FAST: Framework for Assessing Sustainability over Time

by

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FAST: FRAMEWORK FOR ASSESSING SUSTAINABILITY OVER TIME

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Guidance from theory for a more holistic approach to achieving greater sustainability in urban landscapes has yet to be derived for many settings. Often extensions of their surrounding cities, campuses provide a finer scale for experimental design. This study developed a quantitative assessment to guide the transformation of campus landscapes into more instructive demonstrations of social and ecological concern. A Framework for Assessing Sustainability over Time (FAST) was created through an integrative research review and synthesis of validated models: Normalized Difference Vegetation Index, Local Climate Zones, and Impervious Cover Model, and measureable indicators: patch size and connectivity. This framework was applied to the University of Guelph to test the relative quality of landscape components, where principles prescribed by urban ecology were identified and operationalized to improve the environmental sustainability of the campus design. The framework will inform ecological sensitivity in campus and urban design that can influence user awareness.
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CHAPTER ONE: INTRODUCTION

Urban landscape design in North America is faced with becoming more sustainable to begin to reverse its negative toll on the environment. Landscape design is defined by Nassauer and Opdam (2008) as the following:

Intentional change of landscape pattern, for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values. Design is both a product, landscape pattern changed by intention, and the activity of deciding what that pattern could be. (p. 635)

To approach greater sustainability in the built landscape, urban ecology practice and theory suggest that urban systems be reflections of natural ecosystems while maintaining human potential (Bai & Schandl, 2011). This idea is becoming increasingly relevant as rapid urban development in the midst of inevitable climate change brings landscape architecture to novel design challenges. There is potential to build more resilient and ecologically restorative landscapes during this shift (Register, 2006).

Knowing how the affected biophysical environment might fare over time will lead to more design success in this respect. How, and at what stage of a project, might the level of design success be defined in practice? Where, in the landscape, can this definition start to take place to inform broader scale urban development? This study begins to answer these two questions to guide the improvement of evidence based landscape design methods.

Urban ecology aims to understand the intricacies of the relationships between urban culture and the biological environment from a systems perspective (Douglas,
2011). Broad scale, conceptual solutions were found in the literature relating to urban ecology and were developed into operational design guidelines to direct more ecologically sensitive landscape architecture. As general guidelines were derived from urban ecology principles, their application was tested in a finer scale landscape that mimicked its urban surroundings socially and biophysically – a university campus. Campus design is one fundamental part of landscape architecture that can begin to use such ecological principles. Landscapes of higher education can begin to practice what they teach and lead by example while putting urban ecology theories to the test at a smaller scale.

Chapter Two examines urban development as a product of human needs, its negative impact on the very ecosystems that support it and its potential to begin to regenerate these systems. Solutions from urban ecology are reviewed and suggested. The chapter concludes with a discussion on the roll university and college campuses can begin to play in understanding the potential for more resilient design. Chapter Three introduces the goal and objectives of this study, and the methods used to derive the Framework for Assessing Sustainability over Time (FAST). Chapter Four covers the results and analysis of the study – the landscape indicators, and their corresponding measures and models, synthesized to develop FAST. Chapter Five presents the results from the application of a portion of FAST to the University of Guelph’s campus core as a case study. Chapter Six discusses the application results to gain a better understanding of the successes and limitations of each component of FAST and concludes with the study’s future implications.
CHAPTER TWO: LITERATURE REVIEW

The following literature review summarizes the negative environmental impacts associated with North American urban development and design, the evolution of urban ecology concepts and solutions pertaining to this study, and the suggested application of these solutions to a campus setting.

URBAN

Defining what is meant by ‘urban’ has been a challenge (Alberti et al., 2003). The term ‘urban’ varies in meaning across disciplines – cities and towns fall into the category of ‘urban’ (McIntyre, 2011). The definition of urbanization follows Nassauer and Opdam’s definition of landscape design:

Urbanization is both a pattern and process…Despite imprecision in the term ‘urban,’ we know that relative to non-urban areas, urban ecosystems are characterized by high human population density (with associated built structures and services), an altered climate (usually being warmer, especially at night), anthropogenic impervious surfaces, a high concentration of chemicals of anthropogenic origin (e.g. heavy metals, atmospheric gases and particulates), altered productivity regimes (with dampened fluctuations), and a large ecological footprint. These traits are often associated with a changed biota (usually containing more exotic species), altered soil biogeochemistry and local hydrology, and altered rates or ecosystem functions. (McIntyre, 2011, p. 12)
Pinning one concise description to ‘urban’ might be difficult when the term depends on the changing dynamics of the social systems that create human habitats like cities (Douglas, 2011; McIntyre, 2011).

A city is an extension of human phenotypes, reflecting the evolution, behaviour, needs and culture of its citizens (Downton, 2009). The majority of the world’s human population now lives in cities (Douglas, 2011). While we construct our urban habitats we impact the planet more than any other species. Consequentially, ecological processes are affected and, since the industrial era, climate change has been accelerating (Douglas, 2011; Downton, 2009). We are now challenged with the responsibility of understanding how we might reverse the negative role our cities play so that what we build can become a part of the solution to a healthier planet (Downton, 2009; Register, 2006).

The first step is in identifying a city as the sum of its living and non-living parts. People drive the growth of urban infrastructure, the need for more agricultural land and the consumption of energy resources, contributing to the development of a city (Downton, 2009). Historically, demand and local patterns of a population have often played a larger role in shaping the way a city has developed than planning decisions have; therefore, current planning should reflect future demographics leaving the suburbs behind and intensifying city life (Foot, 1998). A city is as much defined by culture and social processes as a natural ecosystem is by its inhabiting species. That a city itself is composed of ‘urban ecosystems’ is a widely accepted idea (Douglas, 2011; Downton, 2009; Register, 2006) – urban areas are ‘synthetic ecosystems,’ or urban ecosystems that can range from completely artificial to undisturbed (Douglas, 2011; McIntyre, 2011). In urban landscapes “every building affects the climate at the very local level. Cities can
affect the climate at the regional level. Collectively, cities affect the global climate” (Downton, 2009, p. 521).

Urban Impacts Globally

With regard to direct surface changes, cities make up only about two percent of the planet and therefore have minimal impacts on global weather and climate. Cities do, however, still demand disproportionate resource shares because they are home to such a large portion of the global population. Consequently, cities do contribute to global climate change in an indirect but powerful way, altering the flux between sources and sinks of greenhouse gases by driving deforestation, transportation of goods, industrial processes and fossil fuel use (Grimmond, 2011).

Urban Impacts Locally

Direct surface changes through urbanization affect the biophysical systems within and surrounding urban areas. Typical cities, as outlined by Wittig (2008), have different sources of energy, origins of matter, composition, methods of waste disposal and energy and material flow direction. The urban landscape changes natural hydrology, increases surface runoff, creates heat islands and decreases evaporative cooling (Gill, Handley, Ennos, & Pauleit, 2007). Where energy and waste cycle in natural ecosystems, in urban landscapes these components travel linearly and have an endpoint (Wittig, 2008). Waste leaves an urban system and often is no longer a resource. In nature, waste is usually a resource within or between systems (Downton, 2009; Wittig, 2008). Like energy, nutrients are brought in from external sources in cities, while in natural ecosystems, these nutrients can be found within the system (Wittig, 2008). Surface permeability is lower in cities and higher in natural ecosystems (Wittig, 2008). “In cities we are not dealing with
isolated systems cut off from external influences, but with open systems involving the
transfer of both energy and matter with their surroundings” (Douglas, 2011, p.17).
Minimizing these differences by creating cities that function more like nature can lead to
a more harmonious relationship between urban and natural ecosystems (Wittig, 2008).

Urban landscapes remain conceptually different from natural ecosystems, with an
unequal give and take between the two (Downton, 2009). Cities rely on the function of
natural systems as they utilize ecosystem services. When functioning properly, ecosystem
services help to maintain a sustainable and healthy landscape for their users. These
services are provided by ecological processes that, for example, recycle nutrients, renew
natural resources, sequester unwanted environmental toxins, and contribute to cultural
identity and the potential for economic growth (Rapport, 1994). An ecosystem service is
of value to humans and provided by the biophysical systems of a landscape (Rapport et
al., 1998). It is also realized that the function or health of the natural ecosystems
supporting our cities depends on how ecologically conscious our city making is (Register,
2006). A healthy ecosystem has an internal order of self maintenance and regulation that
contributes to system resilience, the ability to recover from disease and disturbance
(Callicott, 1992; Callicott, 1995; Rapport, 1995). Healthy ecosystems are economically
viable and support healthy human communities (Bertollo, 2001).

Urban Nature

There is still a common appreciation for nature in cities. Maybe it is nostalgic, or
maybe urbanites can sense that cities operate similarly to natural ecosystems (Register,
2006). The potential to build on this recognition can improve cities for people and other
organisms alike (Register, 2006). Some people find a rich variety of nature in cities while
others see none (Kaplan, 2011). The definition for urban nature depends on societal values, and is general and inclusive (Kaplan, 2011). Nature in cities can be something passively experienced, like a backdrop, secondary to the main activity, or nature can be deliberately used and the main focus of attention. Both experiences tend to simultaneously occur (Kaplan, 2011). Urban nature can play a role in cultivating healthier, more active lifestyles (Douglas, 2011; Tilt, 2011). For instance, a view of urban nature in the form of vegetation along walking paths has been linked to improvements in overall user health and motivation to exercise (Tilt, 2011). It has been suggested that the experience of nature in cities and nature’s contribution to physical health can be considered an ecosystem service (Tilt, 2011). The management, ecological health and availability of nature are of high priority for many urban groups (Kaplan, 2011).

Certain attributes of cities, like urban nature, when emphasized in design, can help to lessen negative environmental impacts. ‘Access by proximity,’ another example, gives cities an upper hand when being compared to sprawled suburbs (Register, 2006).

Cities are blamed for the sheer quantity of their population and pollution and for their demand for energy and other resources, but if the same number of people with the same level of consumption were more dispersed, their impacts would be far greater. (Register, 2006, p. 49)

Distances between daily activities in the suburbs more often require the use of personal vehicles. Living is denser in cities and the need for travel, production of pollution and use of energy can decrease (Register, 2006). By rearranging the form of the city, building new technology and reducing demand for resources, cities can become more compact and possibly come closer to synergy with nature (Register, 2006). “The
urban eco-system is the most elaborate geographical control-system or integrated resource-management system in human experience” (Douglas, 1983, p. 206). The current description of ‘sustainable’ poses that cities be ‘mostly harmless’ to reduce environmental damage and support human potential but cities could be used further to generate health in how they are designed (Downton, 2009).

By definition, urbanization replaces nature and disrupts the health of the natural ecosystems of a landscape – the hydrology, soils, patterns of vegetation, species population dynamics (Downton, 2009). From this point of view, we set nature apart as something that is negatively impacted by cities and, in doing so, fail to see the possibility of a more equal coexistence between city and nature (Downton, 2009). The same bio-geo-chemical processes support all life on earth, including humans. “The concept of urban ecology can perhaps best be understood as a means of reconciling that natural and the artificial in a systematic way” (Downton, 2009, p. 49). Cities rely on ecosystem services and therefore it would be wise to become net contributors to the health of these natural systems. “Cities need to be consciously designed and understood as living systems embedded in the process of the biosphere as key regulators of the global ecology” (Downton, 2009, p. 21).

**SOLUTIONS FROM URBAN ECOLOGY**

The review of the evolution of principles, concepts and definitions that relate to the study of urban ecology, in Chapter Three, provided a theoretical foundation to direct the selection of appropriate urban ecological design principles, for the synthesis of a framework for assessing and informing the sustainability of a landscape design over time.
Resilience

When natural ecosystems are resilient, they persist in the face of disturbance, and in terms of human use, they continue to provide the same services (Rapport, 1994; Walker & Salt, 2006). City design is industrial, based on efficiency and process optimization, making cities vulnerable to disturbance (Downton, 2009). If cities are to be designed more like the natural ecosystems they rely on, they too will probably have a high level of resilience to whatever stress the future may bring (Downton, 2009). Shock, disturbance and stress to a system can be in the form of change such as: sudden natural disasters, extreme weather events or slower changes in climate-related patterns that affect biophysical dynamics (freeze-thaw cycles, precipitation patterns, life cycles of pest species), changes in human population size and needs (transportation, lifestyle), or change in resource availability (energy, food, fresh water) (Rapport, 1994; Walker & Salt, 2006).

Resilience is “the ability of a system to absorb disturbance and still retain its basic function and structure” (Walker & Salt, 2006, p. 1). It is impossible to maintain a ‘sustainable optimal state’ in any system – unexpected disturbances easily and all too often disrupt designs relying on averages (Walker & Salt, 2006). Resilience is based on two central themes: adaptive cycles and thresholds (Walker & Salt, 2006). The adaptive cycle typically has four phases (Walker & Salt, 2006, p.75):

1. rapid growth – when resources are exploited and system components grow quickly
2. conservation – when resources are conserved and the specialists of the system grow slowly
3. release – when disturbances to the system cause connections to falter
4. reorganization – when the system rebuilds its equilibrium and pioneer species thrive.

Socio-ecological systems constantly move through these phases (Walker & Salt, 2006). Adaptive cycles occur across scales. When dealing with one system it is important to note that it is likely a component of a larger system at a broader scale, and both influence each other as they progress through their individual adaptive cycles (Walker & Salt, 2006). For example, disturbances in ecosystems at a finer scale can prevent ecosystems at the broader scale from reaching the tail end of their conservation phase and verging on their release phase (Walker & Salt, 2006).

Thresholds surround stable states of a system and when they are crossed, a system settles into a different stable state, undergoing a ‘regime shift’ (Walker & Salt, 2006). A system might have more than one stable state that can achieve the same function (Walker & Salt, 2006). It can undergo regime shifts and still be resilient but when its ‘resilience limits’ are crossed, the system risks falling into an entirely new stable state with a different equilibrium, structure and function (Walker & Salt, 2006). Understanding the variables driving a system, its feedback mechanisms, its thresholds and its current phase in the adaptive cycle, helps to determine what may push the system beyond its resilience limits and into a new equilibrium (Walker & Salt, 2006).

To build resilience into a system, there are three basic necessities (Walker & Salt, 2006). The first is diversity in both function and response. Certain groups of organisms perform certain functions in an ecosystem. The more diverse the array of functions, the more resilient the system is. Within each functional group organisms can have varying responses. The higher the degree of response diversity per group, the more ways a group has to accomplish the same function, and the more resilient the system is (Walker & Salt,
The second is modularity from loose connections. When system components are too well-connected, effects of disturbances can travel quickly to all parts of the system (Walker & Salt, 2006). The third is tightness of feedbacks where a system can rapidly adapt to stress because of indicators that quickly signal when thresholds might be crossed (Walker & Salt, 2006). A resilient urban system would also have ecological variability, acknowledgement of slow variables (variables associated with thresholds are controlled), social capital (leadership, social networks and teamwork), innovation (embracing change and experimentation), overlap in governance (redundancy is high and public and private governance mix) and ecosystem services (Walker & Salt, 2006). Ecosystem services would have intrinsic value and their preservation, conservation and overall health would be of high priority in a resilient design (Walker & Salt, 2006).

**Ecosystem Health**

Reversing the effect that highly managed urban landscapes have on natural ecosystems might continue with an understanding of the concept of ecosystem health (Bertollo, 2001; Rapport, 1994; Su, Fath & Yang, 2010). The suggestion of ecosystem health was first made by Hutton in 1788 (Su et al., 2010), but it was not until the 1940s that the concept was revived when promoted in the writings of Aldo Leopold (Bertollo, 2001; Leopold, 1966; Rapport, 1994). Since then ecosystem health has been tailored to fit within environmental, social and economic facets of sustainability (Bertollo, 2001; Rapport et al., 1998; Su et al., 2010; Waltner-Toews, 2004). Leopold viewed the ‘wilderness’ as the best example of health because such pristine ecosystems had not yet been altered by humans and were therefore most likely to be capable of self renewal – these ecosystems were thought to have the highest degree of ecological integrity.
(Bortello, 2001). The modern, urban version of ecosystem health reasonably accepts the fact that most of the earth’s landscapes have been modified by humans (Bortello, 2001). Ecosystem health combines ideas from natural, social and health sciences and applies these ideas to the response (degree of homeostasis or resilience) of ecosystems when placed under stress from either or both natural and anthropogenic sources (Bertollo, 2001; Rapport, 1994; Rapport et al., 1998). Health in relation to sustainability demands that, “ecosystems must not only be ecologically sound, but they must also be economically viable and sustain healthy human communities” (Rapport, 1994, p.3).

Ecosystem health continues to be defined; however, there are three general characteristics that are recognized to contribute to an overall level of health: “Ecosystem services maintain a productive capacity, system integrity is a key component of urban ecosystem health, and assessing urban ecosystem health requires a systems perspective” (Su et al., 2010, p.2426). Productive capacity is described by the ability of a system to provide natural resources (Rapport, 1994). System integrity relates ecological integrity and resilience to natural disturbance – the ability of the system to remain whole and functional under stress (Bertollo, 2001). Disturbance to a natural ecosystem and resulting health changes can be measured relative to the system’s natural state. Measuring disturbance to an urban ecosystem becomes a challenge when urban landscapes begin artificially with no practical reference point in terms of integrity (Rapport et al., 1998; Su et al., 2012). Uncertainties associated with the openness of an urban system and evolving social demands leave such a system with no permanent health standard (Su et al., 2010). Ecosystem health standards become unique for every urban landscape and rely on local human concern (Rapport, 1994; Su et al., 2010). Although heavily influenced by
subjectivity, ecosystem health can be evaluated by a set of indicators correlated with certain thresholds that surround the system (Su et al., 2010). These indicators can be environmental, social or economic (Rapport, 1994; Su et al., 2010). Initial categories of possible indicators outlined by Rapport are summarized below.

**Environmental or Biophysical Indicators:** This group of ecology-based indicators relates closely with ecosystem resilience. Measurements might come from “nutrient cycles, energy flows, biodiversity, plant and animal species dominance, cycling or sequestering of toxic substances, or habitat diversity” (Rapport, 1994, p. 4). When an indicator such as the level of primary productivity falls significantly below the predetermined normal, the system could be said to be in distress (Rapport, 1994). “Transformations of the landscape resulting in reduced biodiversity and altered species composition may still be regarded as ‘healthy’ provided that ecosystem services remain sufficient to accommodate societal goals” (Rapport et al., 1998, p. 6).

**Socio-Economic Indicators:** This group of indicators stems from the requirements of a system to sustain human and economic activity (Rapport, 1994). Economic viability, for instance, is often linked to ecosystem resilience. As ecosystems can no longer provide resources due to stressors like pest outbreaks or physical damage, the system’s economic viability falters (Rapport, 1994).

**Human Health Indicators:** This group of indicators deals with the direct effect an environment can have on human health. Indicators in the form of higher levels of disease, toxins or even adverse heat wave effects in human populations can signal ecosystem distress (Rapport, 1994).
Policy Indicators: “Inconsistency in public policy resulting from attempts to satisfy conflicting demands rather than resolving conflict is much in evidence and, in itself, is a sign of ecosystem pathology” (Rapport, 1994, p.5).

Regardless of social pressures (human perspective, scale and values), for urban landscapes to continue to support human populations over time, their ecosystems must still retain certain ecological properties that contribute to thriving ecosystem services (Rapport et al., 1998). When these ecological properties are compromised by a stressor, indicators can show how unhealthy a system is or how close it is to falling into a state of dysfunction (Rapport, 1994). Three case studies were reviewed where a decrease in ecosystem health from anthropogenic impacts was seen through indicators (Rapport et al., 1998). “In each example, stress had resulted in biotic impoverishment, impaired productivity, altered biotic composition to favor opportunistic species, reduced resilience, increased disease prevalence, reduced economic opportunity and risks to human and animal health” (Rapport et al., 1998, p. 397). The initial categories of ecosystem health indicators can be reorganized into the following three that are more ecologically inclined:

Vigour: Higher levels of ecological “activity, metabolism or primary productivity” indicate a healthier system (Rapport et al., 1998, p. 397).

Organization: Higher levels of diversity and system component interactions indicate a healthier system (Rapport et al., 1998).

Resilience: A higher “capacity to maintain structure and function in the presence of stress” indicates a healthier system (Rapport et al., 1998, p. 397).
The concepts of ecosystem health became part of a foundation that helped establish more specific urban ecology principles for design.

**From Ecocity to Ecopolis**

Urban ecological approaches to ‘rebuild cities in balance with nature,’ arise from the fields of ecology, landscape ecology and ecosystem health, with influence from movements and paradigms, including appropriate technology, bioregionalism, the green movement, community economic development, social ecology and sustainable development (Roseland, 1997). These influences fall into a broad framework that outlines a vision for more holistic and proactive urban resilience (Roseland, 1997). Evolving from this framework, ‘ecocity’ and ‘ecopolis’ are two approaches that while similar in theory, have slightly varied explicit guidelines for the application of general urban ecological principles.

Roseland (1997) investigated the origins of the ecocity concept and its evolution. The term, ecocity, stems from Urban Ecology, an organization founded in 1975 by Richard Register and a few Berkeley colleagues (Roseland, 1997). Urban ecology was defined by the following ten principles:

1. revise land-use priorities to create compact, diverse, green, safe, pleasant and vital mixed-use communities near transit nodes and other transportation facilities;
2. revise transportation priorities to favor foot, bicycle, cart and transit over autos, and to emphasize ‘access by proximity;’
3. restore damaged urban environment, especially creeks, shore lines, ridgelines and wetlands;
4. create decent, affordable, safe, convenient, and racially and economically mixed housing;

5. nurture social justice and create improved opportunities for women, people of colour and the disabled;

6. support local agriculture, urban greening projects and community gardening;

7. promote recycling, innovative appropriate technology, and resource conservation while reducing pollution and hazardous wastes;

8. work with businesses to support ecologically-sound economic activity while discouraging pollution, waste, and the use and production of hazardous materials;

9. promote voluntary simplicity and discourage excessive consumption of material goods;

10. increase awareness of the local environment and bioregion through activist and educational projects that increase public awareness of ecological sustainability issues.

Many principles from urban ecology were maintained by Richard Register as he pioneered the concept of ecocities through his publication, *Eco-city Berkeley*, in 1987. In the early 1990s, David Engwicht published similar ideas, reinforcing the term ecocity. Though the principles are general enough to fit a range of urban landscapes, uniqueness in social values in every local situation dictates specific ecocity initiatives. At the time, Roseland stated that the ecocity vision would help remedy a lack of synthesis in sustainable programming (Roseland, 1997).

Practitioners who turned to these paradigms or movements for direction in applying these concepts to the communities where they work and live have...
far] found much inspiration but relatively little guidance. Only recently has there been rapidly growing interest in the practical application of these ideas at the local level. While there are discernible differences in analysis, emphasis and strategy between [designers, practitioners, visionaries and activists], the eco-city theme is broad enough to encompass any and all of them. (Roseland, 1997, p.200)

The five ‘most important’ of approximately forty collected ecocity principles, as deemed by Register in *Ecocities: Rebuilding Cities in Balance with Nature*, are listed below (Register, 2006).

1. Build the city like the living system it is: design should be at human scale, three dimensional and complex in a form that fits function.
2. Make the city’s function fit with the patterns of evolution: restore and regenerate natural systems.
3. Follow the builder’s sequence – start with the foundation: land use patterns should support the health of the city.
4. Reverse the transportation hierarchy: people first, personal vehicles last.
5. Build soils and enhance biodiversity.

Varied sets of principles for application of the ecocity concept to urban design have been derived from Register’s work. For example, five principles to build urban ecosystems with a goal to closely mimic natural ecosystems have been established (Wittig, 2008, p. 30).

1. Media that support life (soil, water, air) must be protected.
2. Energy consumption must be reduced.
3. Material use should be reduced and materials recycling increased.
4. The amount and kind of nature in the city must be enhanced through conservation and restoration activities.

5. A rich variety of spatial structure and space must be provided.

   The application of one principle usually lets urban design achieve one or more of the others in the list (Wittig, 2008). Register (2006) too realized that achieving balance between synthetic and natural components of one subsystem positively influences other relationships in the greater system. The following text explains possible relationships between principles (Wittig, 2008):

   Reduction in material flow (Principle No.3) results in less traffic, and thus a reduction in energy consumption (Principle No.2). Less energy consumption in turn results in fewer emissions and thus less air, water, and soil pollution (Principle No.1). Conservation and promotion of nature (Principle No.4) promotes more unsealed soils (i.e., protection of life media such as soil [Principle No.1]) and also contributes to there being more variety in urban structure and space (Principle No.5). (p. 30)

   The success of the design depends on how well each principle is met however the design must also account for local socioeconomic processes which tend to challenge the realization of the principles (Wittig, 2008).

**Ecopolis**

   The historical context of ecocity involves Register’s support of an earlier set of twelve Ecopolis Development Principles from Downton. At the time, there were few design principles to guide an ecocity to construction. Downton’s twelve came closer than most and seemed to have influenced Register’s (2006) version of ecocity principles. The
same influence can be seen from Register as Downton (2009) later updated and published his most recent set of ten ecopolis principles with ecocity in mind. The two approaches, ecocity (2006) and ecopolis (2009), are shown to be similar in the following text by Downton (2009):

There is a continuum that spans from city through ecocity to ecopolis. Cities are what we have been making for nearly 10 millennia without regard to environmental consequences; an ecocity is a city that takes account of its position within the processes of the biosphere; and ecopolis creates an environment that generates health and dynamic ecological stability… Successful city-making is about the construction of living systems and a truly ‘ecological’ city is exemplified by the ecopolis concept in which the biophysical environmental processes of a region are sustained through conscious intervention, active engagement and management by its human population. In other words, the citizens of the urban ecosystem seek to fit human activity within the constraints of the biosphere whilst building environments that sustain human culture. (p. 21)

In search of a ‘widely accepted, functional definition’ of what makes an ecological city, Downton collected and revised urban ecology and ecocity concepts for further application to urban design calling his synthesized set of principles, Ecopolis Development Principles (EDPs). These were published in Ecopolis: Architecture and cities for a changing climate (Downton, 2009). The term, ecopolis, means ‘ecological, self-governing city,’ a city designed to mitigate the planet’s ecological problems created by humans, and to serve as a more resilient refuge in the face of these problems. While urban sustainability concepts are focused on conservation of resources and design that func-
tions in a ‘mostly harmless’ way with the natural world, ecopolis concepts work within natural ecosystems to make cities more functional for people (Wang, Downton & Douglass, 2011).

Few differences remain between ecocity and ecopolis principles but it was Downton’s (2009) aim to develop a concept closer to an ultimate urban goal where, through natural and synthetic co-evolution, a city’s ecological footprint might actually reach zero while maintaining maximum human potential.

Ecopolis is not a utopian concept…[It is] situated on the sharp contradiction between reductionism and holistic approach, objective and subjective method, quantitative and qualitative data, and vertical and horizontal interconnection, a methodological transition towards ecological integration…not primarily concerned with ecology in the city, but with the ecology of the city… New forms of city living have to be developed that are more sustainable and allow cities to function more like natural ecosystems. People require a technologically sophisticated lifestyle, with electrification, computers, modern communications and multiple transport options. This is possible if a new form of city living, ecopolis, is adopted by greening urban areas through the integration of architecture, planning and ecology, essential to the development of truly viable ecological cities. (Wang et al., 2011, p. 636)

EDPs are meant to guide a city in an ecological way as it evolves as an ecosystem driven by its living components (Downton, 2009). As more EDPs are met by urban design, design gets closer to building an Ecopolis. Addressing one principle may simultaneously address others (Wittig, 2008). There are ten proposed EDPs listed below (Downton,
The first five deal with improving the biophysical realm and the last five with human ecology to maximize human potential in the city landscape (Downton, 2009).

1. **Restore Degraded Land**: clean and heal contaminated and degraded land, reestablish native vegetation, increase farmland, green corridors.

2. **Fit Bioregion**: maintain natural cycles of water and nutrients, create buildings and urban form to fit the landscape and respond to climate, conserve water and recycle effluent, use local materials, respond to region culture.

3. **Minimize Ecological Footprint**: reduce city’s impact beyond boundaries, diverse land use, increase biologically productive land area, urban food production, wildlife reserves, recognize a place for non-human species.

4. **Create Compact Cities**: walkable, minimize car use, access by proximity, complex and three dimensional built form, permeable but defined urban boundaries, most daily needs provided by the city.

5. **Optimize Energy and Resource Use**: renewable, local sources that are not nuclear, buildings designed to use less power, eventually eliminate fossil fuel use, cradle to cradle design.

6. **Contribute to the Economy**: develop ecologically responsible industries, regional trade, exportable green technologies and services, adopt ‘fair trade’ practice, create appropriate information technology, incentives for ecological responsibility.

7. **Provide Health and Security**: eliminate pollution, promote and achieve environmental quality, safe water, recycle effluent for safe reuse, clean air, passive surveillance in built environments, food security, habitat for animals.
8. **Encourage Community:** development is community driven, provide community facilities, encourage social interaction through environment.

9. **Promote Social Justice and Equity:** involve all community in development, affordable housing, encourage public space use, democracy.

10. **Enrich History and Culture**

**Building and Measuring Design Success**

In theory, the success of an urban fractal design, in terms of function that supports human and natural needs, can be measured by how well it achieves the EDPs (Downton, 2009). As suggested by Downton, there are general indicators, referred to as ‘frogsticks,’ that can be adapted to measure initial landscape performance and resulting EDP design achievement levels in various situations (2009). It is recommended that the indicators, or ‘urban ecology checklist,’ be used in conjunction with a program called *Sustainable Human Ecological Development* (SHED), an action tool for ecopolis development. The seven steps of SHED have been derived to aid a design process and maintain a system-based product that will both evolve.

After understanding where in the landscape to settle, the seven steps of SHED, paraphrased below, guide the application of EDPs – the success of the EDPs can be measured by the indicators (frogsticks) (Downton, 2009).

1. **Shedding:** Identify the biophysical context (watersheds and bioregions) and inherent constraints for city making. Realize potential changes associated with a landscape soon to be affected by climate change (such as different precipitation patterns). Understand the carrying capacity of the landscape through various future scenarios and the demands put on the landscape by urban development.
2. **Placing:** Fit people to the landscape in a way that makes sense in terms of past and present synthetic and natural ecologies. Design in harmony with the natural landscape.

3. **Biozoning:** Realize that cities are inseparable from their hinterlands for resource procurement, distribution and management. Locate agriculture (preferably permaculture) and biological resource sites and plan in proximity to them.

4. **Lifelining:** How was the landscape before urban design? Consider the existing natural ecosystems and continue to weave their minimum elements through the urban landscape. Link and restore natural habitats (such as water and vegetation) and the other living species of the landscape.

5. **Proximating:** Consider being places instead of going places – transportation is needed to go to an inconveniently located place. Cultural, social and economic resources should be located according to planning for the least amount of energy.

6. **Patterning:** Predict potential patterns of urban growth, communities, culture and morphologies. Avoid homogenization of the landscape.

7. **Architecting:** Design to mimic nature and do no harm to nature.

   “Frogsticks can be used to identify those impacts of the conventional built environment which separate it from the natural environment” (Downton, 2009, p. 520). These indicators can also demonstrate the level of improvement made by ecological design according to the EDPs. The indicators are provided with details on what to measure but the method for quantifying and qualifying how far urban design strays from natural indicator levels is subjective.
1. **Air:** “Every building affects the climate at the very local level. Cities can affect the climate at the regional level. Collectively, cities affect the global climate.” The load of contaminants in the air should be as close to zero as possible. Use the built environment to produce desirable microclimate changes (such as shelter, shade or breeze) (Downton, 2009, p. 521).

2. **Water:** How closely are hydrological ecosystem functions of the bioregion’s watershed replicated? Ecological development would have equal percentages of water lost to water gained in the system, and no water pollution or waste.

3. **Earth (Soil):** How sustainable are the agricultural systems? Traditional farming leaves soils in poor condition. Achieving good soil quality is linked with achieving healthy levels of (indicators): biodiversity, habitat, biomass, and food production. Look for rooftop gardens and vertical farming.

4. **Fire (Energy):** Convert from non-renewable to renewable energy sources with zero waste of energy.

5. **Biomass:** How high is the level of effective biomass (carbon sequestering and solar energy resource via photosynthesis) / revegetation? Maximize potential for biomass growth for a more stable urban landscape.

6. **Food:** It is possible for a city to become a net exporter of food. How well is food production maximized within the system?

7. **Biodiversity:** How healthy is the level of biodiversity? An ecopolis increases and maximizes biodiversity, re-instates natural ecosystems and responds to climate changes.
8. **Habitat**: Natural ecosystems must not be reduced to service humans only. How much diverse, usable habitat is provided?

9. **Ecolinks**: How well is the urban landscape planned in relation to the entire bioregion? How successful are ecological corridors, if any? Conventional urban development fragments habitats and interrupts migration patterns.

10. **Resource Use**: Is there waste? The ultimate goal is to recycle and conserve waste and resources.

   Some indicators are easily quantifiable and can be directly measured while others require some refining and are further addressed in Chapter Three.

**Ecopolitan Urban Fractals**

An ecopolis is made up of urban fractals which are comparable to mathematical fractals (Downton, 2009). An urban fractal contains the same elements as the larger whole it contributes to (Downton, 2009). In this respect, parts of a city might be considered urban fractals if they have city elements like housing, transportation, commerce, production, and waste systems within a natural landscape pattern. Table 1 suggests some characteristics of an ecopolitan urban fractal, how EDPs might address each and what type of indicator might be used to measure the success of each solution.
Table 1: Applying EDPs and Indicators to an Urban Fractal (Adapted from Downton, 2009, p.496)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>EDPs</th>
<th>Frogsticks and SHEDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to Biosphere</td>
<td>Integrate into biosphere processes to optimize function for human purposes</td>
<td>All</td>
</tr>
<tr>
<td>Relationship to Bioregion</td>
<td>(EDP2) Nurturing bioregions, totally defined by them</td>
<td>Habitat / SHED1</td>
</tr>
<tr>
<td>Response to Place</td>
<td>(EDP1) Very strong</td>
<td>Biodiversity / SHED2</td>
</tr>
<tr>
<td>Protection of Biozones: maintain food production</td>
<td>(EDP1) Ecosystem restoration and re-modeling, urban agriculture</td>
<td>Biodiversity / SHED3</td>
</tr>
<tr>
<td>Ecosystem Connectivity: creating habitat</td>
<td>(EDP1) Conscious connectivity with all elements of environment</td>
<td>Habitat / SHED4</td>
</tr>
<tr>
<td>Urban Form: patterns that define structure and organization</td>
<td>(EDP4) Compact, urban villages, distinct centers determined by topography and place</td>
<td>Resource Use / SHED5</td>
</tr>
<tr>
<td>Pattern of Development: networks that contain essential characteristics of larger city</td>
<td>(EDP7) Walkable, good transit connections, built form corresponds with needs of social exchange and ecosystem function</td>
<td>Ecolinks / SHED6</td>
</tr>
<tr>
<td>Architecture</td>
<td>(EDP3) Organic, highly responsive to climate, place and human needs, use of biomimicry</td>
<td>Resource Use / SHED7</td>
</tr>
<tr>
<td>Ecological Footprint</td>
<td>Zero (or one planet)</td>
<td>All</td>
</tr>
</tbody>
</table>

Because socioeconomic conditions vary in terms of level of urban development, certain ecopolis evolutionary goals can be emphasized through an integrative learning process during and after each design phase. The complete list (with paraphrased descriptions) is as follows (Wang et al., 2011):

1. **Ecological sanitation:** provide citizens with a clean and healthy environment through a synthetic-natural metabolism-like system that accounts for resources and waste.
2. **Ecological security:** provide safe and resilient living conditions.
3. **Ecological industry (EI):** transition from industrial to systems that cycle in as closed a loop as possible. A goal for industrial cities.
4. **Ecological landscape (ecoscape):** Restorative planning and design to rebuild ecological integrity. Combines synthetic biophysical function with ecosystem service vitality to reduce urbanization effects like heat island or hydrological deterioration.

5. **Eco-culture:** An ecological consciousness that shapes decision making is cultivated and engrained in societal behaviour. Human activities can be said to enhance the health of ecosystems when living harmoniously with nature in pattern and process.

**Campus and City**

Landscapes of higher education institutions in North America often resemble their urban backdrop, significantly contributing to environmental degradation when, for instance, activities and systems on campuses use conventional energy sources, pollute water and air, produce waste (Alshuwaikhat & Abubakar, 2008) and fragment natural habitat (Clarke & Kouri, 2009; Dahle & Neumayer, 2001; Rapport et al., 1998). Campuses have been referred to as ‘small cities’ (Alshuwaikhat & Abubakar, 2008; Landsmark, 2011). According to Landsmark (2011):

An average campus is comprised of housing, library and research facilities, independent transportation systems, health and hospital facilities, installed infrastructure, power-generating facilities, sports emporia, data transmission capabilities, lighting and plumbing systems, and a mix of single-purpose and multiuse buildings. Campuses develop and sustain retail operations, parks and playing fields, and shared spaces that encourage repose, recreation, and celebratory assembly… Unlike cities, where a mix of multiple public and private entities develop and maintain physical resources, in a university or college a
single, unitary administration is generally responsible for the oversight of all
campus facilities and functions (p. 52).

Like cities, many campuses accommodate circulation of personal vehicles first
and pedestrians last (Balsas, 2003). Resulting designs showcased parking areas and
vehicular throughways with pedestrian crosswalks as secondary elements.

In the past, traditional campus design and planning strategies have not led to
lower environmental impacts on and off campus, and have not led to social awareness for
change (Finlay & Massey, 2012). Social systems took precedence in most campus
designs while the degrading health of ecological systems was taken less seriously (Bruce,
2011). Infrastructure on campuses was designed to promote future expansion,
connections with the surrounding urban network, sporting events, and efficiency in
systems like stormwater management, waste removal and circulation (Bruce, 2011). In
particular, efficiency objectives contradicted efforts to promote ecosystem health, as
healthy and adaptable landscapes often have a certain level of built-in redundancy
(Waltner-Toews, 2004).

In many cases, campuses are physically large proportions of a city and therefore
can significantly affect their surrounding urban landscape. It is still common for campus
updates to further deteriorate the overall health of the landscape with the addition of new
buildings, transportation routes to support suburban sprawl, and an increase in
impermeable surfaces (Bruce, 2011). However, not all updates are detrimental to the
environment, especially following current intensification efforts in urban landscapes. For
example, more recently the demand for putting environmentally friendly needs of
pedestrians and cyclists ahead of personal vehicles has prompted an evolution of campus
circulation systems (Balsas, 2003). Additional campus efforts also deal with retrofitting building infrastructure to achieve more campus sustainability. But these attempts, among others, remain insufficient by addressing only one aspect of one system at a time. Few have focused on the campus landscape as a tool to visibly integrate environmental responsibility across more than one system (Way et al., 2012). The relationships between human activity and ecological processes in an urban setting generate complex environmental challenges. Solutions to these challenges are more likely to come from multidimensional or ecosystem perspectives (Rapport, 1994).

**University of Michigan**

In a report by Buch, Divringi, McCann, Millard, and Patten (2011), on green initiatives at the University of Michigan, existing landscape design was evaluated and updates were proposed for a ‘pilot site’ in a highly used and visible area of campus with the intent to improve consideration for the environment through design. As the first impression of the university, the campus landscape was initially lacking in terms of sustainability (Buch et al., 2011). Landscape design was conventional – minimal native plantings, large areas of impermeable concrete increased runoff and heat island effects, and pristine lawns were high maintenance, re-sodded, fertilized and mowed (Buch et al., 2011). Biotic relationships became degraded through such practices that do not fit with the natural ecology of the landscape (Buch et al., 2011). One solution given by the authors was to increase surface permeability and decrease the level of management of the green spaces on campus by planting native species (Buch et al., 2011).
University of California, Berkeley: the Heart of the City Project

In 1997, Register and fellow ecocity advocates set out to physically put together components of an ecocity at a small scale to create one of Downton’s ecopolitan urban fractals with the hope that a concrete example might better communicate the ecocity concept (Register, 2006). Called the Heart of the City Project, it was to take place as the restoration of Strawberry Creek, running through the main campus, an area that already possessed a few key ecocity-like features and opportunity to fill in the missing pieces (Register, 2006). With the addition of solar greenhouses, rooftop gardens, pleasant views, public plaza, pedestrian streets, and housing, all linked by multilevel foot bridges and in close proximity to transit, the project was meant to profit local business, become a tourist destination and ecocity showpiece (Register, 2006). The project is still just as relevant and ready to be executed with further support (Downton, 2011).

Even though this fractal has yet to be built, a few strategies were developed and are general enough to guide any Heart of the City project (Register, 2006, p. 333):

1. Find your centers and create Heart of the City projects by filling in the missing pieces.

2. Create a ‘vascular system’ of bicycle and footpaths, as well as transit, from that heart to the other major nearby centers and to the most appreciated natural features in your area.

3. Next or first, whichever sequence can be more easily accomplished, looking at the whole living system, make an ecocity zoning overlay map to help put in order and connect the proper functions of all of the rest of the city, much of it properly returned to agriculture and nature.
Campuses as Fractals

In a recent journal article proposing ecocity strategies for campus design and retrofit, campuses are identified as “microcosms of the broader complexities, environmental issues, concerns and challenges in North American towns and cities” (Finlay & Massey, 2012, p.151). Because campuses are often extensions of their surrounding urban landscape, it is proposed that adaptation strategies for promoting more integrative sustainability in cities and towns be scaled to fit the campus landscape (Finlay & Massey, 2012). The urban campus is an ideal setting to attempt to achieve a higher level of environmentally responsible design before applying the same efforts to entire towns or cities – as suggested with Register’s Heart of the City project which could transform a portion of Berkeley’s campus into an ecopolitan urban fractal (Register, 2006). Opportunity for change often arises in situations lacking complex governance and policy (Waltner-Toews, 2004). Unlike towns and cities, campuses have less intricate government systems, less intensive transportation, consumption and waste systems, and are therefore less likely to encounter the challenges often associated with these complexities (Finlay & Massey, 2012; Landsmark, 2011).

There is an increased awareness of the impact that higher education institutions and their campuses can have on the environment (Finlay & Massey, 2012). The physical and social systems that form campus landscapes can influence the attitudes and processes surrounding sustainability beyond campuses. Changes to biophysical patterns on a campus can ecologically affect the greater landscape network to which the campus belongs. Similarly, what is taught and experienced at higher education institutions plays a role in the development of public awareness as students continue to project learned ideals.
at the community and global scale (Alshuwaikhat & Abubakar, 2008; Dahle & Neumayer, 2001). Institutions of higher education can begin to address urban ecology principles such as those developed by Downton and Register, like the EDPs, and design landscapes that more effectively enhance biodiversity, ecological balance, and the health of the ecosystem services that support their campuses, while promoting, by example, more sustainable thinking within and outside of the campus community (Alshuwaikhat & Abubakar, 2008).

Higher education institutions teach ecologically conscious design but many have not yet committed to incorporating the same practice into the social and physical processes and systems on campus (Buch et al., 2011; Finlay & Massey, 2012). The 2011 College Sustainability Report Card revealed that there were, to date, no institutions in North America that had applied cohesive, multidimensional approaches in an attempt to fully achieve sustainability in all aspects of campus design and practice – most commonly due to a weakness in coordination to address institutional barriers (Finlay & Massey, 2011). So far, only reactive and disjointed measures have been taken to implement more environmentally responsible practices on campuses, nowhere near the level of ecological design proposed by urban ecology (Finlay & Massey, 2011). It is becoming clear that this bandaid approach to sustainability where single parts of systems are targeted is not enough to maintain ecosystem health (Alshuwaikhat & Abubakar, 2008; Way et al., 2012). Promoting innovative experimentation and critical thinking, campuses are ideal living laboratories to cultivate a more holistic and proactive strategy to urban sustainability (Landsmark, 2011; Cortese, 2003; Finlay & Massey, 2012; Moore, 2005; Way et al., 2012). Balancing human needs and natural ecosystem health requires
concurrent attention to multiple system components on a campus (Finlay & Massey, 2012). Because the health of campus landscapes affects the health of campus life, ecological principles should be woven into design (Bruce, 2011). As landscapes are modified to fit increasing urban demands, the ecological functions of these landscapes begin to fail (Rapport et al., 1998). To mitigate the effects of traditional campus design on the health of the environment, an EDP design strategy could work to restore local ecosystem processes while maintaining human capacity and campus life (Bruce, 2011).

Focusing on improving the physical systems that help to shape a campus landscape and support campus activity, concurrently, may guide a more ecologically-minded method of redesign from the land up. There is an opportunity to transform landscapes of higher education into more instructive demonstrations of social and ecological concern while putting urban ecology theories to the test at a smaller scale. A test usually involves a way of measuring achievement. This study focused on a framework to measure the level of sustainability of a landscape design as it affects elements of the natural environment.
CHAPTER THREE: METHODS

This chapter provides the goal and objectives of this study, and the methods used to derive and synthesize the measures and models of the Framework for Assessing Sustainability over Time (FAST).

GOAL

To develop a framework to guide and test the application of existing ecological design principles to campus landscapes.

OBJECTIVES

1. To identify ecological design principles that prescribe a more holistic approach to sustainability in the urban landscape.

2. To identify and operationalize measures for indicating the sustainability of past, present and proposed future urban designs.

3. To apply the derived guidelines to the University of Guelph campus landscape as a case study.

4. To evaluate the success of the framework methods and application for use in urban design.

METHODS

This study will develop a methodology, tailored for use in landscape architecture practice, for more holistically assessing the environmental impact, the resilient and restorative success of a design. Ecopolis Development Principles, as prescribed by urban ecology, were previously identified through the literature review in Chapter Two (Downton, 2009). A subsequent integrative research review (Deming & Swaffield, 2011) will identify an accompanying list of landscape components as indicators for overall
environmental sustainability (Downton, 2009). Several of these indicators (air, water, biodiversity, habitat, ecolinks and soil) are not refined enough to be directly measured and so will be referred to as indirect indicators. The remaining, energy, food and resource use, can be directly measured. Each indirect indicator will be refined to a measureable form. Validated models will then be identified to assess the change in each refined indirect indicator. By research synthesis (Deming & Swaffield, 2011), the models will be organized into a Framework for Assessing Sustainability over Time (FAST), the main result of this study. FAST, as a working guide, is presented at the end of this chapter as Figure 1. To investigate the application of the portion of FAST composed of indirect indicator models, the models will be used to measure the quality of landscape components from a core section of the University of Guelph main campus in Chapter Five.
CHAPTER FOUR: RESULTS AND ANALYSIS

MEASURES AND MODELS

The following Ecopolis Development Principles (EDPs) were identified as a representation of urban ecology theory in favor of more sustainable and more resilient landscape design for the future (Downton, 2009).

**Biophysical:**

- Restore Degraded Land
- Fit Bioregion
- Minimize Ecological Footprint
- Create Compact Cities
- Optimize Energy and Resource Use

**Socioeconomic:**

- Contribute to the Economy
- Provide Health and Security
- Encourage Community
- Promote Social Justice and Equity
- Enrich History and Culture

As shown above, the EDPs can be categorized as biophysical or socioeconomic. The selected landscape components, or indicators, listed below (Downton, 2009) were more closely linked to the biophysical principles which therefore became the focus of this
study. However, the biophysical principles relate to the socioeconomic principles in a positive way. Applying the biophysical principles to decrease stress on each indicator often promotes the socioeconomic principles (Wittig, 2008).

**Indirect Indicators:** Air, Water, Biodiversity, Habitat, Ecolinks, Soil,

**Direct Indicators:** Energy, Food, Resource use

The above indicators can demonstrate the level of improvement made by ecological design according to the EDPs. The method for quantifying and qualifying how urban design affects each natural indicator is subjective (Downton, 2009). Each indirect indicator was adapted and refined to a measurable form.

The measures were chosen from the literature based on capability to predict or affect the state or quality of each indirect indicator, usually despite all other factors at play. Air comfort can be assessed by understanding the microclimate of the site (Brown, 2012; Stewart & Oke, 2012). In most cases, percentage of impervious cover in a landscape has a considerable effect on surface water quality and therefore acts as a good general predictor for that indicator (Schueler, Fraley-McNeal & Cappiella, 2009). Biodiversity potential can be measured by quantitative and qualitative characteristics of habitats and ecolinks found on site (Hodgson et al., 2011). According to the literature, these major predictors are vegetation patch size, stress and diversity, and level of connectivity, for habitat and ecolinks respectively (Hodgson, Moilanen, Wintle, & Thomas, 2011; Franzén & Nilsson, 2010; Pettorelli et al., 2011). A model, or way of assessing each measure, was identified. The corresponding measures and models are summarized in Table 2 for each indirect indicator.
Table 2: Measures and Models Paired for Each Indirect Indicator

<table>
<thead>
<tr>
<th>Indirect Indicator</th>
<th>Measure</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Comfort?</td>
<td>Microclimate</td>
<td>Local Climate Zones (LCZs)</td>
</tr>
<tr>
<td>Surface Water Quality</td>
<td>Impervious Cover</td>
<td>Impervious Cover Model (ICM)</td>
</tr>
<tr>
<td>Biodiversity Potential</td>
<td>*Habitat and Ecolinks</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Vegetation Stress and Diversity, Patch Size</td>
<td>Normalized Difference Vegetation Index (NDVI) and GIS</td>
</tr>
<tr>
<td>Ecolinks</td>
<td>Connectivity</td>
<td>GIS</td>
</tr>
<tr>
<td>Soil Ability</td>
<td>Moisture</td>
<td></td>
</tr>
</tbody>
</table>

*Habitat and Ecolinks were considered to contribute to overall biodiversity potential.

To build a user-friendly framework, the study reviewed the application of models that relied on remote sensing combined with the use of ArcGIS. Remote sensing can provide insight into the quality of landscape components over larger urban sites that a site analysis on the ground may miss (Deng & Wu, 2012). Because data is gathered consistently with repeat coverage, patterns in landscape stress may become more noticeable (Deng & Wu, 2012). Level of resolution becomes a major factor and is addressed in Chapter Six. The integrative research review uncovered suitable models that employ the use of remote sensing to assess the majority of the measures for the indirect indicators.

Models that can involve the use of orthoimagery and ArcGIS, as for this study, were identified to remotely measure microclimate – LCZs (Stewart & Oke, 2012), impervious cover – ICM (Schueler et al., 2009), and vegetation stress – NDVI (Fung & Siu, 1999; Pettorelli et al., 2011). With broader scale sites and/or higher resolution images of NDVI, it is also possible to remotely sense vegetation diversity (Gould, 2000). Patch size and connectivity can be measured directly, without models, using
orthoimagery and tools from ArcGIS 10.1. Finally, soil ability to function as an ecosystem service – support needs of the landscape and its users – often heavily relies on soil moisture (Al Bitar et al., 2012; Champagne, Berg, Belanger, Mcnair & De Jeus, 2010; Al-Shrafany, Rico-Ramirez, Han, & Bray, 2013; Zhu et al., 2012). This study reviewed the potential to remotely measure soil moisture in agricultural sites using multi-polarized and multi-angular RADARSAT-2 SAR data (Gherboudj, Magagi, Berg, & Toth, 2010), and passive microwave soil moisture datasets (Champagne et al., 2010). Review results suggest that the same methods for remote sensing of soil found on a finer scale, urban site have not yet been well explored. Efforts to validate techniques for remote sensing continue (Al Bitar et al., 2012) therefore a model to measure soil moisture has not been identified for this study.

SYNTHESIS

Through the method of research synthesis (Deming & Swaffield, 2011), the models were organized into part of the framework, Table 3.

<table>
<thead>
<tr>
<th>Table 3: Indirect Indicators used in FAST</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indicator</strong></td>
</tr>
<tr>
<td>Air Comfort</td>
</tr>
<tr>
<td>Surface Water Quality</td>
</tr>
<tr>
<td>Biodiversity Potential</td>
</tr>
</tbody>
</table>

FAST is presented in Figure 1 as a useable framework. It provides the measures that should be assessed, the methods and models to take such measurements, instruction on how to compare results for each model over time and how to interpret results.
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measure</th>
<th>Method (maintain for each time period measured)</th>
<th>Assessment over Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>How much renewable energy supplies the site?</td>
<td>(Subjective)</td>
<td>Increase in measures is desirable.</td>
</tr>
<tr>
<td>Food</td>
<td>How much food is produced on site?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource Use</td>
<td>How much is recycled or renewable on site?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indirect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Vegetation Stress</td>
<td>1. Obtain air photo or satellite image of site that has captured red and near infrared light. 2. NDVI analysis per time period: Spatial Analyst, Raster Calculator tool in ArcMap for bands representing red and near infrared light. 3. Raster Calculator tool in ArcMap for Basic Subtract: (newNDVIvalues) – (oldNDVIvalues) = change over time.</td>
<td>1. Understand individual NDVI image results and values: approaching (+1) = increasing health (decreasing stress); approaching (-1) = increasing stress. 2. Understand change over time values: approaching (+2) = increasing health and/or new growth; approaching (-2) = increasing stress and/or loss of growth.</td>
</tr>
<tr>
<td>Potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation Patch Size and Connectivity</td>
<td>1. Optional method: Higher resolution image and larger site: use NDVI and Spatial Analyst, Generalization, Region Group ArcMap tool. If NDVI images are unavailable or site too small, the same ArcMap tools can be applied to air photos. 2. Raster Calculator tool in ArcMap for Basic Subtract = change over time.</td>
<td>1. The assessment of these three measures is defined by the life cycle requirements of species on site. Specifics help to better understand any change over time. 2. Overall, increase in vegetation diversity, patch size and connectivity is desirable.</td>
<td></td>
</tr>
<tr>
<td>Vegetation Diversity</td>
<td>1. Optional larger site method: standard false colour composite for NDVI.</td>
<td></td>
<td></td>
</tr>
</tbody>
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Figure 1: FAST
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measure</th>
<th>Method (maintain for each time period measured)</th>
<th>Assessment over Time</th>
</tr>
</thead>
</table>
| Indirect (continued)       |                                                                         | 1. Classify site based on LCZs table (Stewart & Oke, pp. 1885, 2012).  
2. Refer to table, “Values of geometric and surface cover properties” (Stewart & Oke, pp. 1886, 2012).  
3. Refer to table, “Values of thermal, radiative, and metabolic properties” (Stewart & Oke, pp. 1887, 2012). | 1. Define user needs of site. LCZ quantitative and qualitative characteristics give understanding of site microclimate.  
2. Do LCZs of the site meet user requirements more or less, over time?                                                                                                                                 |
| Thermal Comfort            | LCZs: Local Climate Zones (Stewart, I. and T. Oke. 2012. Local climate zones for urban temperature studies. American Meteorological Society, 93: 1879-1900.) | 1. Calculate % IC on site, optional method: Reclassify air photo pixels with ArcMap Spatial Analyst Iso Cluster Unsupervised Classification tool; further reclassify (all IC assigned one pixel value) with ArcMap Spatial Analyst Reclass tool; calculate % IC pixels from attribute table.  
2. Interpret % with ICM (Schueler, Fraley-McNeal and Cappiella, pp. 313, 2009). | Does IC decrease over time? Less IC is more desirable. <10% is best.                                                                                                                                                                                                            |
| (Microclimate)             |                                                                         |                                                                                                                                                                                                                                             |                                                                                                                                                                                                                        |
CHAPTER FIVE: APPLICATION

To gain an understanding of the applicability of the framework, the indirect indicators were assessed for the past, present and potential future landscapes of a core area of the University of Guelph main campus, as a case study, to measure change in each landscape component over time and inform greater ecological sensitivity in design. The following illustrates the application to one, fairly uniformly-built portion of main campus contained by Gordon Street, College Avenue, Stone Road and The Arboretum for the early 1980’s, the year 2010 (air photo) and 2011 (satellite image, Landsat TM 4-5), and the projected year 2030 (future master plan illustrated by Urban Strategies Inc.). Figure 1 shows the campus study site and surrounding context within a section of the City of Guelph.

Figure 2: University of Guelph core campus study site: Guelph, Ontario. (Air Photo Ref: Southwestern Ontario Orthoimagery Project, 2010.)
LOCAL CLIMATE ZONES

Stewart and Oke provided a model, Local Climate Zones (LCZs), to measure microclimate in a way that allowed for a more objective classification and comparison between sites (2012). Accordingly, the majority of the University of Guelph site fell into the LCZ 5 open mid-rise category for all three time periods. Buildings were usually between 3 and 9 stories tall, with an abundance of scattered vegetation and pervious cover (Stewart & Oke, 2012). Surface cover properties for each LCZ were also provided and indicated a corresponding impervious cover of 30-50% (Stewart & Oke, 2012). A table of thermal, radiative and metabolic properties indicated a surface admittance of 1,400 – 2,000 (J m$^{-2}$ s$^{-1/2}$ K$^{-1}$), a surface albedo of 0.12 – 0.25 and an anthropogenic heat output of <25 (W m$^{-2}$) (Stewart & Oke, 2012).

IMPERVIOUS COVER MODEL

An improved Impervious Cover Model (ICM), the product of a meta-analysis of 65 impervious cover model studies, was used in combination with tools from ArcGIS 10.1 to determine the level of stress the core campus landscape likely had on surface water in the area (Schueler et al., 2009). Figures 2, 3 and 4 represent a pixel reclassification using the ArcMap Spatial Analyst Iso Cluster Unsupervised Classification tool, followed by a further reclassification using the ArcMap Spatial Analyst Reclass tool to assign the same pixel value to all impervious surfaces. An attempt was made to keep tool settings for each time period as similar as possible; however, they did vary due to air photo availability (see Chapter Six).
Figure 3: Impervious cover in 1981: Air photo and corresponding pixel reclassification illustrating pervious and impervious cover on core campus for the year 1981. Impervious cover = 34.15%. (Air Photo Ref: City of Guelph Dept. of Planning & Development.)
Figure 4: Impervious cover in 2010: Air photo and corresponding pixel reclassification illustrating pervious and impervious cover on core campus for the year 2010. Impervious cover = 37.45%. (Air Photo Ref: South Western Ontario Orthoimagery Project, 2010.)
Figure 5: Impervious cover in 2030: Projected core campus master plan and corresponding pixel reclassification illustrating pervious and impervious cover for the year 2030. Impervious cover = 41.06%. (Projected Master Plan Image Ref: Urban Strategies Inc.)

All three time periods fall within the category of nonsupporting according to the ICM. Streams with this category of watershed “no longer support their designated uses in terms of hydrology, channel stability, habitat, water quality or biological diversity” (Schueler et al., 2009, p. 310). Surface water degradation is detectable where impervious cover falls between 2% and 5% (Schueler et al., 2009). Streams affected by landscapes
with impervious cover less than 10 percent are considered to be sensitive, while greater than 60 percent classifies the streams as urban drainage (Schueler et al., 2009).

NORMALIZED DIFFERENCE VEGETATION INDEX

Normalized Difference Vegetation Index (NDVI) was used to quantify the level of vegetation stress (Fung & Siu, 1999; Pettorelli et al., 2011). NDVI was applied to satellite images captured by the Landsat Thematic Mapper 4 and 5 (TM4 and TM5) of the campus site for the years 1984 and 2011, in mid June. Landsat TM 4-5 captured 7 spectral bands in images of 30x30 meter pixels beginning in the year 1984. Band 3 = wavelength 0.63-0.69 (Red) and Band 4 = 0.78-0.90 (Near Infrared) (Gould, 2000; Markham, Storey, Williams & Irons, 2004). The Spatial Analyst, Raster Calculator tool in ArcMap 10.1 was used to determine NDVI values from bands 3 and 4 for each time period on campus. The same tool settings were used in both cases to understand vegetation health and stress over time. Figures 5 and 6 are illustrations of NDVI results for each time period. Though differences may not be visually apparent between 1984 and 2011, NDVI values per pixel indicate change over time. Values closer to (1) indicate healthier vegetation while values closer to (-1) indicate vegetation under stress (Gould, 2000; Markham et al., 2004). Because NDVI values were already standardized (or normalized), a basic subtraction of past NDVI from present NDVI could be done through the Spatial Analyst, Raster Calculator tool in ArcMap. The following formula was run: (NDVI2011-NDVI1984). Figure 7 illustrates the change in NDVI from year 1984 to 2011.
Figure 6: Past Normalized Difference Vegetation Index for core campus: NDVI, June 13, 1984. Areas approaching 1 appear darker green and indicate higher vegetation health.
Figure 7: Present Normalized Difference Vegetation Index for core campus: NDVI, June 8, 2011. Areas approaching 1 appear darker green and indicate higher vegetation health.
Figure 8: Basic subtraction of NDVI results for 2011 and 1984: shows change in vegetation stress over time. Lightest (beige) areas indicate a value of 0, where no change occurred. Areas approaching the theoretical maximum, 2, appear darker green and indicate an increase in vegetation health. Areas approaching the theoretical minimum, -2, appear darker red and indicate an increase in vegetation stress. Circled pixels illustrate areas of change. (Real high = 1.68528, real low = -1.71598.)
The range of values was narrow so a basic subtraction was considered to be a sufficient analysis. Nevertheless, to evaluate the application of the Raster Calculator tool, an image ratio subtraction was done to understand change as a proportion of original values where changes became equally weighted. In cases with wider ranges of values, this would be more meaningful. The following formula was run: \( ((\text{NDVI2011}+2) - (\text{NDVI1984}+2)) / (\text{NDVI1984}+2) \). To eliminate any divisions by values close to 0.0, which would have yielded incorrect resultant pixel values, +2 was added to each set of values. Figure 8 illustrates the results.

**Figure 8:** Image ratio subtraction of NDVI results for 2011 and 1984: shows change in proportion to original values of vegetation stress over time. Lightest (beige) areas indicate a value of 0, where no change occurred. Areas approaching the theoretical maximum, 2, appear darker green and indicate an increase in vegetation health. Areas approaching the theoretical minimum, -2, appear darker red and indicate an increase in vegetation stress. Circled pixels illustrate areas of change.

**Figure 9:** Image ratio subtraction of NDVI results for 2011 and 1984: shows change in proportion to original values of vegetation stress over time. Lightest (beige) areas indicate a value of 0, where no change occurred. Areas approaching the theoretical maximum, 2, appear darker green and indicate an increase in vegetation health. Areas approaching the theoretical minimum, -2, appear darker red and indicate an increase in vegetation stress. Circled pixels illustrate areas of change.
Change shown through image range subtraction was less visible. For the purposes of this study, the basic subtraction provided clearer visual results and is recommended for narrow ranges, as with NDVI.

According to NDVI, change occurred on the campus study site. A notable decrease in vegetation health was seen within the red circle in both Figures 7 and 8. This was likely due to the construction of a new playing field with artificial turf. An increase in vegetation health occurred near the corner of Stone Road and Gordon Street. Overall changes that did occur on campus from 1984 to 2011 appeared to be negative where vegetation stress increased. Results are uncertain due to several limitations surrounding this model (Chapter Six).

Application of this same method to a future scenario would require visual simulation of vegetation on site using existing Landsat TM 4-5 images as measures. For example, if all vegetation was predicted to be mature, healthy and deciduous, a corresponding Landsat image could be superimposed according to the planting plan on site.

**PATCH SIZE, CONNECTIVITY AND VEGETATION DIVERSITY**

The last three measures, vegetation patch size, level of connectivity of patches and diversity and/or richness of vegetation, can be assessed in different ways. With higher resolution images for NDVI and broader scale sites, patch size and connectivity can be measured using the Spatial Analyst, Generalization, Region Group ArcMap tool. If such NDVI images are unavailable, the same ArcMap tools can be applied to air photos. The tools can be used to reclassify pixels and find area of each unique patch as well as show connectivity between patches. Change over time can be highlighted by pixel
using the same method as for change in NDVI. For this case, patch size and connectivity were not major factors within the study area. Landsat TM images can also be used to determine diversity and/or richness of vegetation due to the bands captured (Pettorelli et al., 2011). Landsat TM 4-5 bands 1-4 can be altered through a standard false colour composite where bands become represented by colour in a way that visually emphasizes vegetation characteristics that would not normally be apparent in real colour. Figures 9 and 10 show a standard false colour composite including the near infrared band. Near infrared was displayed in red, red was displayed in green and green was displayed in blue. Through this composite infrared became visible allowing vegetation type to be assessed.

Figure 10: Past standard false colour composite for core campus: June 13, 1984. Red areas represent vegetation.
In both Figures, differences in types of vegetation depending on infrared reflectance, especially in the arboretum above the study site, were shown. Most notable on site, was the overall increase in vegetation stress or what may have been a decrease in vegetation altogether, reinforcing previous NDVI assessments.

**APPLICATION OF FRAMEWORK RESULTS**

The results from each model of the framework applied to the University of Guelph campus study site were summarized. The site fell into the category of LCZ 5 with a surface admittance of 1,400 – 2,000 (J m$^{-2}$ s$^{-1/2}$ K$^{-1}$), a surface albedo of 0.12 – 0.25 and an anthropogenic heat output of <25 (W m$^{-2}$). Surface water quality, measured by the ICM, was classified as nonsupporting. Results over time suggest a decrease in surface
water quality with an increase in impervious cover: 1981 = 34.15%, 2010 = 37.45% and 2030 = 41.06%. A reduction of impervious cover to 25% would bring surface water quality to the status of impacted behavior. Surface water would, in this case, still show clear signs of poor health. Reducing impervious cover to <10% would classify surface water quality as sensitive. Biodiversity potential in the study site decreased over time, according to measures of NDVI. Vegetation stress increased over time and amount of vegetation likely decreased. Overall, indicators suggested the need for improvement in the design of the core campus study site to decrease negative environmental impacts.

Modifications to the design of the study site were not directly informed by the indicators. Instead design suggestions were guided by the ecopolis development principles. The indicators were measured following the conceptual implementation of logical design adjustments that support the uses of the site. For example, it would not have made sense to simply reduce impervious cover in the landscape. Instead it might have been more logical to increase usable green space for recreation or urban farming, which would in turn reduce impervious cover. However, the principles and indicators, as discussed below, were often difficult to separate. Returning to the first five ecopolis development principles: restore degraded land, fit bioregion, minimize ecological footprint, create compact cities, optimize energy and resource use, the following might be applied to the study site to improve results when being measured by the indicators:

1. To restore degraded land, native or non-native vegetation capable of surviving the site’s urban conditions, including soils, and suitable for improving site biodiversity could be established in a strategic pattern across the landscape. Measured by the framework, this could show an increase in vegetation patch size, decrease in
vegetation stress, and increase in the level of patch connectivity. Thoughtful establishment of vegetation as green infrastructure would likely show as an increase in biodiversity potential, an increase in permeable surface (possibly rain gardens) and a reduction in impervious cover.

2. Fitting the landscape to the bioregion would mean taking cues from the natural landscape. Again this would involve promoting the growth of appropriate vegetation. Vegetation patterns would link to the surrounding landscape to increase connectivity as measured by the framework. Water cycling would become more natural, decreasing impervious cover and increasing surface water quality.

3. The site’s ecological footprint might be minimized by efforts to grow food in the landscape and reduce energy use through the application of microclimatic principles. An increase in the potential for human thermal comfort by reducing undesirable microclimatic characteristics might once again involve the use of green infrastructure, which could provide a place for other species in the landscape.

4. Creating a more compact landscape might mean putting pedestrians first by increasing site walkability and proximity to a variety of amenities. Dealing with the campus site, desire lines might be followed while unused footpaths might be removed. Vehicular use on campus may be reassessed and the need for roadways into the heart of campus may lose importance, save what is necessary for emergency access.

5. Optimizing energy and resource use can be done through similar microclimatic applications. For example, solutions found through the use of vegetation can de-
crease urban heat island effects in appropriate areas, minimizing the requirement for more energy-intensive cooling.

In Chapter six, the discussion of the application of the development principles to the campus site gives a better understanding of the indicators measured. In many cases, the use of green infrastructure seems to play a key role.
CHAPTER SIX: DISCUSSION AND CONCLUSIONS

The LCZs model was used to classify the whole campus site as LCZ 5, open mid-rise. Results from the model relied on human judgment of qualitative data and though the authors, Stewart and Oke (2012), had refined the model, there was still room for error. The thermal, radiative and metabolic values provided by the LCZs model were taken as good estimates. It should be noted that these values can vary depending on soil wetness, material density, surface colour and roughness, latitude, season and population density (Stewart & Oke, 2012). LCZs are generic and rely on homogenous, reduced landscape descriptions but sites can have unique characteristics that do not fit the mold (Stewart & Oke, 2012). One solution may be to break the site down and define each landscape type by its own LCZ. If the landscape were to be broken into smaller landscape types, based on finer scale characteristics, the classification may be different and indicate a new set of potential improvements on site. For example, if Johnston Green, the main green space on campus, was excluded from the study site, the site might be classified as a mix of LCZ 2, compact mid-rise, and LCZ 8, large low-rise, with mostly paved land cover. Surface admittance, surface albedo and anthropogenic heat output change accordingly. The most notable change is in anthropogenic heat output, from LCZ 5 at <25 (W m⁻²), to LCZ 2 at <75 (W m⁻²) and LCZ 8 at <50 (W m⁻²) (Stewart & Oke, 2012).

An understanding of the year-round microclimate on campus was gained but it remained very general. According to Stewart and Oke (2012), corresponding temperature regimes described by the LCZs model can be assigned to any site fitting a particular LCZ description. LCZs rely on averages, therefore nothing more specific about a site’s
microclimate can be estimated, especially in landscapes that experience wide seasonal variation.

The measured percentage of impervious cover (40%) on-site supported the estimated microclimate classification of LCZ 5 (assigned 30-50% IC). For this particular site, the method of simply visually assessing an air photo and knowing the general size of buildings to determine the LCZ seemed to work. It would be interesting to attempt a visual assessment of other sites to see if measured impervious covers matched what was first predicted by the LCZs.

Impervious cover increased over time for the site though it was not determined whether this increase was significant. The ICM itself was easy to follow and provided valuable information about the site’s role as a watershed contributor. While giving a general understanding of site permeability, the finer details were missed. The level of permeability for pervious surfaces could not be assessed. For example a rain garden might have a much higher level of permeability compared to an area of lawn affected by drought. The method for calculating impervious cover prior to interpretation was limited and is further discussed below in the next section.

Biodiversity potential was species dependent but specific species were not defined for the study and only general results could be estimated. The type of native vegetation, patch size and level of connectivity should ideally be tailored to the requirements of the animals in need. For example, connectivity requirements for an insect is likely entirely different than for a small mammal. Evaluating the method for this portion of the framework with certain species in mind would lead to a better understanding of its accessibility.
According to measures of NDVI, biodiversity potential of the study site decreased over time with vegetation stress as the indicator. For example, the basic subtraction showed loss of vegetation in an area of construction on site to build an artificial turf playing field. NDVI evaluation in an urban area might provide information on the health of street and residential trees. Vegetation stress may be observed to be linked to landscape use. For example, areas of vegetation where the soil has been highly compacted may show an increase in stress over time depending on the species growing.

Visualizing the infrared reflectance may have found an increase in vegetation stress on site or a loss of vegetation. This result fits with the basic subtraction results but could also be riddled with error. Image settings varied between 1984 and 2011 to compensate for lack of visual consistency. An overall difference in colour composition between 1984 and 2011 might be explained by limitations surrounding the methodology and technology – bands were displayed with a colour variation between the sites that likely cannot be explained by landscape change alone. Application would be more useful in a broader scale site with more obvious patches of vegetation and same image capture and analysis methods. Patches of specific species can often be identified and the difference between deciduous and coniferous vegetation becomes visible. Results from NDVI for the past and present site can be further explored over a variety of time periods to understand if they make sense with the actual landscape.

TECHNOLOGICAL SOURCES OF ERROR

FAST has other limitations. While there were more accurate methods to assess each indicator in the framework, the focus was on developing a quick and accessible way to measure landscape components over time. Technology became the most obvious
source of error in the application of the framework – as this technology improves, the models will produce results faster and more accurately.

Methods were limited by the quality of air photos used to measure change in impervious cover from past to present. Air photos from the 1980’s were a challenge to find, available in gray scale and of poor resolution. The only one available from the resources used by the study was from 1981. The 2010 air photo, on the other hand, was coloured and at a higher resolution. Methods to reclassify pixels to measure the percentage of impervious cover for both years were kept constant. However, the 1981 photo was, quite literally, too grainy and needed to be blurred before pixel reclassification. Pixel reclassification also relied on colour. This led to overestimation of impervious cover in some areas and underestimation of impervious cover in other areas. In the gray scale photo, shadows on impervious cover appeared as dark as vegetation and were therefore reclassified as pervious cover. In the coloured photo, pervious field cover that appeared the same colour as impervious hardscape was often reclassified as impervious cover. An alternative method may involve higher resolution satellite imagery that captures red and near infrared wavelengths, and uses NDVI as the model to detect and classify landscape components more accurately. Even still, hardscape with a degree of permeability would not be classified as pervious cover and would have to be manually reclassified.

Results from the models used to determine biodiversity potential were subject to several sources of error. Landsat images often showed cloud cover – disrupting NDVI measurements for the area. Images were selected, in part, based on lack of cloud cover. Methods to measure NDVI change over time between 1984 and 2011 were kept constant.
However, as with the issues surrounding the air photos used in this study, the NDVI results were influenced by changing technology. The 1984 satellite image was captured by Landsat TM 4 while the 2011 satellite image was captured by Landsat TM 5. The difference between images may be most apparent in the standard false colour composites where visual assessment of each image was affected. 30 x 30 meter pixels became another source of error when dealing with a site of finer scale. Each 30 x 30 meter pixel was an average representation of higher resolution details. Landscape components smaller than one pixel, such as a narrow footpath, visually disappeared once pixels were averaged, so a detailed assessment of the site became a challenge. Using current technology, these methods are better suited for broader scale sites and coarser assessments. As Landsat improves image resolution, this issue will likely be resolved.

While recognizing the listed sources of error, conclusions were made based on the application and discussion of the framework. The general, conceptual application of ecopolis development principles to the campus often involved the enhancement of native green infrastructure. Doing so could have improved biodiversity potential, indirectly decreased impervious cover and provided the opportunity to alter site microclimate to increase human thermal comfort. It is possible that a focus on green infrastructure might lead to a simplification of the framework where other indicators may become obsolete. FAST has the potential to become a useful tool for design professionals to assess sustainability in a more holistic way prior to the build phase of a landscape project.

**FUTURE IMPLICATIONS**

The development of FAST was a beginning for building a framework based on remote sensing to assess the change of multiple landscape components affected by design
over time. The applicability of FAST can be better understood the more it is used. This study tested change from one specific time of year in the early 1980’s, to one specific time of year in the present, to one potential future. What might the results from each model show about the same landscape over shorter intervals of time, from season to season, from times of drought to times of heavy precipitation, or from past to vastly different future scenarios? The framework can remain a quick and accessible assessment while also being further developed with updated technology and better methods – whether they lead to more accurate results and/or simply increase efficiency of the framework. Remote sensing allows for easier synchronized evaluation of broad sites and insight into wider landscape patterns all at once and over time, compared to ground measurements. This is not to say that remote sensing should replace a detailed site analysis on the ground; rather, it can contribute valuable knowledge that may otherwise be overlooked. As shown through this study, finer-scale site analyses can benefit as well, and results will improve in detail with higher resolution technology. As urban areas continue to expand, more environmental challenges will be encountered. The impact urban development will have on ecological systems can be monitored in a more consistent way. When it comes to resilience, more warning systems can be derived from landscape indicators and remote sensing, such as those used in this study, to identify when rapid development may push a stable ecological system to its threshold and when a regime shift may occur. Stress on ecosystems from natural disasters and climate change, such as drought and pest species outbreaks, can be detected in real time and can also be predicted using simulated images compatible with the models in FAST.
A framework like FAST can be used to learn from a landscape’s past to present, and can become a common and useful tool to assist professionals in evidence based design. FAST can allow for landscape design concepts to be efficiently tested for ecological potential before the build phase of a project to minimize associated risk or cost.

Using campus landscapes as the testing grounds for landscape design with a focus in urban ecology will increase the ecological sensitivity of the campus while promoting social and economic potential. As institutions that practice what they teach, universities and colleges can begin to lead by example and influence user awareness in a demographic that will expand its knowledge beyond the educational setting. Another design challenge lies in how lessons of resilience can be communicated to users. Since campuses are often microcosms of their cities in environmental and social pattern, successful designs as measured by frameworks like FAST may be broadened and locally extended to build more resilient and regenerative landscapes.
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