framework, selection and analysis of policy and case studies, preparation of figures.

Giles Thomson, PhD Candidate

Newman, P (20% Contribution)

Identification of low carbon technologies, supervising, revising and editing the manuscript.

Professor Peter Newman, Principal Supervisor

Publication 2: Co-Author Statements

Thomson, G., and Newman, P. (2016) Urban Fabrics and Urban Metabolism – From Sustainable to Regenerative Cities. *Resources, Conservation and Recycling*
(Peer reviewed journal, invited paper. Submitted (accepted with revisions, still in peer review))

Thomson, G (60% Contribution)
Preparation and completion of manuscript, analysis of case studies.

Giles Thomson, PhD Candidate

Newman, P (40% Contribution)
Supervising, revising and editing the manuscript.

Professor Peter Newman, Principal Supervisor

Publication 3: Co-Author Statements

Thomson, G., Newton, P., and Newman, P. (2016) Urban Regeneration and Urban Fabrics in Australian Cities. *Urban Regeneration and Renewal*. 10:2 Henry Stewart, London

(Peer reviewed journal, Published)

Thomson, G (50% Contribution)

Preparation and completion of manuscript, selection and analysis of case studies, analysis of data on Perth

Giles Thomson, PhD Candidate

Newton, P (see statement from Professor Peter Newton on the following page)

Newman, P

Supervising, revising and editing the manuscript.

Professor Peter Newman, Principal Supervisor

Publication 3: Co-Author Statements

To Whom It May Concern

I, *Giles Thomson,* contributed 50% to the paper/publication entitled "Urban Regeneration and Urban Fabrics in Australian Cities".

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Professor Peter Newton

(Full Name of Co-Author 1)

(Signature of Co-Author 1)

Professor Peter Newman

(Full Name of Co-Author 2)

(Signature of Co-Author 2)

Publication 4: Co-Author Statements

Thomson, G. and Newman, P. (2016) Sustainable Infill Development. In: *WA Infill Housing Futures*. Rowley, S., Ong, R., Duncan, A. (Eds)
Peer review book chapter (Accepted, forthcoming)

Thomson, G (80% Contribution)

Preparation and completion of manuscript, selection and analysis of case studies.

Giles Thomson, PhD Candidate

Newman, P (20% Contribution)

Supervising, revising and editing the manuscript.

Professor Peter Newman, Principal Supervisor

Publication 5: Co-Author Statements

Thomson, G. (2016) Material Flows, Information Flows and Sustainable Urbanism. *9th International Urban Design Conference Proceedings*, Canberra, Australia
(Peer review conference paper)

Thomson, G **(100% Contribution)**
Sole author.

Giles Thomson, PhD Candidate

Publication 6: Co-Author Statements

Thomson, G. and Rauland, V. (2014) GRID: A new governance mechanism for financing eco-infrastructure at the district scale. *7th International Urban Design Conference Proceedings*, Adelaide, Australia

Thomson, G (50% Contribution)

Preparation and completion of manuscript, selection and analysis of case studies (Low carbon eco-districts, Value capture, Property Assessed Clean Energy (PACE), On-Bill Repayment (OBR), BIDs & GRIDs)

Giles Thomson, PhD Candidate

Rauland, V (50% Contribution)

Supervising, co-authoring and editing the manuscript, selection and analysis case studies (Green bonds.ESCos,leasing arrangements and community owned renewables, BIDs & GRIDs)

Dr Vanessa Rauland, Co-Supervisor

Publication 7: Co-Author Statements

Thomson, G., Newman, P., and Matan, A. (2013) A Review of International Low Carbon Precincts. *State of Australian Cities 2013 Conference Proceedings.* Sydney, Australia

Thomson, G (80% Contribution)

Preparation and completion of manuscript, selection and analysis of case studies.

Giles Thomson, PhD Candidate

Matan, A (10% Contribution)

Supervising, revising and editing the manuscript.

Dr Annie Matan, Co-Supervisor

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If you are not the copyright owner of the material in question, I would be grateful for any information you can provide as to who is likely to hold the copyright.

I look forward to hearing from you and thank you in advance for your consideration of my request.

Yours sincerely

G R Thomson.

Giles Thomson

Secretariat Urban Design Dec 9 (3 days ago)

to me

Dear Giles,

Thank you for your email.

I have confirmed with the Committee that you will be able to include the requested articles in your thesis appendix. The book of proceedings for the 2016 Conference will be available shortly, and an email will be sent out once they are released.

If you need any further details, please let me know.

Kind Regards,
Katherine

Katherine Ortiz | **Conference Secretariat**
9th International Urban Design Conference
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From: Giles Thomson [mailto:gilesrthomson@gmail.com]
Sent: Thursday, December 8, 2016 6:59 PM
To: katherine.ortiz@astmanagement.com.au; Secretariat Urban Design <conference@urbandesignaustralia.com.au>
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