Ecosystem-based Design:

Addressing the loss of biodiversity and nature experience through architecture and ecology

by

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Abstract

This thesis is based on two observations. First, that conventional buildings cause two major losses that involve non-human nature – the loss of native biodiversity and the loss of non-human nature experience for the buildings' human inhabitants – and that these losses both contribute to a perceived separation between humans and the rest of nature. Second, that there appears to be a growing interest in connecting buildings with nature but there is little agreement on what it actually means to 'design with nature'. As such, the purpose of this study is two-fold: (1) to describe the meaning of 'designing with nature' in current architectural practice and provide a working definition of nature-based design, and (2) to explore how this can be interpreted to encourage human connectedness with non-human nature, while addressing the two major losses mentioned above. It is thus an attempt to reframe the role of building as one that provides for all inhabitants of a site, both human and non. A framework was developed that captures and summarizes the dominant ways in which design draws on nature. The framework emphasizes the importance of using ecosystems not only as models, but foremost as context. The core concepts of the framework can thus be discussed from the perspective of buildings that *act like* an ecosystem and that *interact with* their ecosystem, and are described as: ecological sense of place, regenerative ability, ecosystem health, mutually beneficial relationships, context, appropriate management, functions, ecosystem principles, values, patterns, conditions, and adaptations. Although the concepts presented in the framework are themselves not new, the way in which they are organized does contribute a new perspective on the field of nature-based design. In addition to providing a graphic model that summarizes the essence of an evolving field, the research highlights the role of scale and place in linking building design, native biodiversity, nature experience and connectedness with nature. It thus acts as a backdrop on which to bring a discussion of ecological citizenship into the architectural dialogue.

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Acknowledgements

This thesis represents a several-year long exploration that I don't think could have played out any way other than how it did. In hindsight it was a natural progression that led me to figure out just what it was that thrilled me about architecture, as well as what terrified me.

During the first month of working on this thesis, I was asked whether my point of departure for my study was architecture or nature. A simple yet crucial question. I thank my student colleagues for shedding light on the importance of that distinction.

I wish to send a big thank you! to the many people who helped me keep my enthusiasm one step ahead of my frustration:

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Chapter 1

Introduction

Building on the human-nature relationship

You don't have to be very wise or very perceptive to see what a mess we've made of our beautiful earth. We can tell from our man-made environment, sometimes at a single glance, whether we're getting deeper into or climbing out of trouble.

Malcolm Wells (1981:ix)

1.1 Background

1.1.1 The human-nature paradigm shift

We are nature.

What at first glance appears to be a simple and obvious revelation, this statement reflects a deeper insight into the human condition. “One of the fundamental issues [throughout human history has been] the relationship between humans and the rest of nature. Are humans an integral part of nature or are they separate from it and in some way superior to it?” (Ponting 1992:141). This fundamental way in which humans view the world and their place in it has acted as the philosophical basis upon which human actions have been justified (Ponting 1992). The majority of these actions, however justified, have indeed enabled a differentiation between humans and the rest of nature, though not for reasons of superiority. Ponting describes this difference in his book *A Green History of the World*:

> In their relationship to the ecosystem, two factors distinguish humans from all other animals. First, they are the only species capable of endangering and even destroying the ecosystems on which they depend for their existence. Second, humans are the only species to have spread into every terrestrial ecosystem and then, through the use of technology, to have dominated them (Ponting 1992:17).

Beliefs regarding the relationship between humans and the rest of nature vary among religions and traditions (Capra 1996, DuPlessis 2006). In Western society, however, the dominant paradigm since the Enlightenment has been a mechanistic or reductionist one, where humans are separate from and ‘masters’ of nature, and where nature is understood by studying its individual parts rather than looking at the whole (Capra 1996, Rees 1999). It is argued that in recent decades, the paradigm has begun to shift to an ecological one where humans are seen not only as an integral part of nature, but where nature is understood as being a whole system, whose components are ever-changing and interconnected (Capra 1996, Rees 1999, Dunlap et al.

2000). Hence at the core of the ecological paradigm is the recurring theme of connectedness – both between humans and the rest of nature, as well as among every aspect of nature. Many argue that long-term sustainability will require that this paradigm shift toward connectedness be widespread and present throughout all aspects of daily life (e.g. Capra 1996, Kals et al. 1999, Dunlap et al. 2000, Gouveia 2002, Schultz & Zelezny 2003, Kellert 2005).

1.1.2 Urban development, biodiversity loss & the decline of nature experiences

As Ponting (1992) points out, during ninety-nine percent of human history, humans have lived a nomadic hunter-gatherer lifestyle. This lifestyle, he argues, is "without doubt the most successful and flexible way of life adopted by humans and the one that caused the least damage to natural ecosystems" (Ponting 1992:18). As populations grew, however, and the nomadic lifestyle shifted to one of agriculture and permanent settlements, it became increasingly necessary to exert control over nature in order to yield greater quantities of food, the result of which was an expanding disruption of the natural cycles of ecosystems.

Even though the practice of agriculture and the rise of settled societies brought about major changes to ecosystems worldwide, they still necessitated an awareness of and connection to local sources of materials and energy. With what Ponting (1992:267) calls the "second great transition in human history", the industrial revolution (agriculture being the first), came an increased sphere of human influence at a global scale. The shift from renewable to non-renewable sources of energy – fossil fuels – provided a more easily stored, distributed, and readily available energy source. People were therefore no longer reliant on local resources and became increasingly distanced from the processes of the non-human natural world, thereby fueling the worldview of humans as separate from nature.

The industrial revolution also triggered the widespread movement of people into cities, causing two types of major losses. The first loss is that of native habitat and biodiversity. According to several studies (Vitousek et al. 1997, Sanderson et al. 2002, MEA 2005), all of the earth's ecosystems have been dramatically transformed by human actions (figure 1.1). Urbanization and building construction continue to endanger more species than any other human activity (Czech et al. 2000) by displacing native plant and animal species, introducing non-native species to an area, and by altering biogeochemical cycles at both the local and global scales (McKinney 2006).

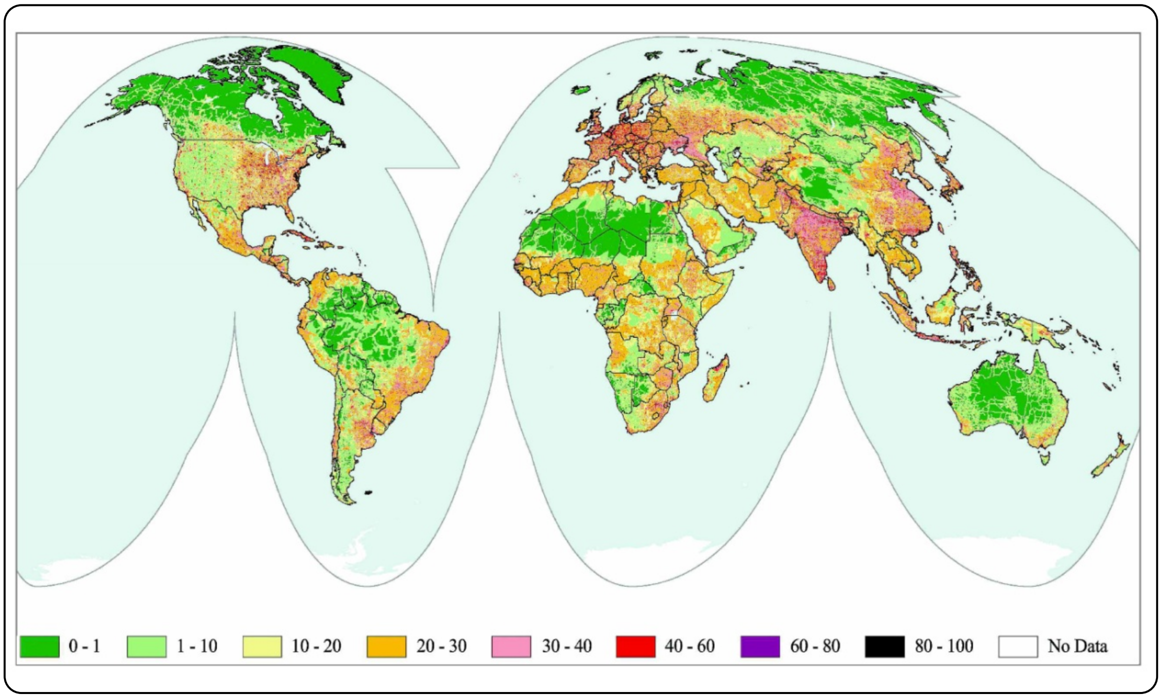


Figure 1.1. The human footprint – the amount of human influence, expressed as a percentage, on the land surface in every biome (from Sanderson et al. 2002).

The second loss brought on by urbanization is that of everyday direct experiences of nature. The built environment tends to displace plants and animals and diminish local ecological processes, distancing people both physically and psychologically from non-human members of their ecological community. This lack of interaction with nature has been described as the "extinction of experience" (Pyle 2003) or "nature-deficit disorder" (Louv 2005) and has been shown to be a major contributor to the apathetic, disconnected, ecologically illiterate state that is fueling today's unsustainable lifestyles (Pyle 2003, Schultz et al. 2004). The fact that North Americans are "more often taught to identify types of cars than types of birds" and that most can identify "one thousand corporate logos but less than ten native plants" are prime examples of this illiteracy (Hawken 1993:214). Despite this unfamiliarity with non-human nature, it is argued that the need for engagement and interaction with it is inherent in all humans, as described by the notion of "biophilia" (Wilson 1984, Kahn 1999, Kellert 2005). Most westerners spend over ninety percent of their lives in buildings (Evans & McCoy 1998) and two-thirds of that time in their homes (Farrow et al. 1997). The places where people live and work therefore hold considerable potential in offering "opportunities for meaningful interactions with the natural world" (Miller 2005: 430).

1.1.3 Limitations of 'green' design

In recent years, the proliferation of environmental anomalies has created a sense of public and increasingly political urgency. The paradigm of machine, dominance and unrestrained exploitation has, out of necessity, slowly shifted to one of conservation and managed exploitation (Dunlap et al. 2000). This shift towards conservation and mitigation is reflected in the growing interest in environmentally conscious building design and in the growing number of high performance buildings constructed and certified using assessment tools such as the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™.

Although tools such as LEED™ have done much for raising awareness of the effects of buildings on the natural environment among the general public in North America, they currently make it possible to design 'green' buildings without understanding, responding to, or incorporating native ecosystems, their biodiversity and their processes (Kibert et al. 2002a). Their categories and credits primarily focus on the effects that buildings have on non-human nature in terms of resource use and emissions. Although two of the Sustainable Sites credits of LEED™ (credits 1

(Site Selection) and 5 (Reduced Site Disturbance)) address the issue of displacement of plant and animal habitat by development, there is little to no mention of the importance of native species, nor the potential for reestablishing their habitat within the building footprint, let alone the consequences this may have on the human-nature connection. By showing little more appreciation for or engagement of their native ecosystems than their non-green counterparts, 'green buildings' are thus limited in their ability to nurture the human-nature connection and a widespread change in worldview.

1.1.4 Towards a nature-based design

In view of the shortcomings of 'green' design as represented by tools such as LEED™, there appears to be a growing recognition of the need to move beyond environmental mitigation and high performance building towards design that connects buildings and their users with some form of non-human nature. Examples of this interest in integrating buildings and nature can be found in industry developments such as the Living Building Challenge developed by the Cascadia Region Green Building Council. The Living Building Challenge is offered as an extension of rather than an alternative to LEED™ that uses prerequisites rather than credits to encourage buildings to be designed to "operate as elegantly and efficiently as a flower" (CRGBC 2008) (figure 1.2). Interest in connecting buildings with nature has even arisen within the public mainstream through recent condominium slogans (figure 1.3). The degree to which these examples are justified for claiming non-human natural properties, however, is questionable.

So, what, then does it mean to design buildings with nature?

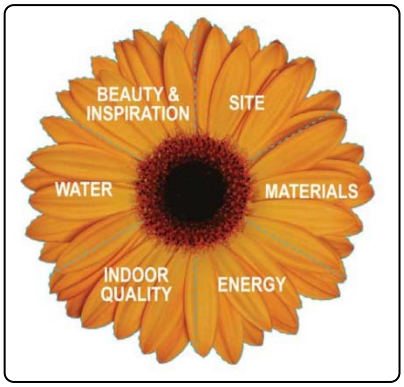


Figure 1.2. The ‘petals’ of the Living Building Challenge (CRGBC 2008).

Figure 1.3. Examples of advertisements for condominiums in Metro Vancouver claiming ‘natural’ qualities of their design: (a) Coast by Bastion Development Corporation (photo – author, logo - www.bastiondevelopment.com); (b) Jameson House by Jameson Development Corp. (www.jamesoncorp.ca).

A brief review of the architectural literature suggests that there is a range of ways in which nature has been drawn upon to inform building design (e.g. Lyle 1994, Van der Ryn & Cowan 1996, Benyus 2002, McDonough & Braungart 2002, Kibert et al. 2002a, Graham 2003, Kellert 2005, Kellert et al. 2008). This range appears to be quite vast, suggesting that there is little agreement on what it in fact means to design with nature. This inconsistency also makes it difficult to appreciate how the field of nature-based design is evolving and where one’s own philosophy fits within it. A model that identifies dominant themes among the various approaches and suggests a set of core concepts would thus be particularly valuable in the initiation of a discussion on the role of nature in building design. To date, no such model has been developed nor has a comprehensive study been conducted that clarifies the meaning of designing buildings with nature.

Furthermore, the concepts of native biodiversity and nature experience do emerge in the literature, however they are predominantly found in relation to design of the landscape surrounding a building, rather than in relation to the building itself. Since buildings are typically the root of the problem in these two areas, then perhaps they also represent the best potential source for solutions. The current literature appears to suggest otherwise, however, by overlooking the potential for buildings to play a role in bringing native biodiversity back to their site and into the daily lives of their users. There is also little mention of how this may influence the sense of connection that building users feel towards non-human nature. As such, this is an indication that there is considerable room for discussion of what might otherwise remain a missed opportunity.

1.2 Objectives & Thesis Questions

This thesis is based on two observations. First, that conventional buildings cause two major losses that involve non-human nature – the loss of native biodiversity and the loss of nature experience - and that these losses both contribute to a perceived separation between humans and the rest of nature. Second, that there appears to be a growing interest in connecting buildings with nature but there is currently little agreement on what it actually means to 'design with nature'. As such, there are two major objectives to this thesis, each with their own subsidiary objectives and associated research questions.

The first major objective is to:

- Describe the meaning of 'designing with nature' in current architectural practice.

Subsidiary objectives are to:

- Provide a review of the multitude of architectural approaches that draw on nature to inform building design.
- Provide a working definition of nature-based design and express this in the form of a graphic model.

In order to address these objectives, the following research questions were asked:

- In what ways do current approaches to design draw on nature?
- Despite seemingly different focuses, are the approaches really that different? Is there overlap of their common threads?
- Are core ecological concepts reflected in the design approaches?
- If so, could this be the core of a nature-based design?
- Are the core concepts mutually exclusive ideas or are they inherently linked?

- Can this linkage be clearly and concisely represented?

Because non-human nature is at the heart of the two losses caused by conventional building design and construction practices, one might assume that ‘designing with nature’ would necessarily address those losses, and thus also address the fundamental goal of enhancing human connectedness with non-human nature. But does it?

The second major objective of this study is therefore to:

- Explore how this newly defined nature-based design can be interpreted to encourage human connectedness with non-human nature, while addressing the two major losses caused by conventional building – the loss of native biodiversity and the loss of nature experience.

Subsidiary objectives are to:

- Explore the link between creating habitat for native biodiversity, providing opportunity to experience this biodiversity, and the fundamental goal of enhancing human connectedness with non-human nature.

- Suggest that, when approached through the lens of the ecosystem framework and its core concepts, buildings can play a leading role in enhancing this connectedness and reducing the perceived separation between human and non-human nature.

These objectives were addressed by the following research questions:

- How are native biodiversity, nature experience and connectedness with nature linked?
- Can buildings and the proposed framework be useful in describing this link?

1.3 Scope

Based on the research objectives outlined in the previous section, there are four main components to this thesis:

- *Chapter two* discusses some of the more prominent approaches to environmentally conscientious building design and investigates the ways in which they draw on nature. The underlying principles of various lines of ecological theory are also discussed, helping set the stage for the development of a model that places native ecosystems at the centre rather than at the margins of the design process.

- *Chapter three* summarizes dominant themes and suggests possible core concepts of nature-based design. Results are presented in the form of a framework that merges ecological with building design theory, suggesting key elements that contribute to a solution for both the loss of native biodiversity and the loss of nature experience. The framework is described both as a relational model and as a process to guide design.

- *Chapters four and five* discuss each element of the framework in greater detail. *Chapter four* describes the variables first in general terms, and then also for how the variables of an ecosystem-based design process provide different design parameters than those of conventional buildings. *Chapter five* describes each cornerstone and method, first in general terms and then for how they can inform design by either using ecosystems as context or as model. The way in which the variables inform the methods is also discussed here and case studies are given to illustrate applied examples.

- *Chapter six* then explores the hierarchical relationships between all of the concepts, particularly how the methods are influenced from below by the variables and from above by the cornerstones to inform the design of buildings that create habitat for native biodiversity and provide opportunities to experience this biodiversity, and ultimately contribute to a greater connectedness with non-human nature. Any constants or recurring themes between the methods are also highlighted.

This study is intended to be conceptual rather than one that offers specific application. Although possibilities for application are discussed, and strategies are suggested, they intentionally do not culminate into fully-fleshed out designs. The intention was to use the conceptual design suggestions to provide evidence of their possibility and hopefully, to capture the imagination of designers and inspire other opportunities for design and future research.

1.4 Methodology

The process of inquiry undertaken in this qualitative research was two-fold. The data collected and interpreted to address the first objective (to describe the meaning of ‘designing with nature’ in architectural theory) was then used to inform the line of questioning for the second objective (to explore how nature-based design can be interpreted to encourage human connectedness with non-human nature, while addressing the two major losses caused by conventional building). The first line of inquiry employed descriptive research methods while the second was more exploratory in nature.

In the first case, standard keyword search techniques were employed to identify prominent approaches to architectural design that draw on elements of nature. Using combinations of terms that included ‘design’, ‘buildings’, ‘architecture’, ‘nature’, ‘ecology’, ‘environment’, ‘ecosystem’, ‘connection’, ‘integrated’, etc., eight dominant approaches emerged from the review. These approaches were green design, ecological design, biophilic design, biomimicry, industrial, construction and building ecology, and regenerative design. Although the review is believed to be comprehensive, it is recognized that other approaches exist. These were not included in this study as they did not appear to permeate the literature to the degree of those that were selected for exploration.

A content analysis of the eight design approaches was then undertaken to draw out their key underlying principles and concepts. In order to provide an ecological perspective, various lines of ecosystem ecology theory were also investigated, particularly those of human, landscape, urban and restoration ecology.

A relational analysis was then carried out on two levels: to identify (1) how the design and ecological approaches relate to each other (despite seemingly different focuses, are they really that different? Is there overlap of their common threads? If so, could this be the core of a nature-based design?); and (2) how the concepts themselves that are in common between approaches relate to each other (Are they mutually exclusive ideas or are they inherently linked? Can this linkage be clearly and concisely represented?). The relationships identified resulted in a model that summarizes the interrelated nature of the core concepts of a nature-based design approach. The inherent interconnectedness between the concepts allows for a number of possible combinations. Consequently, although the elements are arranged in what is believed to be the most effective representation, it is recognized that the resulting framework is just one of several possible outcomes.

The second major objective, that of exploring the potential for nature-based design to address the two major losses caused by conventional building, as well as its subsidiary objectives, were addressed using discursive logical argumentation.

1.5 Terminology

Several concepts that are key to this thesis are defined here:

- **Human and non-human nature**

  This thesis emphasizes the fact that humans are just one of many animal species that make up the biotic components of ecosystems, and therefore the distinction cannot be made between humans and nature because we are elements of nature. The distinction is therefore rather made between human-derived elements of nature (e.g. buildings, roads, urban infrastructure, social institutions, etc.) and non-human elements of nature (e.g. vegetation, non-human animals, solar radiation, etc). This thesis recognizes that although an element may not have been constructed by humans, for example water droplets in clouds, their distribution and role in ecosystem processes may be profoundly influenced by human actions. For the purpose of this thesis however, such elements will be referred to as non-human unless the aim is to draw attention to the role humans have had in influencing the element in question.

- **Connectedness to nature**

  In this thesis, connectedness to nature is used to refer to three types of connection with non-human nature: (1) a psychological connection, which can be influenced by (2) a symbolic connection and/or (3) a physical connection.

  The psychological connection of people with non-human nature refers to a person's implicit belief that "s/he is just as much a part of nature as are other animals (Schultz et al. 2004:32). It is the understanding that humans and nature are part of the same community, a greater ecological community (Leopold 1949, Dutcher et al. 2007). This concept is also referred to in some literature as 'ecological identity' (Schultz et al. 2004). As Pyle (2003:206) points out, this "strong individual sense of connection to nature and natural processes is utterly essential to the healthy coexistence of humans with their biological neighbours and physical setting" (Pyle 2003:206). This psychological connection can be the result of a symbolic connection through vicarious experience and/or a physical connection through direct experience, as discussed further in chapter three.

Throughout this thesis, these connections are also referred to as *re*-connections or *re*-integrations. As described in previous sections, the separation of humans from nature occurred at some point in relatively recent history. Therefore when cultivating a connectedness with nature, it is really a reconciliation or re-connection. The term re-integrate or re-integration is used interchangeably with re-connection although integration does imply a deeper sense of unification to form a whole.

- **Ecological literacy**

If 'literacy' is the ability to read, then ecological literacy or 'ecoliteracy' is the ability to "understand the language of nature" (Capra 2005:19). It is the ability to see, interpret and understand the interconnectedness of organisms and ecological systems (Orr 1992). Ecoliteracy requires not only ecological knowledge or education, but also a sense of connectedness and experience with non-human nature (Berkowitz et al. 2005).

- **Ecological citizenship**

Ecological citizenship is the recognition that as an inhabitant of the earth and its ecosystems, we as humans have both rights and responsibilities when it comes to other members of the biotic community (Sutton 2007). It too requires a sense of connection with and care for non-human nature and involves putting that care and literacy into action. It is the ultimate goal of environmental education and ecological literacy (Berkowitz et al. 2005) and is a driver of pro-environmental behaviour, an example of which is the decision to purchase, construct, and/or use environmentally conscientious products, which include buildings (Stern 2000).

- **Environmentally conscious building design**

In the context of this thesis, this is used as an umbrella term for any approach to building design that displays concern and solutions for environmental issues. Existing approaches to such design are driven in various degrees by performance-based (e.g. efficiency, conservation) and nature-based (e.g. cycles, ecosystems, functions) principles. Examples include green design, ecological design and biomimetic design. The term ‘sustainable’ design, although commonly used in practice, is not used in this thesis. ‘Sustainable’ design embraces a broader range of issues, e.g. social and economic, whereas this thesis is predominantly focused on the ecological aspects of sustainability.

- **Nature-based design**

This thesis describes nature-based design as that which uses some aspect of non-human nature as a point of reference. The concept of an ‘ecosystem’ is that which is most often drawn upon, as both a model and context for design. Nature-based design is described in further detail in chapter three.

- **Local ecosystem**

A building or person's local ecosystem consists of the living organisms and non-living abiotic environment that exist within their site, whether at the scale of a property, a neighbourhood, or an entire region. Depending on the amount and type of development, one's current local ecosystem may be quite different from its native ecosystem.

- **Native ecosystem**

A native ecosystem refers to the communities of plants, animals and abiotic elements that existed on a site prior to development. A local ecosystem can therefore be considered native if such biotic and abiotic elements still exist as a connected functional unit.

Native (or indigenous) plants and animals are those that occur naturally in a specific geographic area, which in North America are those that existed there prior to European settlement. Biodiversity that is not of local origin is considered *exotic, introduced, or non-native*. If non-native species decrease native biodiversity they are considered to be *invasive*.

The abiotic features that are native to a site are those non-living features that existed there prior to development and that native flora and fauna depend on for habitat. These include temperature, light, wind and moisture levels, landform, soil composition, and nutrients.

- **Ecological restoration**

As discussed earlier in this chapter, “ecological restoration is necessary because the relationship between human society and [non-human] natural systems is not as mutualistic as it should be” (Perrow & Davy 2002:xiii). In most urban situations, native biodiversity and the habitat on which they depend have been dramatically reduced by replacement with human habitat. Ecological restoration therefore refers to the assisted recovery of an ecosystem, either in whole or in part, that has been degraded, damaged, or destroyed (SER 2004, Apostol 2006).

To ‘restore’ is to return something to a previous state. The state that restoration ecologists consider appropriate is that which reflects the structure and composition of an ecosystem’s historic trajectory at the point just before it suffered a radical change (SER 2004). It is widely recognized however, that although no restoration will exactly recover its former state due to the dynamic nature of ecosystems and constantly changing constraints and conditions, the general trajectory and composition can be sought (Clewell 2000, Higgs 2003, SER 2004).

In this thesis, the term restoration is used somewhat loosely as using ‘restoration’ in its true sense would negate the use of buildings. However, by incorporating growing space into a building, for example, it may be possible to at least in part give back the land it displaces to the plant and animal species native to its site while still supporting its human users. This thesis therefore attempts to change the way in which the act of building on a site is viewed, using restoration as the means by which a building can become physically connected and re-integrated with its native ecosystem.

Chapter 2

Theoretical Background
Ecology in design & research

The nice thing about using ecology as a model is the concept of all kinds of strange things that technologists don't think about: pulses, day and night, seasons, cold and warm. How do you design these things in so that they dance with each other?

John Todd (Zelov 1995)

2.1 Design and Nature

This section will address the objective of *providing a review of the multitude of architectural approaches that draw on nature to inform building design.*

The characterization of the relationship between architectural design and non-human nature has a long and varied history. The following summaries represent some of the more prominent current approaches in which nature has been drawn upon and interpreted to inform the design of the human built environment. The philosophies behind these approaches offer valuable insight into the complexities of nature and nature-based design and each, to various degrees, help shape the proposed framework described in chapter three.

2.1.1 Green design

The relationship between green design and nature is typically one of conservation. As is evidenced by the performance categories of most current assessment tools (e.g. Leadership in Energy and Environmental Design (LEED™) in North America; Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan; and the Building Research Establishment Environmental Assessment Method, (BREEAM) in the U.K.), the focus remains on resource efficiency and environmental mitigation rather than enhancement (Eisenberg & Reed 2003, Kellert 2005). As represented by current assessment methods, green design can be considered an umbrella term for performance-based environmentally conscious building design. Although BREEAM doesn't go so far as to promote buildings as integrated members of natural ecosystems, its Ecohomes credit Eco4 (Change of Ecological Value of Site) begins to address ecological value and the sharing of habitat by assessing the change in the number of species supported on site.

To their credit, current assessment methods have played a large role in mainstreaming environmentally conscious design strategies that promote resource conservation and energy efficiency, an initial awareness without which any further progress may not have been possible. This basic awareness, along with the mainstreaming of design strategies and increasing market acceptance, are perhaps green design's greatest contributions to the building industry. Some of the greatest hindrances of current assessment methods and their impact on green building practice, however, are 1) the lack of embodiment of the notion of humans as nature, and 2) their linear, non systems-like approach. Also, the standards of conservation, efficiency and mitigation that characterize this approach limit its ability to have anything more than a neutral impact on the earth's ecosystems.

2.1.2 Ecological design

Like green building, ecological design has developed into somewhat of an umbrella term for environmentally conscious building design, but represents more the nature-based end of the spectrum. The major distinction is that here the focus is shared between the non-human and the human-built environment. Whereas green building practice currently casts humans as an outside force degrading "the environment", emphasizing mitigation and being "less bad", ecological design was one of the first approaches to view a building and its site no longer as separate entities, but rather as a comprehensive whole in which the human and non-human inform each other (Van der Ryn & Cowan 1996, Orr 2002). Ecological design can be considered as "any form of design that minimizes environmentally destructive impacts by integrating itself with living processes" (Van der Ryn & Cowan 1996:18).

The theoretical foundation of ecological design is a human-nature partnership and Van der Ryn and Cowan (1996) list conservation, regeneration and stewardship as key strategies of achieving this partnership. They also emphasize the importance of making nature visible as a way of cultivating this relationship on a personal level. Orr (2002) further describes the standard of ecological design as ‘health’ of soils, plants and animals, including humans, or as Yeang (1995) describes it, that of both the biotic and abiotic components of ecosystems. The limitation of the philosophy behind this approach, however is that although it begins to recognize humans and their activities as members of an ecosystem, it remains focused on minimizing adverse effects to the ecosystem. It values ecosystems for their ability to continually provide humans with services (Van der Ryn 2005), hence maintaining much of the impetus on benefits to humans rather than to all species. The key concepts that this approach emphasizes are therefore a human-nature partnership, stewardship, systems thinking, natural experience, context, conservation, regeneration, and health.

2.1.3 Biophilic design

Whereas green and ecological design concentrate on the human dependence on natural processes for physical and material support, biophilic design draws attention to the inherent need for interaction with natural elements for emotional and spiritual well-being. Biologist and evolutionary theorist E. O. Wilson defines biophilia, the theory behind biophilic design, as the “innate tendency to focus on life and lifelike processes” (Wilson 1984:1). He, along with others (Kahn 1999, Kaplan & Kaplan 1989, Heerwagen 1993, Kellert 2005) argues that the affinity for and need to affiliate with life is inherent in all humans and evolved through millennia of taking cues as to conditions and resources that promote survival and reproductive success. Orr (2002:25) describes how we, as humans “fit better in environments that have more, not less [non-human] nature. We do better with sunlight, contact with animals, and in settings that include trees, flowers, flowing water, birds, and natural processes than in their absence”. To provide humans today with such cues and conditions is the basis of biophilic design.

Kellert (2005:5) describes biophilic design as consisting of two basic dimensions: organic (or naturalistic) design and vernacular (or place-based) design. Organic design, or what Heerwagen (2003) terms “bio-inspired” design, emulates or evokes conditions found in nature such as forms and features of natural elements like water, trees, and flowers, spatial characteristics such as open views and the prospect of refuge, and sensory qualities such as light and colour (Heerwagen 2003, Heerwagen & Gregory 2008, Kellert 2005). Vernacular design on the other hand provides a connection to place through an understanding of its culture, history and ecology (Kellert 2005). These two dimensions of biophilic design have been argued to have two major types of benefits, the first being that biophilic features tend to encourage productivity, emotional well-being, learning, and healing in humans (Wilson 2006). The second benefit, less promoted in the design industry but no less important, is that such features can also foster an interest in and appreciation for nature. The key concepts emphasized by this approach are those of organic form, experience and place.

2.1.4 Biomimicry

Biomimicry is most conventionally referred to as a science that studies nature’s processes and then attempts to take inspiration from these to design human technologies (Benyus 2002). The term was popularized by Janine Benyus in her book *Biomimicry: Innovation Inspired by Nature* (2002). Central to the approach is 1) gaining an understanding of nature’s processes and 2) drawing inspiration from them rather than a literal imitation.

Apart from being one of the first approaches to look deeper into the functioning of ecosystems, biomimicry offers two major contributions to the nature-based design movement.

First, as developed by the Biomimicry Guild (2006), it offers a step-by-step design methodology on how to learn from and design as nature does. It provides even those with little ecological knowledge an idea of where to begin when looking to learn how nature can inform design. Using this methodology, the biomimetic design process can be approached from two perspectives: 1) identifying something about nature and investigating how it can be applied to design (biology to design); 2) identifying the design challenge and investigating how the similar challenge is resolved in nature (design to biology). The Biomimicry Guild (2006) proposes that both processes can be considered from three perspectives: mimicking 1) form, 2) process, or 3) ecosystem. Pedersen Zari (2007), on the other hand, suggests that the three elements of 1) organism, 2) behaviour, and 3) ecosystem, which can then each be described in terms of form, material, construction, process, and function, are more inclusive of all the possible qualities of non-human nature that can be mimicked at the various scales and therefore represent a more comprehensive model. Common to both classifications, however is the importance of the concept of the ecosystem.

Second, biomimicry has contributed a comprehensive set of ecosystem principles that, over the years, have been organized into a conceptual framework that describes how ecosystems work by the way they evolve and the way in which resources are shared between organisms. Such principles are key to an ecosystem-based approach given that consideration of the whole system is inherent in each of the principles. Although the concepts of relationships and systems thinking appear central to the biomimetic philosophy, ecosystem level mimicry has yet to be meaningfully explored at the building scale. Nevertheless, the concepts that biomimicry draws attention to in theory are those of principles, processes, functions, form, conditions, adaptations, relationships, and ecosystems.

2.1.5 Industrial, construction and building ecology

Although many definitions exist of industrial ecology, it’s foundation is commonly accepted as the energy and material effective cycles of nature (Garner & Keoleian 1995, Erkman 1997, Ayres

2002, Lifset & Graedel 2002, Tilley 2003). Industrial ecology focuses on connecting product design and manufacturing processes in a manner that cycles energy and material effectively, emulating a natural ecosystem. Inherent in this metaphor and therefore key to the approach is the rejection of the concept of *waste* (Graedel & Allenby 1995, Kibert et al. 2000, Kibert et al. 2002b, McDonough & Braungart 2002). McDonough & Braungart (2002) popularized the term "waste equals food" to describe how the concept of waste does not exist in non-human nature because one organism's waste is food for another, i.e. all products should be seen as nutrients whether they are within biological or industrial systems (McDonough & Braungart 2002).

Both construction and building ecology can be considered subsets of industrial ecology, however their design principles were developed to be more specific to the building and construction industry (Kibert et al. 2000). Kibert et al. (2002b) define construction ecology as the development and maintenance of a built environment with a materials system (1) that functions in a closed loop and is integrated with eco-industrial and natural systems, (2) that depends solely on renewable energy sources and (3) that fosters preservation of natural system functions. Graham (2003) offers a more concise, yet no less complex definition of building ecology as the study of the interdependencies of building and nature.

The fields of industrial, construction and building ecology have been particularly key in helping advance the theory and application of both the systems perspective and the biological analogy, i.e. the 'ecosystem metaphor', in relation to human activities. More recent advances in industrial ecology are investigating deepening the ecological foundation of the approach to better encapsulate the complexities of ecosystems, with particular respect to energy and the way its flow through a system induces dynamic non-equilibrium, self-organization and adaptation (Kay et al. 1999, Kay 2002, Spiegelman 2003). In keeping with the more recognized description however, its key contributions to nature-based design are the concepts of conservation, efficiency, effectiveness, functions, cycles, and systems.

2.1.6 Regenerative design

Although it can be appreciated that preservation and conservation are valuable initial measures, they do not address the fundamental issue of humans as co-natural members of an ecosystem. Regenerative design accounts for the potential for humans, through their activities and artifacts, to encourage the evolution of healthy ecosystems. It regards the "self-organizing and self-healing properties of living systems", along with the natural and cultural characteristics of that system's 'place' as the drivers of design (Eisenberg & Reed 2003:2). In this sense it can be seen as complimentary to biophilic design in that regenerative design merges the science of place and the science of natural systems (Reed 2007). Moreover, like biomimicry, it delves deeper into the complexities of living systems. Regenerative design also implies continual human and community involvement beyond initial restoration efforts. It gives rise to communities whose "life support systems are integral parts of the local landscape" (Lyle 1994:266).

Central to the application of regenerative design is the notion of 'regeneration', implying renewal, resilience and functioning. Lyle (1994:10) describes regenerative design as design that "provides for continuous replacement, through its own functional processes, of the energy and materials used in its operation". He further suggests that regenerative design is that which participates in the ecological functions of the land it displaces and incorporates complex communities of organisms. This approach to design therefore suggests that humans can revitalize their environments by both allowing nature to do some of the work, and by contributing their share of efforts to restore the system and keep it cycling with appropriate resources (Lyle 1994). Regenerative design could therefore be considered a next generation of ecological design that moves beyond a human/non-human relationship of mitigation towards one of recovery and continuous renewal. In addition to recovery and renewal, this approach also emphasizes the key concepts of systems, place, self-healing, co-evolution, community and the sharing of responsibility.

2.2 Ecology

The various approaches to design outlined in the previous section illustrate an increasing shift in emphasis of the need to form some type of connection with human systems and non-human natural systems and processes. The concept of the ecosystem is that aspect of non-human nature that repeatedly appears throughout the discussion of nature-based building design. Whereas the previous section described how architectural approaches view and embrace non-human nature and ecosystems, this section describes relevant fields of ecology that offer an ecological perspective to compare against the design approaches. Are core ecological concepts reflected in the design approaches?

Ecology is the study of the relationships between organisms and their environment (Smith & Smith 2000). Derived from the Greek word *oekologie – oikos* (household) + *logos* (study) – it is literally the study of the household - nature - of which we as humans are a part. It is an interdisciplinary science, merging elements from many of the physical and biological sciences, and offers both theoretical and applied knowledge of nature's processes.

2.2.1 Ecosystem ecology

Ecosystem ecology is that branch of ecology that is concerned with the interactions, i.e. the flows of energy and matter, between the biotic and abiotic components of ecosystems. An ecosystem is a community of different species that interact with one another and with the abiotic, non-living environment. Ecosystems are typically described by the scale in question (e.g. a forest is an ecosystem, but so is each tree or fallen log unto themselves), their structure (e.g. their living and non-living components), their processes (e.g. the flow of energy and cycling of matter), and their adaptability and processes of change (e.g. evolution and succession). Complex systems theory is also used to describe ecosystems, listing the movement of energy and matter as the main organizing processes, causing self-organization, diversity and resilience (Odum 1983, Kay et al. 1999, Holling et al. 2002).

2.2.2 Human and urban ecology

Human ecology is the application of ecological theory to the human species. It combines the biophysical and social factors of ecology, sociology and anthropology and describes the relationships between humans and their environment (Machlis et al. 1997). Correspondingly, urban ecology is the study of the city as an ecosystem and can be considered a subset of human ecology as humans are the creators and keystone species of cities (Rees 1997). This definition of urban ecology reaches beyond the study of non-human species in cities, and highlights the fundamental fact that humans are key ecological entities whose major habitats take the form of houses and cities. In human and urban ecology, humans are therefore the dominant biotic elements, while the structures they build are predominantly considered abiotic resources. It is this realization that humans are actually part of nature that is driving the new ecological paradigm (Dunlap et al. 2000).

2.2.3 Landscape ecology

Landscape ecology studies the structure, function, and change in interacting ecosystems and the heterogeneous patterns that result at the landscape level. Because many landscapes have been influenced by human use, it often merges the study of the patterns of natural landscapes with those of human land use (Turner 1989). Landscape ecology can be considered rooted in ecosystem ecology, geography, and where human development is concerned, human and urban ecology (Forman 1995b). It considers landscapes as mosaics of patches and corridors within a background matrix (Forman & Godron 1986) and looks at the functioning of the various systems of the mosaic as a result of the mosaic pattern. It is therefore important to the understanding of the effects of human and urban ecological processes because it views them in relation to their surrounding systems.

2.2.4 Restoration ecology

Restoration ecology is the science behind the practice of the ecological restoration of ecosystems. Ecological restoration is the "process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed", by providing it with the structure and composition of its historic state at a point just before the ecosystem suffered a radical change, and the ability to eventually regenerate and sustain its functions on its own (SER 2004, Apostol 2006). It requires the setting of both broad and more detailed goals that describe what is expected of the restoration, and involves planning, implementation and management to achieve the goals. The research and applied knowledge that has emerged from restoration ecology are both important, especially in urban settings, because they provide consensus as to what should be restored as well as experience on how to accomplish it.

Chapter 3

Results

Core concepts and an ecosystemic design framework

Humans need so much more than just clean air to thrive. Humans need the rest of the living world…. What would happen if we designed buildings not to separate ourselves from the nonhuman world, but to meet our needs by interacting with it?

Carol Vernolia (2008:87)

This chapter will explore the objective of *providing a working definition of nature-based design*. It answers the related questions of how the design approaches draw on nature, how the design and ecological approaches relate to each other, and how the concepts that are in common between approaches relate to each other.

3.1 The Core of Nature-Based Design

The dominant themes of each of the approaches to environmentally conscious, and more specifically nature-based design as described in the previous chapter are listed in figure 3.1.

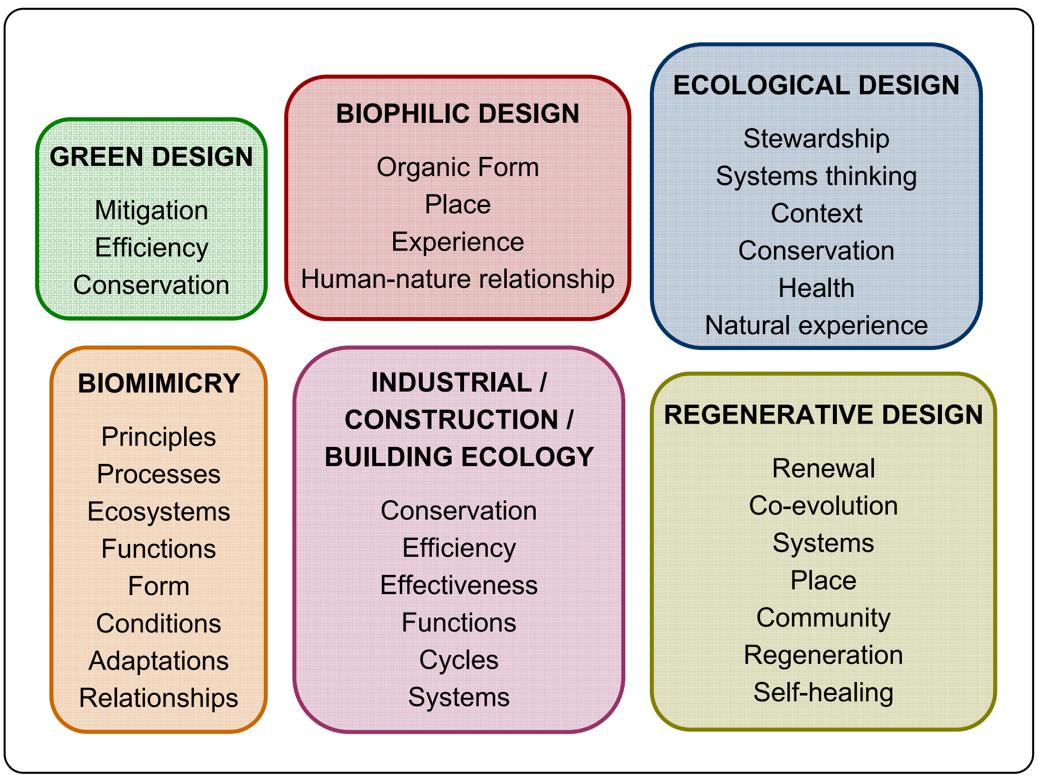


Figure 3.1. Dominant themes of various approaches to environmentally conscious and nature-based design.

From these themes emerge various common threads that can be described as follows:

- The notions of mitigation, conservation and efficiency as emphasized primarily by green building, but also integral to other approaches (as preliminary objectives rather than end goals);
- The notion that humans are integral parts of nature as expressed by biophilia, ecological and regenerative design;
- The concept of the ecosystem, both as a model as put forth by biomimicry and industrial, construction and building ecology, and as context as suggested by ecological and regenerative design;
- The importance of place and local context as discussed by biophilia, ecological, and regenerative design;
- The goal of ecosystem health, either for the continual provision of services to humans as suggested by ecological design or because non-human nature has inherent value and self-healing abilities as suggested by regenerative design;
- The notion of community, partnership, and stewardship suggesting that the functioning and management of a system should be the mutual responsibility of both its human and non-human members as conveyed in ecological and regenerative design, and that these communal relationships can be described by principles, as put forth by biomimicry;
- The concept of processes and cycles that uphold natural system functions as considered by industrial, construction and building ecology and biomimicry;
- The notions of adaptation and (co-)evolution as presented by biomimicry and regenerative design;

- The idea of form and structure and of the conditions thereby produced as discussed in biomimicry and biophilia;
- The importance of being able to experience non-human nature as put forth by ecological design and biophilia.

These last two concepts, of incorporating or representing natural forms and making these forms accessible, will emerge as important issues throughout this thesis as they arguably represent the link between architecture and connectedness with nature.

Since many environmentally conscious design approaches draw on ecosystem ecology, several of the above themes are echoed in the following ecological disciplines, while others, particularly the concepts of pattern and the management of native ecosystems, offer new perspectives from which to approach connecting buildings with nature:

- The concepts of self-sustaining systems, communities, interactions, functions, processes, flows, cycles, and evolution as described by general ecosystem ecology;
- The belief that humans and their by-products are just some of the many components of the earth's ecosystems as put forth by human and urban ecology;
- The importance of portraying the type and extent of relationships that different systems have to each other and, as emphasized in landscape ecology, the patterns that result;
- Restoration ecology adds the concepts of native and indigenous as qualifiers to the discussion of form, context, and functions.

Figure 3.2 provides a graphical display of the overlap between the concepts.

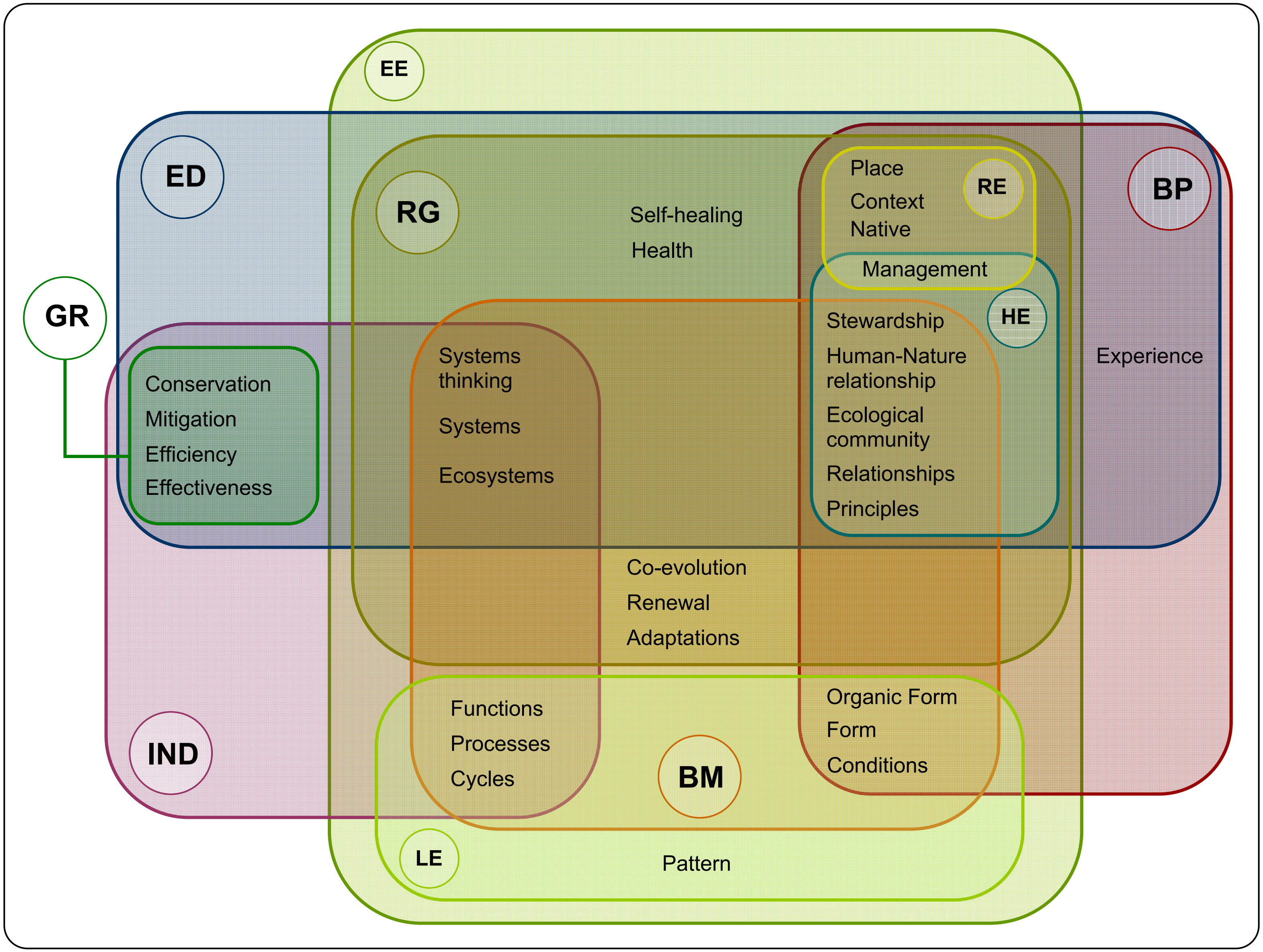


Figure 3.2. Conceptual overlap of nature-based design and ecology approaches. GR=Green design; ED=Ecological design; IND=Industrial, Construction, and Building ecology; RG=Regenerative design; BM=Biomimicry; BP=Biophilic design; EE=Ecosystem ecology; HE=Human ecology; LE=Landscape ecology; RE=Restoration ecology.

3.2 From ‘Nature’ to ‘Ecosystem’

All of the approaches to environmentally conscious building design discussed in the previous section, with the exception of green building, use some aspect of non-human nature as a point of reference. Overall, the concept of the ecosystem is the most referenced. Although the term seems less ambiguous and has less social loading than the term ‘nature’, it is an equally complex notion. As in ecology, ecosystems are typically referred to in a variety of ways, with regard to scale, structure, processes, and adaptability. As such, these characteristics permeate the framework outlined in the next section and described in detail in chapters four and five.

In addition to the qualitative referencing, there are two main ways in which the approaches make use of ecosystems (figure 3.3):

- As *models* – how the built environment can be *based on* and *act like* an ecosystem
- As *context* – how the built environment can be *based in* and *interact with* its ecosystem

3.2.1 Connecting people by connecting buildings

As figure 3.3 outlines, the way in which design makes use of ecosystems, either as models or as context, will influence its ability to enhance its users’ connectedness with non-human nature due to the type of nature experience it can provide.

Designing the built environment to act like an ecosystem offers a vicarious experience and symbolic connection with a representation of non-human nature. A built environment that is designed to interact with its ecosystem, on the other hand, can offer a direct experience of and physical connection with non-human nature.

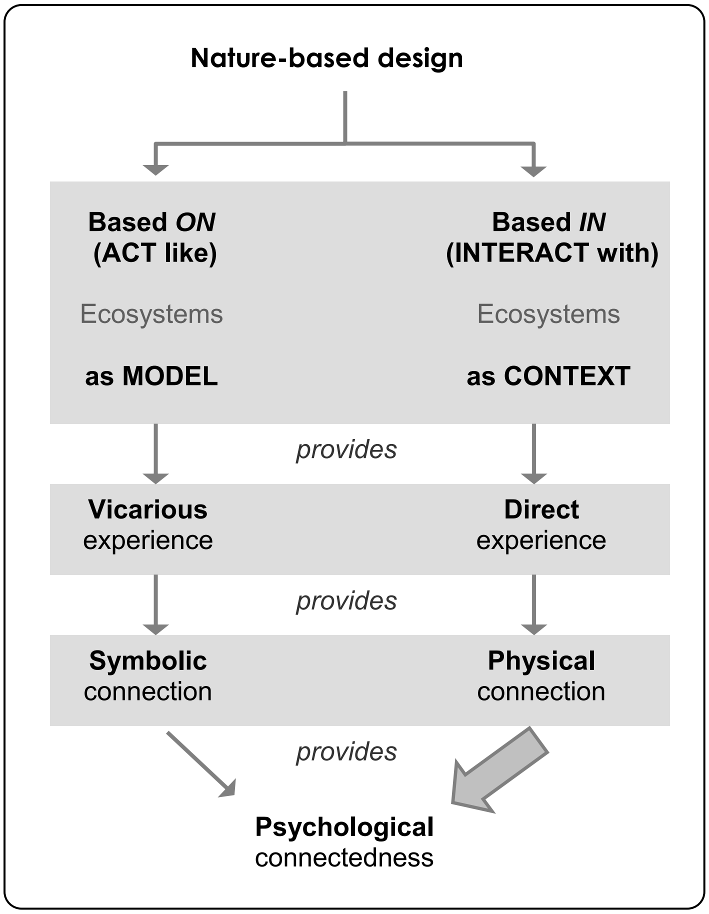


Figure 3.3. The duality of nature-based design.

According to Kellert et al. (2008), both types of experience provide a connection that satisfies biophilic requirements to some degree, however they and others (Orr 1992, Pyle 2003) argue that a physical connection through direct experience offers greater opportunity to enhance connectedness and ecological literacy and ultimately an ecological citizenship.

Nature Experience

An 'experience' can be defined as perceiving or encountering something through the senses (tactile, audio, visual, olfactory, gustatory) either from up close or at a distance. A 'nature experience' therefore takes place when some aspect of non-human nature is encountered. Since people spend over ninety percent of their lives in buildings (Evans & McCoy 1998), opportunities to experience nature would be greatly increased if the buildings themselves incorporated non-human natural features. In order to experience the physical connection between building and ecosystem, that connection needs to be made accessible through any of the senses. A building therefore has the opportunity to provide nature experience not only to its users but also to passersby and the wider public.

Ecosystem as Model

As the human built environment is now a key component of many ecosystems, using those systems as models is useful if humans and their constructs are to fit in and be compatible with non-human processes. Such metaphorical translation of ecosystemic features into buildings, however, can only provide a vicarious experience with non-human nature, as contact is only with a representation of nature, rather than actual natural elements themselves (e.g. pictures, cyclic resource use, curvilinear shapes). This vicarious experience is therefore limited to providing only a symbolic connection and thus also a limited connectedness with non-human nature, due to its inability to provide a deeper sense of intimacy, immersion and discovery (Kellert 2002).

Ecosystem as Context

The use of ecosystems as context for the built environment has the potential to offer a very different type of experience than their use as model would. A built environment designed to interact with its ecosystem can provide direct contact and experience with real elements of non-human nature (e.g. sunlight, plants, non-human animals) and thus provide building users or passersby with opportunities for a physical connection. “The forms of buildings…have always been a major means of making connections between people and environment” (Lyle 1994:45). Therefore buildings that reduce the separation between the human and non-human, i.e. are integrated with their ecosystem, can potentially contribute to “solutions for [psychologically] reconnecting people with nature” (Lewis 1993:798).

3.2.2 What is meant by 'interaction'?

For buildings, 'physical connection' and 'interaction' refers to an integration of building and landscape, or the material joining of built structure with ecological structure. It suggests a blurring of boundaries between building and landscape, human and non-human. It conjures images of buildings that appear to be rooted into the soil rather than sitting on its surface, or ones that display a continuity of materials, helping to dissolve, at least aesthetically, disparities between building and landscape. Roofs, walls and other exterior elements of buildings that typically represent the interface between inside and outside, human and non-human habitat would thus be logical building elements with which to manifest the integration.

3.2.3 Interaction, accessibility and the two losses

The issue of making those elements of a building that are integrated and interacting with their ecosystem accessible to humans in order to provide experience of non-human nature has been discussed above. This, however, only addresses the loss of nature experience. In order to also provide a solution for the second loss caused by conventional buildings, i.e. to create habitat for native biodiversity, the building element needs not only be accessible to humans, but to local non-human nature as well. Integrating buildings using their exterior elements such as walls and roofs would therefore not only provide opportunity to reduce the perceived separation between building and ecosystem, but would also provide surfaces accessible to many non-human species. As such, it is with these features in mind that the interaction of building and ecosystem will be discussed in subsequent chapters of this study.

3.2.4 The importance of basing a building in its ecosystem

As described above, the use of ecosystems as both model and context are both valid and valuable approaches to design, however a built environment that is designed to interact with its ecosystem is suggested to be of greater significance for instilling a sense of connectedness with nature. It is also only through this interaction that the loss of both native biodiversity and nature experience can be addressed. As such, a model that describes the core of nature-based design would be one whose concepts can encourage the design of buildings that not only *act like* an ecosystem, but that first and foremost *interact with* their ecosystem.

3.3 The Ecosystem Framework: A Relational Model

Based on the core concepts of the design and ecology approaches, two notions emerge that can be considered essential to nature-based design. These are, first, that the ecosystem is a valid and crucial construct in design, both as model and as context, and second, that humans are integral members of these ecosystems. These represent central notions in the framework proposed in this study. The framework describes an 'ecosystem' approach whose central goal it is to re-integrate humans with their native ecosystems through the act of building. As such, the term 'ecosystem-based' approach will be used instead of 'nature-based' approach throughout the remainder of the thesis when referring to the model developed in this study.

The other core concepts in figure 3.2 can be considered hyponyms of the two principal ones described above. Since the way they are treated within the design approaches are qualitatively different, they can themselves be further categorized. Some are treated more as objectives or subgoals, some more descriptive of ways to achieve these goals and others more descriptive of variables that could influence and be influenced by design. This categorization of the core concepts resulted in the three-tiered model illustrated in figures 3.4-3.7:

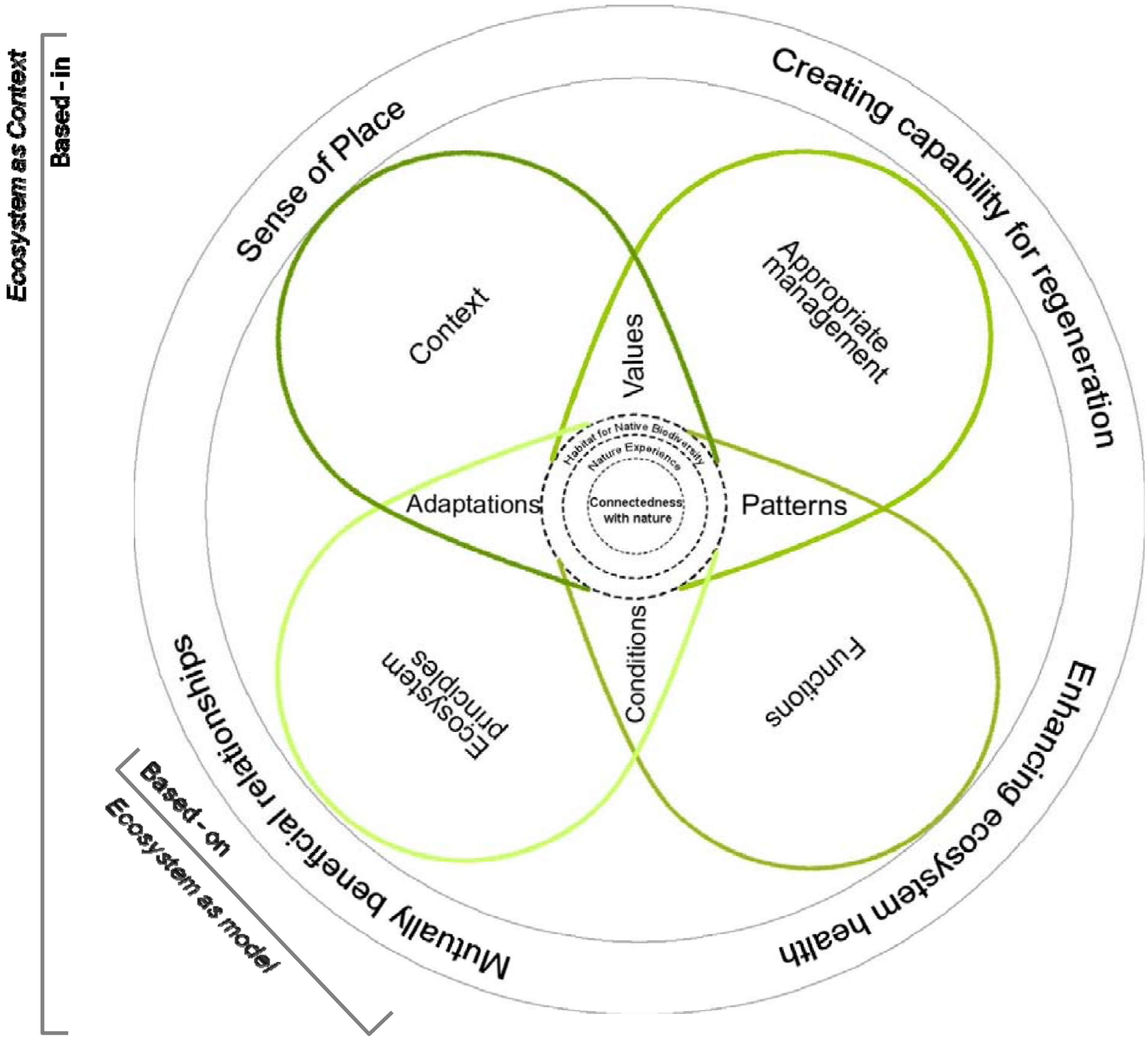


Figure 3.4. The ecosystem framework.

- Level One (figure 3.5), the cornerstones, are considered to be the fundamentals of the ecosystem approach and break down the principal goal of enhancing connectedness with nature into the following sub-goals:

    1. *Foster an ecological sense of place:*
       Reflect an awareness of and care for native ecosystems
    2. *Enhance ecosystem health:*
       Encourage native ecosystem functions
    3. *Create the capability for natural systems to regenerate themselves:*
       Share human habitats deliberately with other species by allowing the renewal of native ecosystems
    4. *Create mutually beneficial relationships between humans and other species:*
       Act like your ecosystem to more effectively interact with it

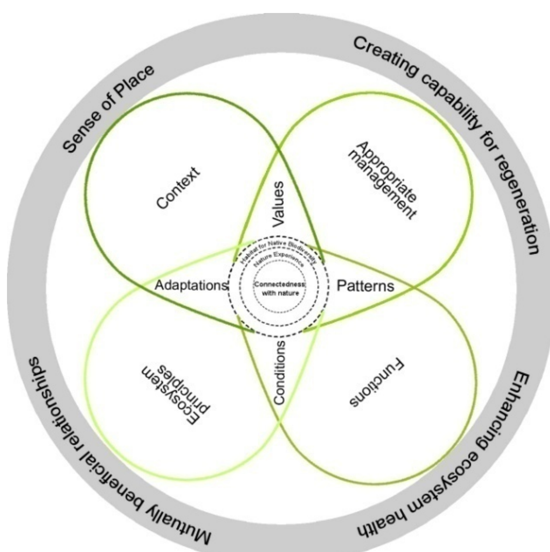


Figure 3.5. Highlighted is the first level of the ecosystem framework – the cornerstones.

- Level Two (figure 3.6), the methods, are the key steps within the design process that can be used to achieve the cornerstones. They are constrained from below, by the parameters set by the third level, the variables (figure 3.7) as well as from above, by the cornerstones. The methods are to:

    1. *Understand one's ecological context*
        and reflect this context in the building

    2. *Encourage ecosystem functioning*
        by balancing functional requirements of native biodiversity with building functions

    3. *Use appropriate management*
        to merge ecosystems with buildings and dissolve functional and aesthetic disparities

    4. *Use ecosystem principles*
        to test the design's ability to act like an ecosystem

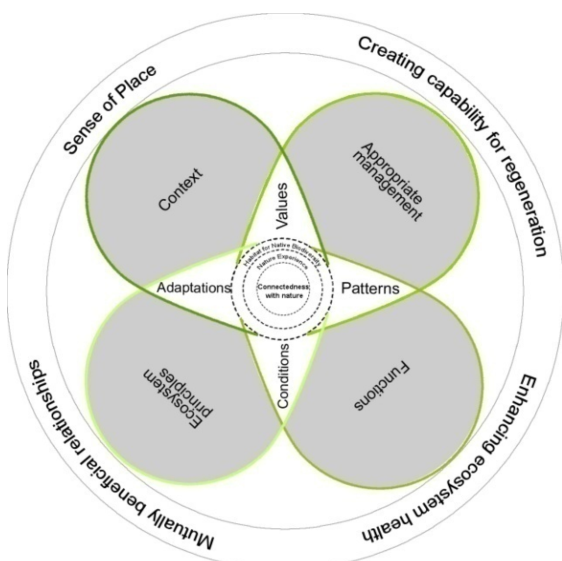


Figure 3.6. Highlighted is the second level of the ecosystem framework – the methods.

- Level Three (figure 3.7), the variables, set the parameters for an ecosystem-based design. They can be considered fundamental to ecosystem-based design since they must exist within the declared parameters in order to perform the methods and achieve the cornerstones. The parameters would differ for conventional building, thus their qualities here are particular to ecosystem-based design. The variables are categorized as:

  1. *Values:*

     Biospheric and natural aesthetic values propel and are reflected by design

  2. *Conditions:*

     Conditions conducive to the survival of other species are created

  3. *Patterns:*

     Human networks are interwoven with non-human patterns

  4. *Adaptations:*

     Natural processes of change are allowed to occur

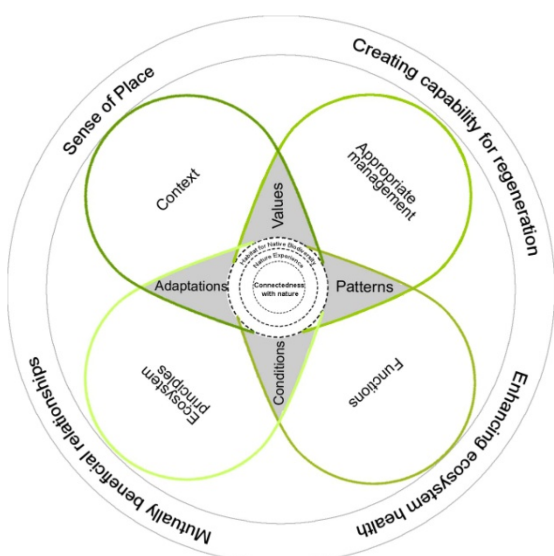


Figure 3.7. Highlighted is the third level of the ecosystem framework – the variables.

3.3.1 A non-linear model

A major criticism of existing approaches to environmentally conscious building design is that they use linear models to describe complex systems (Lyle 1994, Biomimicry Guild 2007, Kay 2002, McDonough & Braungart 2002, Pedersen Zari & Storey 2007). A linear model, no matter how well described, will always be inadequate for understanding a complex world of networks due to its inability to adequately represent relationships between constituent elements. Conversely, the framework presented here is a systems model that allows one to understand and work on each of the parts while appreciating the whole network. It brings existing 'tools' together into a single 'toolbox', by taking a collection of seemingly disconnected ideas and describing their relationships to each other.

3.3.2 The ecosystem framework and the duality of nature-based design

The duality of a nature-based design, as described in the previous section, is also reflected in the ecosystem framework (figure 3.4). The importance of basing a building *in* its ecosystem is highlighted by the ability to discuss each and every one of the concepts from the perspective of buildings that interact with their ecosystem.

The fourth cornerstone (creating mutually beneficial relationships between humans and other species), along with its method (adhering to ecosystem principles), is that portion of the framework that also incorporates how buildings should *act like* their ecosystem in order to more effectively interact with it.

These perspectives will be discussed in further detail in chapters four and five.

3.4 The Ecosystem framework: A Design Process

In addition to acting as a relational model and illustrating the relationships between the key concepts of the approach, the ecosystem framework can also be useful as a design tool. The framework offers a path to follow when investigating the potential for a building to act like and interact with its ecosystem so as to create habitat for native biodiversity and provide opportunities to experience this biodiversity, thus enhancing connectedness with nature. The basic process for designing buildings that address these issues are represented by the second level of the framework, the methods (figure 3.8). As will be discussed in future chapters, information that emerges through one method is useful for another. Since the results of one method informs the next, a logical consecutive order suggests itself. In general, the steps in that order are to:

1. *Understand the ecological context*
   and reflect this context in the building
2. *Encourage ecosystem functioning*
   by balancing functional requirements of native biodiversity with building functions
3. *Use appropriate management*
   to merge ecosystems with buildings and dissolve functional and aesthetic disparities
4. *Use ecosystem principles*
   to test the design's ability to act like an ecosystem
5. *Re-evaluate the context*
   to identify new opportunities for integration

Each step is discussed in more detail in chapter five. It should be reiterated, however, that this thesis is primarily a theoretical investigation into the core concepts of nature-based design, how they relate to each other, and how they relate to the loss of native biodiversity, nature experience, and connectedness with nature. It is not meant to be a thorough investigation of how they can translate into detailed decision-making in the design process. The aim of this section is purely to introduce the potential of the framework to inform the direction of the design process.

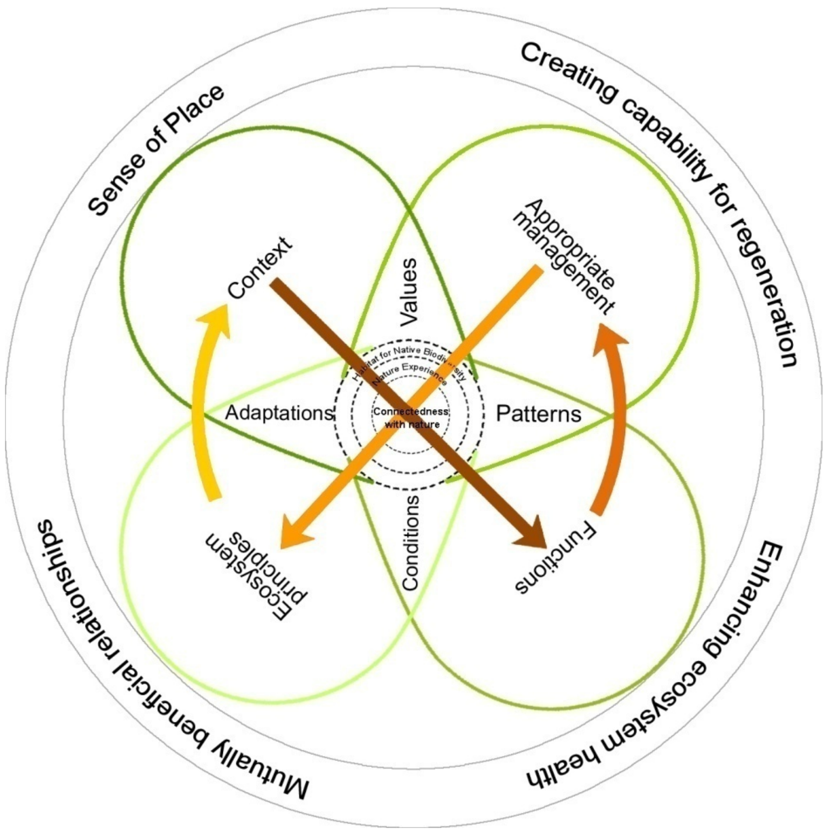


Figure 3.8. The ecosystemic design process.

3.4.1 A continually evolving process

The structure of the framework also conveys that the ecosystemic design process is a continually evolving one. As with the biomimetic design spiral (Biomimicry Guild 2006) (figure 3.9) and the Markus/Maver map of the design process (Lawson 2006) (figure 3.10), the continual circular path around the framework implies that an ecosystemic project is never complete as it is continually adapting to a changing context. With each iteration of the process, new learning takes place -

strategies that fit within the model are promoted and those that don't are re-investigated for how they can. This cyclical process reinforces the ecosystemic nature of the model and describes that how over time, humans and their habitats can become increasingly re-integrated with their local ecologies as we continue to gain a greater understanding of what that entails (figure 3.11).

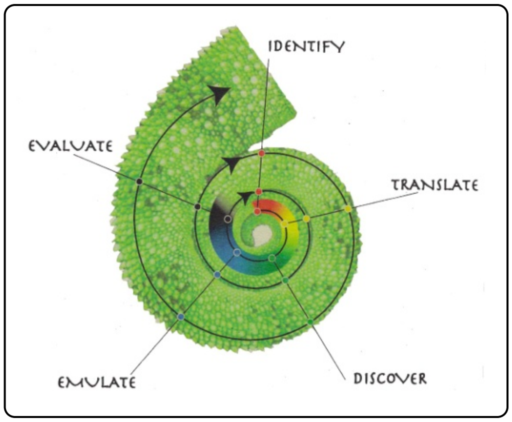


Figure 3.9. The Challenge to Biology design spiral as developed by the Biomimicry Guild (from Biomimicry Guild 2006).

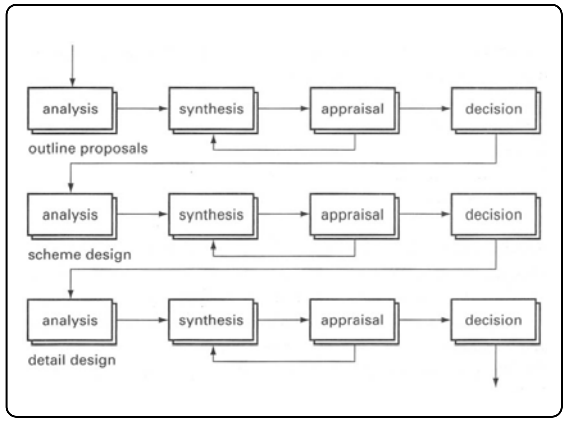


Figure 3.10. The Markus/Maver map of the design process (from Lawson 2006).

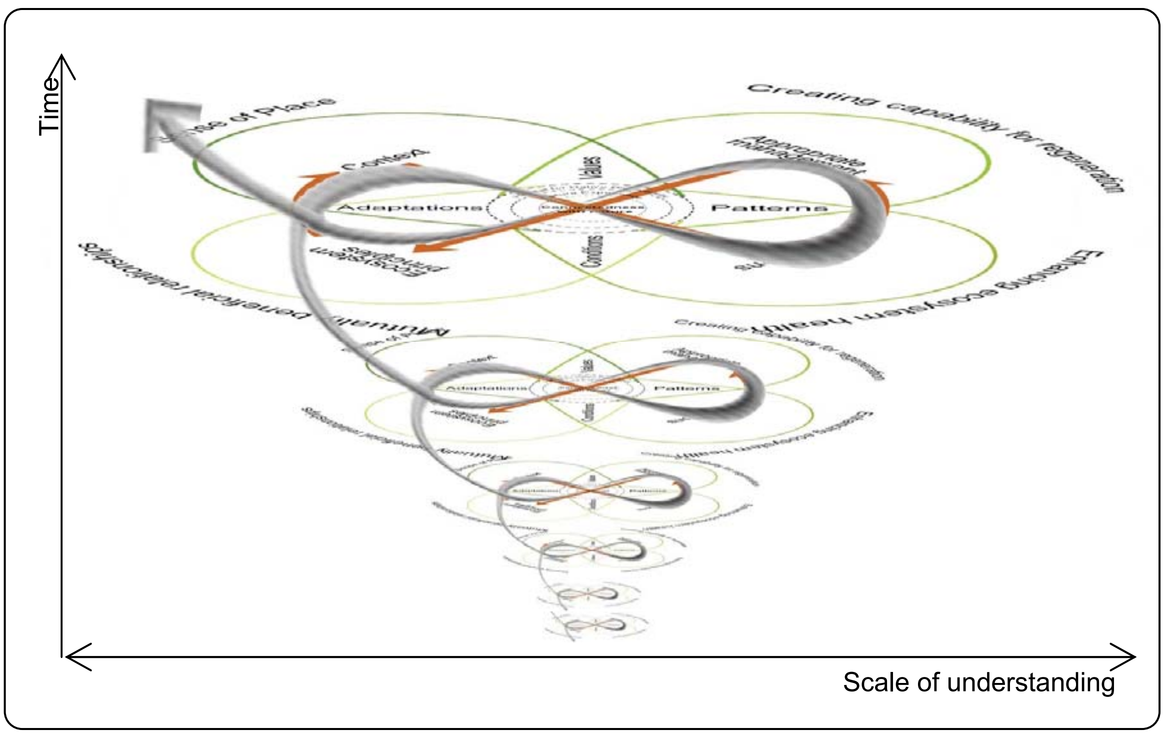


Figure 3.11. The ecosystem-based evolutionary design spiral - with each iteration of the design process, the scale of understanding increases and humans and their habitats become increasingly re-integrated with local ecologies.

3.4.2 Who is the framework useful to?

As a design tool, the framework is useful not only to the initial design team, but also to anyone involved at any stage, from design to occupation to maintenance to re-design. This includes building owners and occupants. By involving each of the human stakeholders, they have the opportunity to become acquainted with the overall goal of the project - to enhance connectedness with non-human nature while creating habitat for native biodiversity and opportunities to experience that biodiversity. In particular, involving the occupants, whether it be through maintenance responsibilities for the home owner, or just casual experience with the local flora and fauna, helps make them aware of the larger picture that the model addresses and adds richness to the local nature experiences brought back into the realm of daily life by the project.

3.4.3 Order for discussion

In the following chapters, each element of the framework will be defined and discussed in detail for its role in the ecosystem approach. Because the methods are constrained both from below by the parameters set by the variables and from above by the cornerstones, these two latter levels of the framework will be discussed first, setting the stage for a discussion of the methods.

It is recognized that discussions of each of the framework concepts can fan-out considerably, particularly since each is a rapidly evolving field of study in and of itself. Their discussion within this study is therefore an attempt to provide support for their inclusion in the framework, and an overview of their content as it relates to buildings, native biodiversity, nature experience, and connectedness with nature. They are by no means meant to be conclusive and comprehensive summaries of the respective fields.

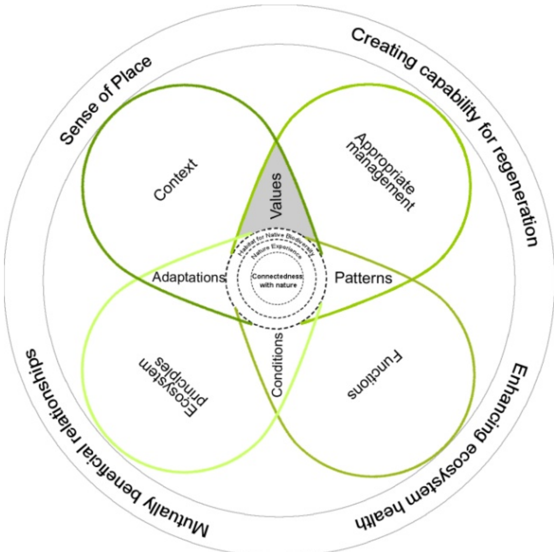
Chapter 4

The Ecosystem Framework
Variables

We are learning that we ourselves are a fundamental part of nature's ecosystems, and that the systems that we create inextricably tie into existing systems.

Arthur Erickson (1972)

4.1 Values



In general, ‘values’ refer to a person or group’s beliefs concerning mode of conduct or end state (Rockeach 1973). They represent the shared ideas about what is good, right, and desirable in a society and are both an individual or personal phenomenon as well as a social or community occurrence (Schwartz 1999). They shape our desires and expectations regarding how we live and are determinants of attitudes and behaviours (Rockeach 1973, Schultz & Zelezny 1999, Moisander 2007).

Ecological values

Values can be termed ‘environmental’, ‘ecocentric’, or ‘ecological’ when the relation of humans to the natural world is of interest (Schultz et al. 2004, Dutcher et al. 2007). Ecological values are rooted in the degree to which people believe that they are part of nature, referred to as their connectedness with nature (Schultz 2002, Dutcher et al. 2007). The more one feels connected to nature, the more likely they are to be concerned with other species and not just themselves or other people. As such, the values can be categorized into three orientations according to their source for environmental concern: egoistic (concern for self), social-altruistic (concern for other people), or biospheric (concern for all living things) (Stern & Dietz 1994, Schultz 2001, Schultz & Zelezny 2003, Snelgar 2006) (figure 4.1). The egoistic and social-altruistic value orientations can together also be considered as anthropocentric, and biospheric as biocentric or ecocentric in some literature (Thompson & Barton 1994, Snelgar 2006).

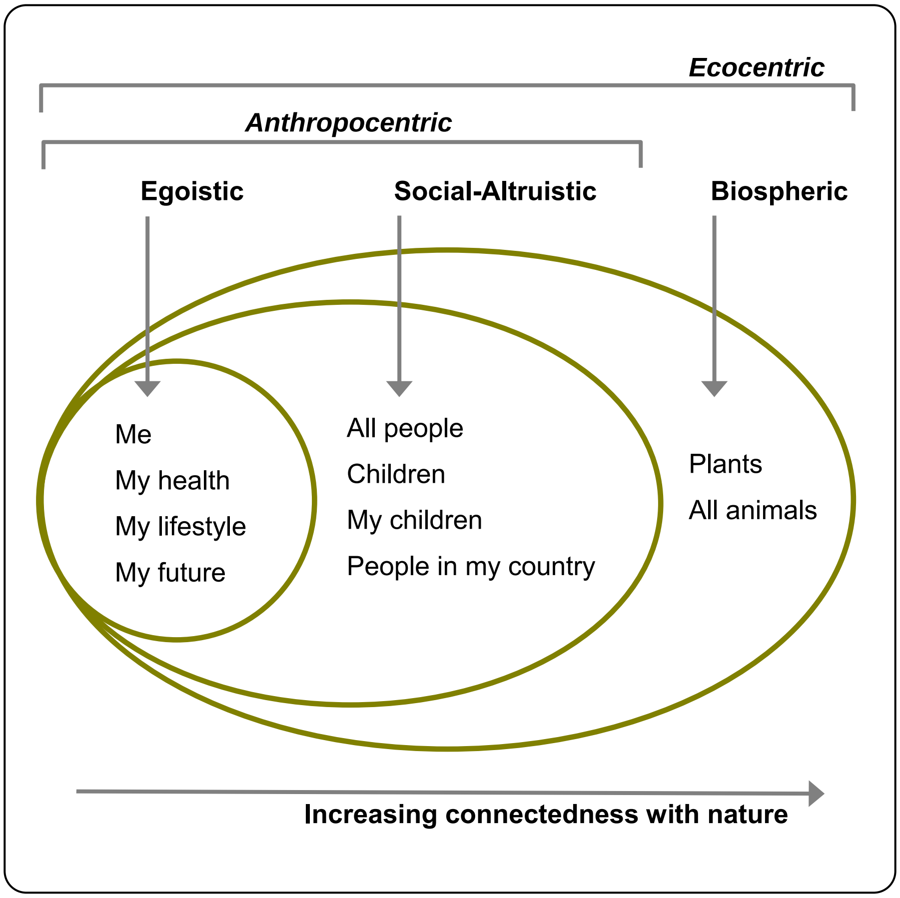


Figure 4.1. Ecological value orientations and their basis for environmental concern.

The New Ecological Paradigm (NEP) has shown that people are starting to care more about environmental issues and that ecological values are beginning to play a greater role in the decisions people make (Dunlap et al. 2000). The resulting impact that these values will have on sustainability, however, will depend on which type is the more prevalent. Although catering to egoistic values is thought to be more effective at eliciting pro-environmental behavior over the short term (e.g. using less energy will save you money), biospheric values have been shown to reflect a stronger feeling of connection with nature and be better predictors of long-term pro-environmental behavior (e.g. using less fossil fuel energy will reduce the amount of carbon dioxide released to the atmosphere, and lessen the risk of habitat and biodiversity loss through climate change) (Stern et al. 1995, Karp 1996, Stern et al. 1998, Schultz 2002, Schultz & Zelezny 2003). Therefore, since biospheric values reflect a greater connectedness with nature and are likely to lead to long-term pro-environmental behaviour, "any activity that reduces an individual's perceived separation between self and nature will lead to an increase in that individual's biospheric concern" and more likely to pro-environmental behaviour (Schultz 2000:403).

Buildings are one example of human activity that, through their current design, typically segregate people from nature (Schultz 2002, Schultz et al. 2004, Kellert 2005). Kellert (1996) lists nine ways to describe people's perceptions of nature which underlie their ecological values (table 4.1). In a later study (Kellert 2005), he describes how buildings that reflect these perceptions differ in their ability to connect people with nature. For example, the human need for shelter has in many instances translated into a dominionistic and negativistic relationship through the need to be protected from nature – not just from the elements, but particularly from animals and insects. Conversely, the integration of buildings with their native ecosystems as proposed by this study would offer more of a naturalistic relationship through direct experience of nature, thereby encouraging a more positive connection. This type of design may therefore require a shift in our values and in our perception of desirable interactions with other species and require us to become accustomed to the "occasional encounter and not be so anxious" (Sauer 1998:185).

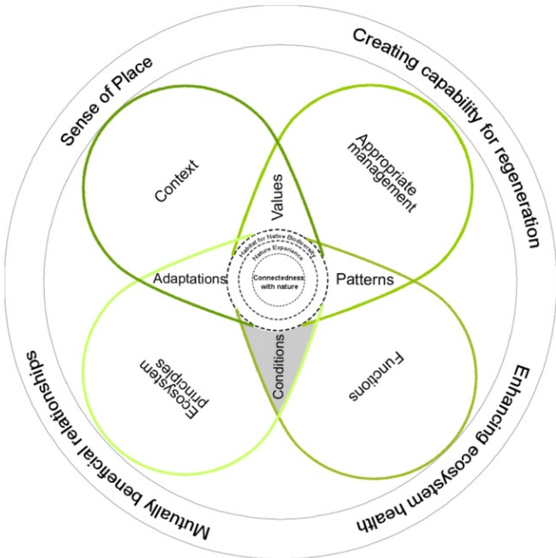
Table 4.1. Dimensions of human perceptions of nature (from Kellert 1996).

Utilitarian	Practical and material exploitation of nature
Dominionistic	Mastery, physical control, dominance of nature
Negativistic	Fear, aversion, alienation from nature
Moralistic	Spiritual reverence and ethical concern for nature
Humanistic	Strong emotional attachment and “love” for aspects of nature
Naturalistic	Direct experience and exploration of nature
Scientific	Systematic study of structure, function, and relationship in nature
Aesthetic	Physical appeal and beauty of nature
Symbolic	Use of nature for language and thought

Kellert (2005) also warns against a concerted pursuit of a utilitarian connection with nature as this would risk diminishing or suppressing other equally important connections. A current example of this is the promotion of green roofs for their stormwater management and insulation properties. A focus on these utilitarian benefits has overshadowed their potential to contribute to wildlife habitat and therefore to greater biospheric values (Brenneisen 2006, Thuring 2007).

Therefore, if buildings can be re-designed to connect people with nature, then they can also potentially encourage a shift towards biospheric values, and hence long-term pro-environmental behaviour and more sustainable lifestyles.

4.2 Conditions



In ecology, the term 'conditions' typically refers to a range of environmental requirements essential to support the life of an organism (human or non-human) or the overall functioning of the greater ecosystem. In integrating humans with their native ecosystems, four categories of conditions can be considered. These are those conditions:

- required by non-human species
- required by humans
- produced by non-human aspects of the ecosystem
- produced by human-derived aspects of the ecosystem

At the scale of the individual organism, all species have a range of conditions, or microclimates in which they thrive. For plants, these conditions are mostly abiotic and include ranges in temperature, soil moisture, ph level, amount of sunlight, and nutrient availability (Schulze & Beck 2005). Non-human animal species, on the other hand, are particularly dependent on plants for the local conditions they produce (Schultz 1990, Elton 2001). Plants, along with abiotic elements (e.g. rocks, water in its various states) provide animals with food (either directly or indirectly by supporting prey species), shelter, comfort, and pathways for mobility. Therefore, by providing appropriate abiotic conditions, it is possible to encourage particular plants and animals to thrive in that setting (figure 4.2).

Humans too have a range of conditions under which they thrive and from which their needs are met. Humans also require habitats that provide food, shelter, comfort, pathways for mobility, as well as opportunities for recreation and social interaction (Machlis et al.1997). The difference, however, is that in order to meet many of these needs, humans no longer depend on local conditions, but appropriate biological production globally and rely on the import of energy and materials from sources sometimes thousands of miles away. Buildings based in their native ecosystems, as proposed in this study, will therefore be those that provide for the needs of their human residents while “tuning” into the “conditions of their bioregion” (Thayer 2003:4). They can do this by accommodating and responding to local conditions (like many green buildings already do right now), and by producing appropriate micro-climatic conditions to encourage native plant and animal species (figure 4.2).

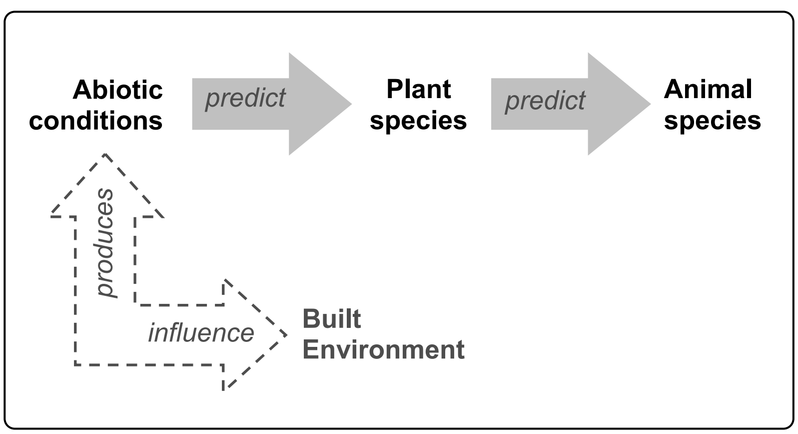
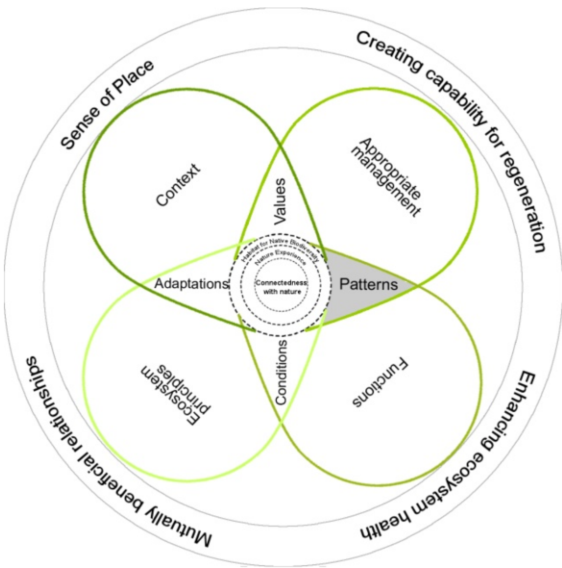


Figure 4.2. How ecosystem structure develops and the relationship between abiotic conditions and the built environment (adapted from Adams et al. 2006).

4.3 Patterns



Patterns in non-human nature refer to a variety of concepts regarding both form and process. Natural patterns are most frequently described in terms of:

- An integration of parts and wholes (Kay 2002, Kellert et al. 2008)
- Hierarchy of scales (Kay 2002, Thayer 2003)
- Age, change, growth and successional development (Odum 1969)
- Geometry such as spirals, branching, waves, fractals and shapes resisting straight lines and right angles (Thompson 1992, Ball 1999, Day 2002, Van der Ryn 2005)
- Rhythmic patterns of season and daylight (Odum 1959, Knowles 2006)

Human design patterns on the other hand are typically described by land use patterns (Forman 1995a), institutional or social patterns (Zucker 1988), or patterns in the physical design of cities and buildings (Alexander et al. 1977).

Although the built environment shares similar types of patterns as those described in non-human nature (e.g. buildings can be seen as discrete parts that comprise an overall whole across increasingly larger scales of a neighbourhood, a municipality, a city, and a region), these patterns often appear isolated from those of non-human nature, as if they have simply been overlayed upon the landscape, rather than merging with it. For example, most urban human habitats reflect a grid-like pattern of square buildings, pavement and impervious surfaces, contrasting sharply with the organic forms generated by forces of non-human nature (figure 4.3).

Armed with an understanding of the natural patterns native to one's bioregion, designers of the built environment (planners, landscape and building architects) can together help to delicately interweave human networks with the network of water and habitat upon which our companion species ultimately depend (Thayer 2003).

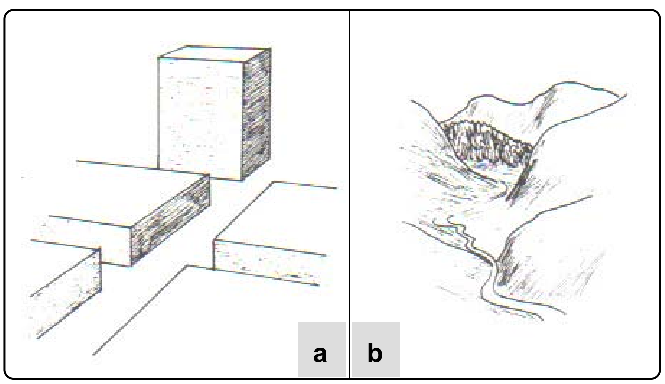
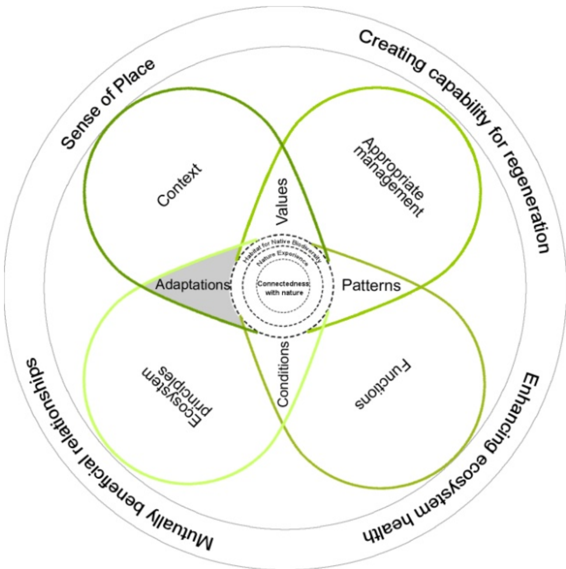


Figure 4.3. The contrast between the (a) straight lines and right angles of human designed patterns of form and (b) energy generated and fluid non-human natural patterns of form (from Day 2002:121).

4.4 Adaptations



Ecosystems, with both their human and non-human members, are continuously changing, constantly evolving and adapting to changing conditions across various scales (Holling et al. 2002, Peterson 2002). “Change is natural to life – things that don’t change aren’t alive” (Day 2002:145). Adaptations can therefore be considered as actions by which an organism or species becomes better suited to its environment. These adaptations allow life to adjust to its surroundings and keep on living. It does so through the use of feedback loops that allow it to recognize changing conditions, and respond to those changes, constantly adjusting itself to its context to remain within a range in which it can thrive. It is this ability to learn about and respond to local conditions that keeps ecosystems in a state of dynamic non-equilibrium.

Where humans dominate the ecosystem, however, these “natural processes of change are, more often then not, severely altered” (Lyle 1994:22). Rather than adapting to our environment, we often exploit or manipulate our surroundings to suit our wants and needs. “Instead of changing the land to fit the needs of our buildings, perhaps it would be more respectful to adapt buildings to the land” (Day 2002:37).

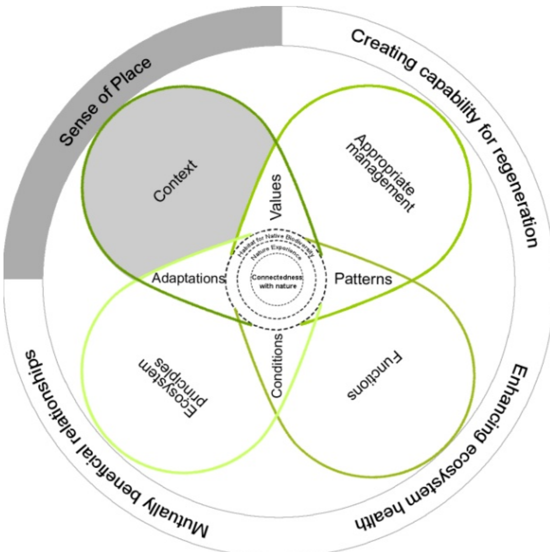
Chapter 5

The Ecosystem Framework
Methods & Cornerstones

Any building… should be an elemental, sympathetic feature of the ground, complementary to its nature-environment, belonging in kinship to the terrain.

Frank Lloyd Wright (Kellert 2005:130)

5.1 Sense of Place



Through these [direct] experiences [in the natural world], we become aware of how we ourselves are part of the web of life, and over time the experience of ecology and nature gives us a sense of place. We become aware of how we become embedded in an ecosystem, in a landscape with a particular flora and fauna; in a particular social system and culture.

Fritjof Capra (2005:xiv)

Industrialization has bestowed “standardization and ever-increasing mobility, for people as well as resources” upon Western society (Eisenberg & Reed 2003:2). This mobility and its associated rootlessness, however often bring about a disconnect between people and the places they inhabit (Relph 1976, Kellert 2005). Kellert (2005:60) argues that along with this ‘placelessness’, with the “growing unfamiliarity and disconnection with the places we inhabit” comes a lack of commitment and care for those places. Knowledge of and appreciation for one’s place help to connect people to it, develop care and respect for it, and are therefore necessary for the development of a caring and responsible pursuit of sustainability. Many therefore argue that the re-awakening of one’s connection to their place though education and experience must be one of the first steps in sustainable design (Alexander et al. 1977, Beckley 2003, Reed 2007, Heerwagen & Gregory 2008, among others).

This connection to one’s place is commonly referred to as ‘sense of place’ in human ecology and geography or ‘place attachment’ in environmental psychology circles (Williams & Vaske 2003). Although numerous definitions of sense of place have been proposed, it is most commonly understood as being a product of both the qualities of the individual person (e.g. emotions, values, knowledge base) and qualities of the setting (both biophysical and socio-cultural) (Relph 1976, Tuan 1977, Steele 1981, Brandenburg & Carroll 1995, Stedman 2003, among others)[1] (figure 5.1). The concept is used to describe the meaning that people give to a setting in terms of familiarity with and knowledge of that setting, as well as the feeling of belonging or attachment to the setting (Hammitt & Stewart 1996, Stedman 2003, Brown & Raymond 2007).

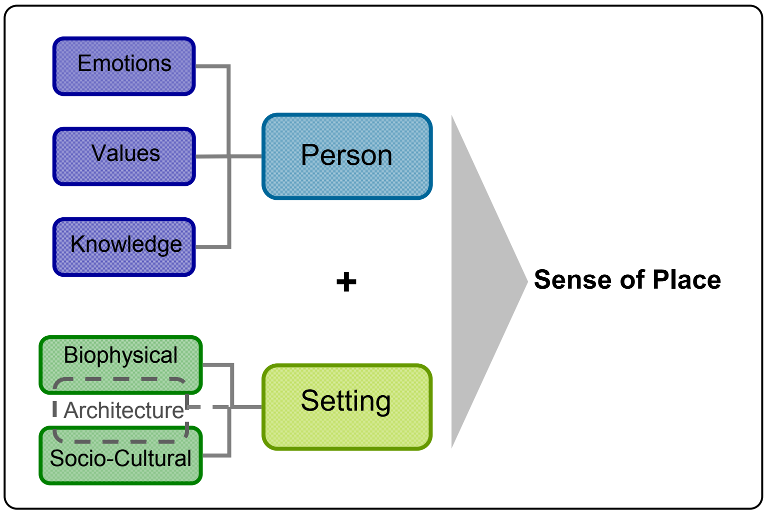


Figure 5.1. Elements contributing to sense of place. Architecture and the built environment can be seen as being at the interface of the biophysical and socio-cultural sources of sense of place.

Beckley (2003) and Kellert et al. (2008) discuss the continuum between the biophysical and socio-cultural features that attach people to places. The biophysical aspects that connect people with place include landscape or geological features (e.g. topography, waterways) and ecological features (ecosystems and their biodiversity). The socio-cultural aspects on the other hand include anything associated with human occupation of a landscape (social networks, institutions, historical meaning).

[1] An important differentiation is made between *settings* and *places*. *Settings* are physical and social surroundings, whereas *places* are the result of user experience of a setting (Steele 1981, Brandenburg and Carroll 1995, Stedman 2003).

Architecture, being a human construct in a biophysical landscape, can be seen as being at the interface of these two sources of place attachment (Beckley 2003) (figure 5.1). Despite this, discussions of sense of place and the built environment predominantly tend towards socio-cultural perception of space, material use, and building style (Alexander et al. 1977, Norburg-Schulz 1979, Steele 1981). Rarely does local ecology and its biodiversity enter the sense of place discussion in architecture, unless with reference to preservation and reduced site disturbance. Instead of instilling a sense of local ecological place, current architecture typically does the opposite by insulating its users from having to experience non-human nature. “Our days are lived mostly within a world of cars, houses, offices, and malls, all heated or cooled to comfortable year-round temperatures, decorated with exotic plants, and supplied with goods and foods supplied year-round from all over the world. In this context, we could be living anywhere” (Harwell & Reynolds. 2006:9).

The approach to an ecosystem-based design proposed in this study suggests that more attention needs to be paid to the potential for buildings to positively impact the ecological dimension of sense of place. By reflecting an awareness of and enhancing the presence of local ecology into the settings where people spend most of their time, i.e. in buildings, and in particular their homes, their knowledge of and appreciation for their ecosystems is potentially increased. This increased understanding of the interconnectedness of their ecosystems, referred to as ecological literacy (Orr 1992), in turn increases their attachment to the ecology of their place, further strengthening their ecological identity and citizenship (Thayer 2003). As Thomashow (1995:192) describes it, “sense of place [is] literally the roots of ecological identity.”

Furthermore, incorporating an ecological sense of place specifically into built structures (instead of or in addition to the landscape) creates an increased sense of connection because it physically helps blur the boundaries between building and landscape. Incorporating local non-human ecological features into buildings helps to integrate rather than isolate a building from its site (Day 2002). This is a stark contrast to the detached, stand-alone condition of most North American buildings. Kellert et al. 2008 describe this continuity of building and landscape and the incorporation of local habitats and ecosystems as biophilic features that trigger preferred and effective responses, furthering the feeling of familiarity and connection with the non-human aspects of one's setting.

5.1.1 Context

To develop a feeling of connection to one's surroundings, i.e. a *sense of place*, one needs to also recognize the broader context of their setting. Like the setting itself, its context can be understood in both biophysical and socio-cultural terms. Van der Ryn and Cowan (1996:40) suggest that design that deepens one's sense of place is that which "begins with the richest possible understanding of the ecological context" and "develops solutions that are consistent with the cultural context". The approach proposed in this study promotes this idea that the biophysical or ecological context, which is often overlooked, needs to be better represented. Such a representation requires an initial understanding of the interconnectedness that exists with the greater surrounding system, i.e., ecological literacy. Being ecologically literate within one's context suggests an awareness of what can be called one's 'ecological address'.

Scale

There are several scales at which one's ecological address can be understood and that are important for designing a built environment that is integrated with its ecosystems. The setting is whatever scale is under consideration in a given design – in architecture this is often that of the individual building. Spatially, its context is the scales above (larger) and below (smaller) it, and temporally, those before, current, and after. These contexts must be known in order to determine if the design is a 'good fit' or not (Thayer 2003).

- Spatially – Using a building as the scale of the setting:

  > The larger scale of understanding is that of the bioregion. A bioregion is a geographic area with common characteristics of soil, climate, and native plants and animals (Berg & Dasmann 1978). As Berg (1995:5) explains, “the concept of a bioregion is uniquely useful for putting ourselves back into nature rather than on top of it”. Boundaries within bioregions are often delineated by watersheds (the land area from which water drains to a given point). The smallest watershed can be considered the basic unit for design that re-integrates humans with their local ecologies (Eisenberg & Reed 2003, Thayer 2003). Knowledge of one’s bio- or eco-region provides an understanding of one’s place in the broader ecological community, whereas knowledge of watersheds helps make one aware of their connection to systems both upstream and downstream. Currently, however, watershed boundaries rarely coincide with political boundaries. The concept of bioregionalism or bioregional thinking, however suggests that sustainable communities will be those whose ecological boundaries transcend their political ones (Thayer 2003).

  > The smaller scales consist of the local micro-ecosystem and its individual components native to the building site (e.g. stream, forest, wetland). The physical integration of building and landscape at this scale will blur the boundaries not only between the human built components (e.g. neighbouring homes) but also between human and non-human components (e.g. a roof and a tree canopy). This intimate and detailed incorporation of the smaller scale can only take place when an ecological literacy of the larger scales of the watershed and bioregion are achieved. Like every building has a street address, so too should it reflect its ecological address.

- Temporally – The spatial scales can be considered across the various periods of time of the:
    - > Past – for insight into what existed prior to human development and for how the present spatial context came to be
    - > Present – as an analysis of what currently exists
    - > Future – to suggest the potential for the design to evolve and adapt to future changes in context

5.1.2 The relationship between ecological values, context and sense of place

The relationship between values and context is two-dimensional and reciprocal. Values influence:

1. the attitudes and behaviours that implicitly guide design
2. how a design is perceived

In the first relationship, the values under consideration are those of the designer – in order for the built environment to reflect ecological values, it is likely that the person(s) responsible for its design hold ecological values of their own. Designers therefore have a great deal of potential to play a leadership role in the way we associate ourselves with nature.

In the second relationship, a built environment that reflects ecological values has the potential to instill or transfer these values to people who experience it (Rapoport 1990). Because values are "congealed" in buildings, (Rapoport 1990), and often exist across a timescale during which time values can shift, buildings and their designers have the opportunity to transfer their values to not only their present day users, but to those of future generations as well.

Because values are central to both the manifestation and interpretation of context, they in large part also drive the personal aspect of sense of place (Rockeach 1973, Schultz & Zelezny 1999, Moisander 2007). As mentioned earlier, by reducing the separation between self and nature, concern stemming from biospheric values is increased. When the connection is made with local nature at the smaller spatial scale of one's own property, and by association, their bioregion, one's ecological sense of place is increased in addition to their biospheric values. Therefore designs that reflect values of care and responsibility for the non-human natural world (biospheric values) can contribute to an understanding and experience of ecological context at both an intimate, personal level and larger community level, and hence encourage the development of a richer ecological sense of place.

Didactic Art

Although it offers a symbolic rather than a direct connection with non-human nature, didactic art can be a useful design tool to transfer biospheric values to building users and inform an ecological sense of place.

Islandwood, an environmental learning centre on Bainbridge Island, WA, offers several examples of such didactic art (Islandwood, n.d.) (figure 5.2). Each overnight guest room is named after a native species, carved into ceramic tile by a local artist. Each room's light sconce is embedded with a constellation visible at different times of the year from Islandwood. Sinks depict salmon, a particularly important local species, as a reminder of the connection between drains and salmon habitat. Also, the learning centre's fireplaces are each made of different types of rocks representative of the geology of the Pacific Northwest, and their mantles have carvings depicting the food chain.

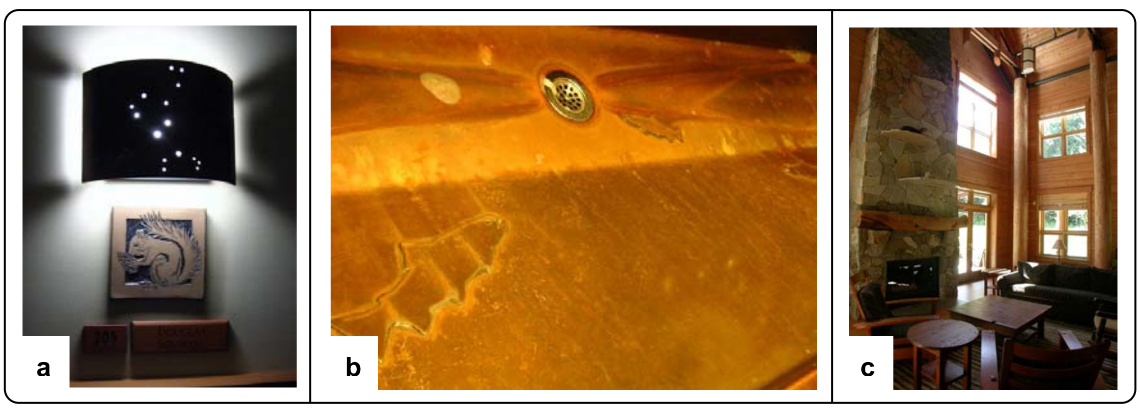


Figure 5.2. Art that reflects ecological values and a sense of place at the Islandwood environmental learning centre: (a) lodge rooms are named after native species and light sconces are embedded with contesllations (from chicu, n.d.); (b) salmon are depicted swimming towards the drain of sinks (from chicu, n.d.); and (c) each fireplace is constructed with a different material representative of the local geology (from SBSE, n.d.).

Through their design, whole buildings can also act as didactic art, passively communicating environmental messages to their occupants (Mitchell 2005). Artist and architect Friedensreich Hundertwasser embedded his building-scale art with his philosophies and values concerning humans living in harmony with nature. His residential Waldspirale in Darmstadt, Germany and Hundertwasser Haus in Vienna, Austria reflect his vision of an architecture based on natural forms, diversity (no two windows are the same) and vegetation (figure 5.3). Many of his buildings have 'tree tenants' – trees grown from inside the building with limbs extending from windows.

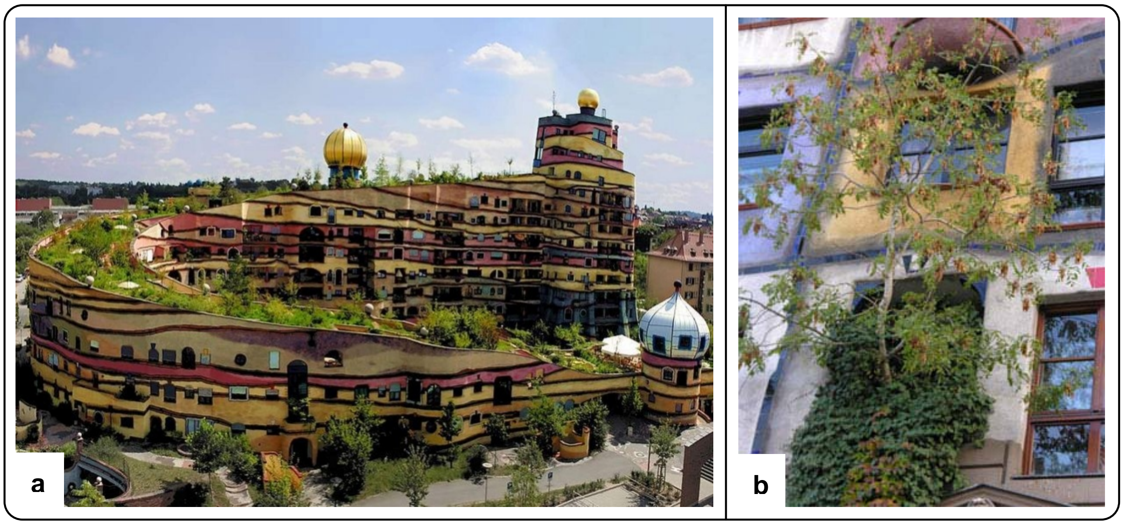


Figure 5.3. (a) Hundertwasser's Waldspirale (from www.news.thomasnet.com); (b) Tree tenant of Hundertwasser Haus (from www.escapeartist.com).

5.1.3 The relationship between adaptations, context, and sense of place

"Places aren't static" (Day 2002:151). Both settings and the way in which people experience a setting will change over time as communities develop, materials age, new uses and requirements emerge, and social norms, expectations and values shift. Both human and non-human aspects of ecosystems are therefore constantly evolving to these changing conditions at all scales of their context, which then drives further changes.

A system's ability to adapt to these changes in context, however, is highly dependent upon the rate at which the changes occur. At the smaller scale, ecosystems tend to undergo change faster, while larger scale systems are slower to catch up (Holling et al. 2002) (figure 5.4). Furthermore, the faster, smaller scale change can stimulate change at larger scales through the use of innovation, thereby challenging the constraints imposed on it by the larger scale. These dynamics can also be applied to design and innovation of the built environment. While the larger scale of the neighbourhood, with its social norms, tends to constrain the design of buildings at the small scale, buildings can also drive change at the larger scale of the neighbourhood by gradually introducing new ideas through the design of individual buildings. For example, change in ecological values and context can be affected throughout a neighbourhood by beginning with one building per block that is integrated with its ecosystem. That one building has the potential to transfer the ecological values inherent in its design to neighbours and passersby that experience it. Those people may then decide to incorporate similar ecological restorations into their own buildings, helping to gradually enhance the ecological character of the neighbourhood. This cross-scale adaptation to change in ecological values allows an ecological sense of place to be developed more quickly at the smaller personal level and gradually at the larger neighbourhood level.

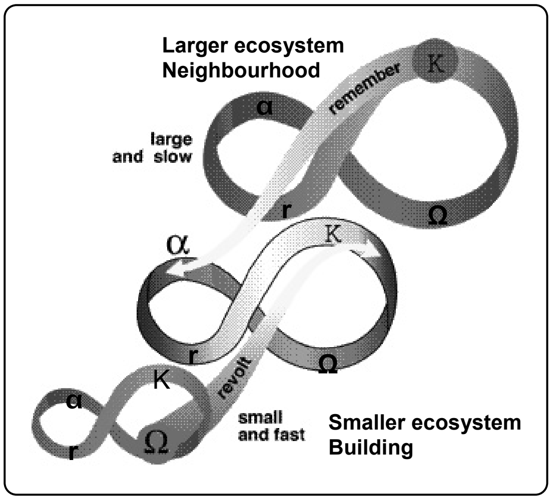


Figure 5.4. Panarchy model showing the rate of change at various scales of the adaptive cycle (adapted from Holling 2001). The phases of the adaptive cycle describe the changes ecosystems go through: (r) growth, (K) conservation, (Ω) release, and (α) renewal.

Also, introducing non-human nature at the smaller and more intimate scale of the individual person and building offers more opportunity for direct participation and to witness the detailed aspects of the adaptive processes of growth and renewal of one's native ecosystem. Experience of these phases offers a sense of being alive and a higher level of biophilic nourishment (Lynch 1972, Day 2002, Kellert et al. 2008). Providing opportunities to repeat such experiences throughout the larger community offers a richer participation with more aspects of the system, thereby fostering a deeper connection with the neighbourhood and the larger ecosystem as a whole.

By adapting the design of buildings to reflect their ecological context, they also become better equipped to cope with changes to that context. One type of change that is affecting both human and non-human aspects of ecosystems worldwide is climate change. "While restoration is made more difficult by climate change, it can conversely be seen as a possible adaptive management approach for enhancing the resilience of ecosystems to these changes" (Biringer & Hansen 2005:31). Therefore by integrating buildings with their ecosystems through restoration, they are helping each other to buffer against likely changes in the future.

Lloyd Crossing Sustainable Urban Design Plan & Catalyst Project

The Lloyd Crossing Sustainable Urban Design Plan & Catalyst Project in Portland, Oregon is an example of a project that takes time, adaptation and place into consideration for its design (Mithun 2004). The project consists of a long-term plan and a catalyst project. The catalyst project itself was a mixed-use development pilot project in the neighbourhood that would provide guidance for future development over the next 45 years. The overall goal of the project is to reduce the net environmental impact of future development to levels approximating those of the pre-development conditions of the site (figure 5.5). The 'pre-development' metrics used were based on habitat, water and energy values for the 54-acre study area based on a mature-mixed conifer forest. Results of the catalyst project suggests strategies and actions to be implemented incrementally in order to reduce present day 2004 levels to pre-development levels by the year 2050.

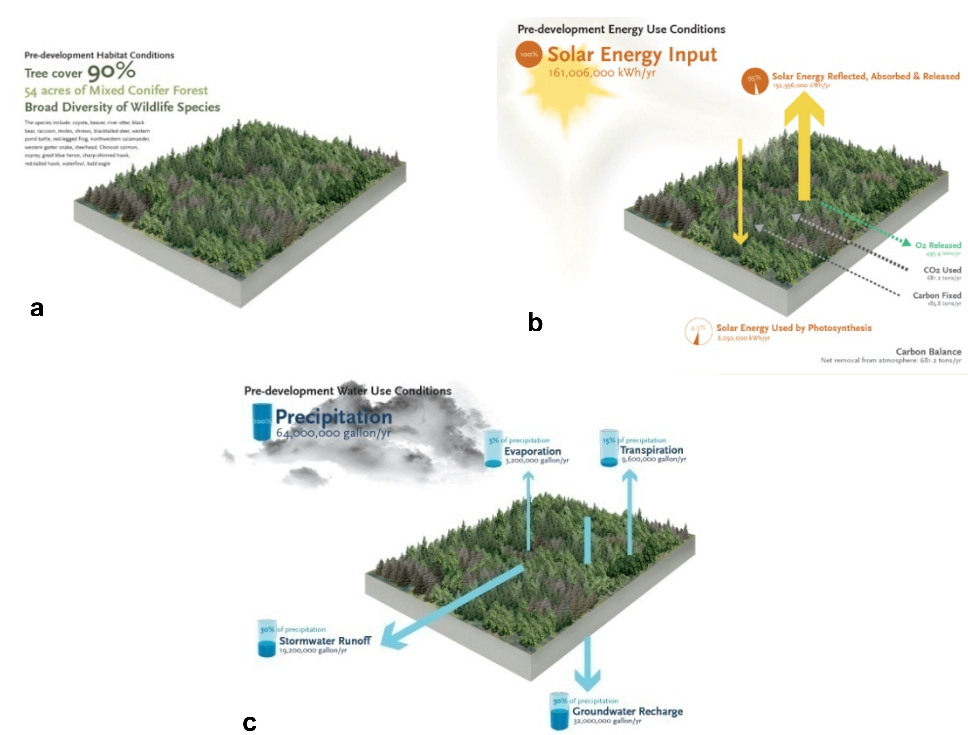
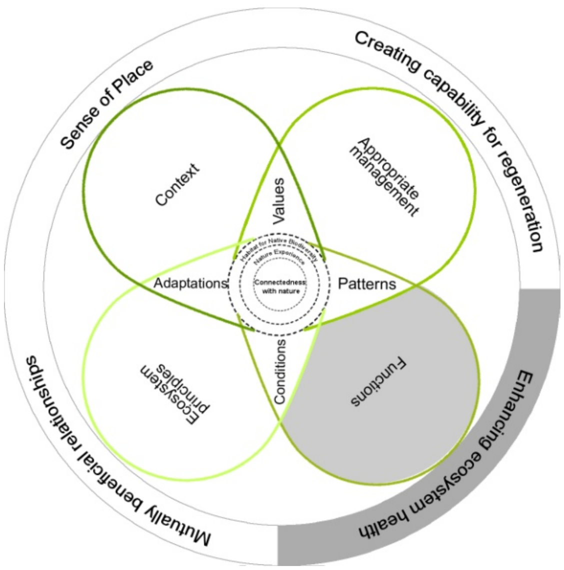


Figure 5.5. Pre-development (a) habitat, (b) energy and (c) water metrics for the Lloyd Crossing Sustainable Urban Design Plan & Catalyst Project (from Mithun 2004).

5.2 Ecosystem Health



You cannot have well humans on a sick planet – it's obvious… Human health is a subsystem of the Earth's health.

Thomas Berry (Day 2002:113)

The concept of 'health' is treated in various ways within discussions of the built environment. Both human health and ecosystem health are recurring points of interest, however the treatment of the two is arguably unequal, favouring a focus on the effects of the built environment on human physical and mental health, and productivity. Discussions of human health are typically reserved to the effects of air and light quality, and material toxicity (Roodman & Lenssen 1995).

Ecosystem health, on the other hand, is most often discussed with regard to the built environment in terms of how it provides for human health. Rarely are healthy ecosystems described for their intrinsic value alone as a context for buildings. Rather, healthy ecosystems are seen as being important because of the services that they provide to human users of buildings. One of these services, which Kellert (2005) argues to be one of the most overlooked yet most significant because of its potential to contribute to the new ecological paradigm shift, are the biophilic benefits that ecosystems offer to people through nature experiences. He argues that the greater the environmental quality, i.e. the health of the ecosystem, the more positive the nature experience, and therefore the greater the biophilic benefit.

Human health and ecosystem health are therefore clearly linked with regard to the built environment (figure 5.6). However as Reed (2007) suggests, an emphasis should perhaps be placed on restoring ecosystem health as it is the primary basis for sustainable community design due to the reciprocal benefits between ecological integrity and human emotional health. By contributing to the healing and restoration of native ecosystems, buildings can therefore help maximize the health benefits to both humans and to the ecosystem as a whole.

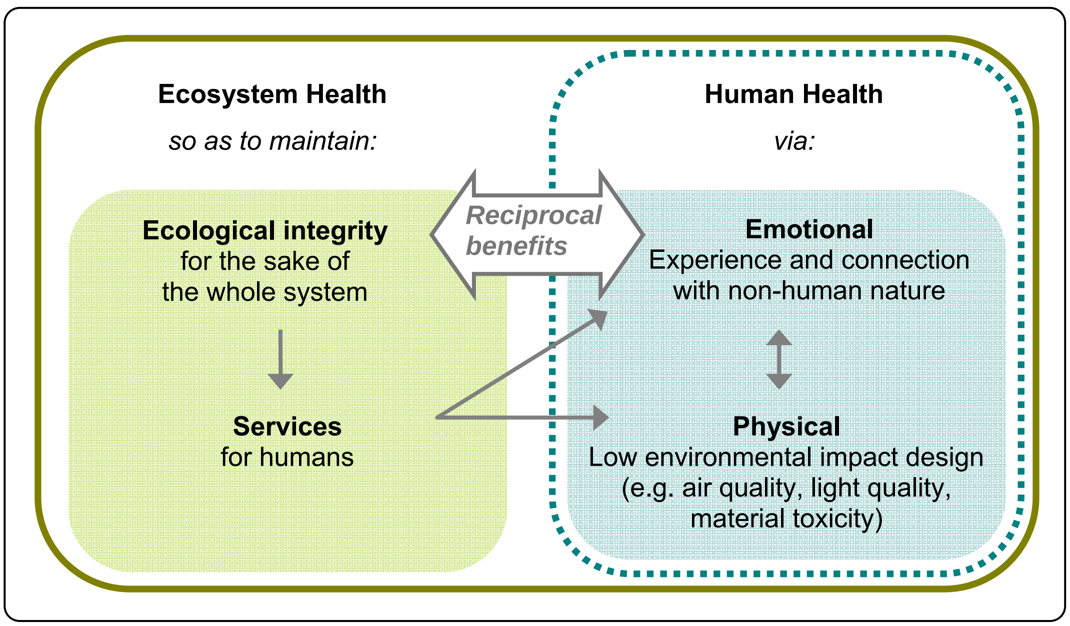


Figure 5.6. Categorical division of the discussion of 'health' in architectural literature and the links between them.

But what exactly is ecosystem 'health'? Depending on one's purposes or background, this may mean a range of things. Conservationist Aldo Leopold defines ecosystem health as the "capacity of the land for self-renewal" (Leopold 1949:221), whereas the Canadian Forest Service emphasizes the utilitarian value placed on ecosystem health by defining it as the capacity to maintain its ecological functions while meeting the economic needs of society (NR Can 2006).

The Society for Ecological Restoration International, whose goal it is to restore ecosystems to health defines ecosystem health as “the state or condition of an ecosystem in which its dynamic attributes are expressed within ‘normal’ ranges of activity relative to its ecological stage of development” (SER 2004:7). It includes in that definition the concept of integrity, i.e. possessing the biodiversity necessary to sustain normal ecosystem functioning. The common thread uniting these, and others’ definitions (e.g. Kimmins 1996, Rapport et al. 1998, Clewell et al. 2005) is the underlying importance of the functioning and dynamism that exist in a healthy ecosystem. Therefore buildings that enhance ecosystem health will be those that encourage normal ecosystem functions.

5.2.1 Functions

Ecosystems must be able to uphold their basic functions in order to remain healthy. The state of these functions therefore dictates the overall performance of the whole system. The individual members of an ecosystem (its plants, animals (human and non-human), and microbes) each influence this performance through the processes of their life activities (Christensen et al. 1996). Collectively, these processes contribute to specific ecosystem functions, which can be categorized as habitat, regulation, or production functions (de Groot et al. 2002) (table 5.1). The function of providing habitat can perhaps be considered the most crucial, however, since an ecosystem’s functional characteristics are a direct consequence of their structural features (Franklin & Spies 1991). Since habitats are composed of structural features, they are indicative of the functions upheld by the ecosystem.

Contrary to the often quoted ‘form *follows* function’ principle in architectural design, it is believed that in ecosystems ‘form *determines* function’ or rather ‘function follows form’ (Sauer 1998, Spies 1998, SER 2004). Lyle (1994:43) perhaps best describes this relationship in more systemic and feedback inclusive terms using “flow follows form follows flow”, where ‘flow’ represents the processes that contribute to function. Buildings are in essence structural elements that take on various forms. If their structures were to include forms representative of their native ecosystem, then perhaps they would be better equipped to uphold the functions appropriate to their site.

Table 5.1. Functions and processes of natural ecosystems (adapted from de Groot et al. 2002).

Ecosystem Functions	*Processes*
Habitat Functions	*Providing habitat (suitable living space) for wild plant and animal species*
Refugium	Provision of habitat for resident and transient populations
Nursery	Provision of reproductive habitat
Production Functions	*Provision of Natural Resources*
Food production	Conversion of solar energy into consumable form as sustenance
Raw materials production	Conversion of solar energy into biomass for uses other than sustenance
Genetic resources	Assurance of existence of genetic information
Regulation Functions	*Maintenance of essential ecological processes and life support systems*
Gas regulation	Regulation of atmospheric composition (CO2/O2 balance, O3, SOx)
Disturbance prevention	Dampening of env. Disturbances & fluctuations by ecosystem structure
Water management	Regulation of hydrological flows
Soil regulation	Retention & Formation of soils
Nutrient regulation	Acquisition, storage, processing and cycling of nutrients
Toxin regulation	Removal & breakdown of excess and harmful nutrients and compounds
Pollination	Movement of floral gametes
Biological population control	Population control through trophic-dynamic relations

Diversity

Biodiversity, the genetic variety, species variety, and functional variety that make up ecosystems, has been shown to be essential in the ability of an ecosystem to function, maintain itself and remain resilient (Naeem et al. 1994, Schulze & Mooney 1994, Tilman et al. 1996). Functional diversity, the range of services provided by various species or smaller ecosystems, is particularly important as it provides a system with resiliency, or the ability to return to a dynamic steady state following a disturbance. The diversity of structural form that results from species diversity, particularly that of plants, also contributes to the system's functioning and resiliency. It provides a variety of microhabitats that support various plant and animal species which, in turn, increases the potential for niche differentiation and further functional diversity (Spies 1998). Therefore, the greater the biodiversity across a variety of scales, the more effectively resources are used. This provides the system with both a variety of and redundancy in responses to disturbance, resulting in healthier systems over the long term (Diaz & Cabido 2001, Peterson 2002).

The biodiversity of ecosystems at all scales has been dramatically reduced by current processes of urbanization and the appropriation of resources for human use (Vitousek et al. 1997, Adams et al. 2006). This reduction in the number of species and their populations has therefore had a significant impact on the functioning of ecosystems worldwide. In addition to homogenizing species composition, development has fragmented and degraded habitats, disrupted hydrologic flows, and modified energy flow and nutrient cycling (Alberti 2005). This degradation of ecosystem functions has occurred as a result of the processes humans have used to produce functions in their own urban habitat. Despite ecosystem and building functions being closely analogous (table 5.2), the processes by which they are achieved tend to differ, often resulting in incompatible patterns and conditions and disconnected functioning. Perhaps then through the re-structuring of human habitats to include the structure of native ecosystems and their biodiversity, the functional diversity of native ecosystems can be regained.

Table 5.2. Analogies between ecosystem and building functions.

Ecosystem Functions	Processes	Ecosystem Examples	*Building Functions*	Processes	Building Examples
Nursery (Plants)	Provision of reproductive habitat	Growing surface and soils	*Protection from elements (weather, biological) & Privacy*	Protection from the stresses of extreme temperatures, high winds, excessive ultraviolet radiation and intruders; Acoustic & visual privacy	Walls, roofs; Spatial design and materials selection to dampen the transmittal of sound and interrupt incoming sightlines.
Refugium (Animals)	Provision of habitat for resident and transient populations	Tree trunks for cavity nesting birds; Branches for roosting			
Food production	Conversion of solar energy into consumable form as sustenance	Leaves, fruits, seeds	*Food production*	On-site provision of food for building users	Urban agriculture on living walls and roofs, windowsill gardening
Raw materials production	Conversion of solar energy into biomass for uses other than sustenance	Branches for nest building	*Energy collection & use; Resource production & use*	Passive and active production and use of energy; Material resources are recycled and reused within and between buildings.	Thermal mass, solar heating, building integrated photovoltaics; Deconstruction material reuse
Nutrient regulation	Fixing, storage, processing and cycling of nutrients	Nurse logs			
Soil regulation	Formation & retention of soils	Fallen leaves decay and contribute organic matter to soils; Root systems hold soil in place	*Structural support*	Assembly of materials to create structure that carries loads and protects against environmental disturbances (e.g. seismic, flooding, wind)	Foundations, walls, roofs
Disturbance prevention	Buffering of environmental disturbances & fluctuations via the stability of ecosystem structure	Soils store water, reducing flooding; Foliage intercepts rainfall preventing compaction and erosion			

Table 5.2. (cont'd) Analogies between ecosystem and building functions.

Ecosystem Functions	Processes	Ecosystem Examples	*Building Functions*	Processes	Building Examples
Moisture regulation	Regulation of hydrological flows through evaporation, evapotraspiration, infiltration,topography, and storage	Foliage intercepts rainfall that is then more gradually held and released by soils	*Moisture regulation*	Water acquisition & use; Maintenance of comfortable humidity levels	Creation, conveyance and cycling of potable, grey and black water
Gas regulation	Regulation of atmospheric composition (CO_2/O_2 balance, O_3, SO_x)	Photosynthesis	*Ventilation*	Ventilation strategies which provide air flow and gas flux, particularly that of CO_2 & O_2.	Windows, HVAC
Toxin regulation	Removal & breakdown of excess and harmful nutrients and compounds	Leaf veins channel water to clean leaf surface; Wetland sedimants and plants absorb and breakdown excess nutrients	*Sanitation*	Cleansing of air, water, surfaces and waste management	Proper ventilation, materials selection and on-site water treatment

5.2.2 The relationship between patterns, ecosystem functions and ecosystem health

When discussing pattern with respect to ecosystem function, three scales can be considered:

- structural form and pattern of individual features; which gives rise to a
- pattern in community composition and succession; which in turn contributes to
- landscape patterns

The manifestation of these patterns will determine which functions the system can uphold and to what degree. Currently, in most urban areas, pre-existing patterns characteristic of native ecosystems have been replaced by very different patterns of human development (figure 5.7), threatening the ability of local ecosystems to function. The buildings in such areas occupy a considerable portion of the landscape and are therefore significant contributors to this discrepancy (Forman & Godron 1986). Creative and purposeful re-design of these structures could enable the native patterns to emerge again, helping to restore the ecosystem's ability to function (Alberti 2005, Apostol et al. 2006).

The first task in the process is to determine the most appropriate health-generating pattern of relationships for a particular project in its place (Reed 2007). This will mean restoring pre-existing patterns to the greatest degree possible, while merging growing space for human uses (e.g. urban agriculture) with them in a way that is consistent and does not impede function. This may require compromise and consideration of adjacent and alternate uses of growing space when both habitat and agricultural requirements compete for the same space.

In the context of this thesis, the function of providing habitat is considered primary because, by its nature, and when healthy, it is inclusive of the other regulation and production functions in non-human nature. The patterns that will contribute to habitat for non-human species will be those that are characteristic of native ecosystems. The ways in which human habitat can be incorporated into these patterns and how non-human nature can be incorporated into human patterns will be highly dependent upon the scale under consideration.

Figure 5.7. Characteristic patterns at the (i) watershed; (ii) stand/neighbourhood; (iii) patch/property scales of (a) an intact forest and (b) an urban area.

Patterns and function at the scale of the neighbourhood

At the larger scale of the neighbourhood (figure 5.7ii), a homogeneous pattern of properties and road networks emerges, reflecting a highly regimented pattern of pervious and impervious surfaces (Band et al. 2003). In contrast, a non-human dominated landscape viewed at the same scale, would reflect the similar heterogeneity and diversity as that experienced at the smaller scale. This basic similarity at different levels of scale is the result of fractal growth patterns (Heerwagen 2003), that reflects a connectivity that tends not to occur in current human dominated systems.

In urban areas, the patterns that emerge are typically ones of increased impermeability, inhibited successional development and resulting decreased habitat connectivity. Impervious surfaces, along with manicured lawns and gardens represent 'permanently young' systems with little diversity, held back from developing according to their natural tendencies. These types of properties fragment the landscape and lessen its ability to uphold its functions at the larger scales. Therefore the successional stage (the developmental stage of an ecosystem as it moves from bare ground to mature vegetation) appropriate to the larger scale of the watershed will influence the specifics of the design at the smaller scale of the building.

Where larger scale successional patterns are being lost, as in most urban and suburban areas, small patches that are connected and reflect a similar successional stage can provide useful, heterogeneous bits of nature throughout developed areas. These small patches can be in the form of individual properties and their structures aggregating into entire neighbourhood blocks. "The yard scale, the property occupied by a single residential dwelling, is relatively small, but a mosaic of environmentally beneficial yards can in the aggregate contribute to ecological health" (Nassauer, 1997). Furthermore, small patches, whether physically connected or acting as stepping stones[2] provide different benefits and can be considered supplemental to large patches

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[2] A stepping stone is an ecologically suitable patch of habitat where an animal temporarily stops while moving along a heterogeneous route (Forman 1995a).

(Forman 1995a, Sauer 1998, Rudd et al. 2002, Rosezweig 2003) (figure 5.8). Adjacent blocks or neighbourhoods whose individual properties are connected can then act as larger stepping stones made of the smaller stepping stones of the individual properties. If enough neighbourhoods are involved, connectivity at the scale of the watershed and a restoration of larger landscape patterns becomes increasingly achievable. With an ever increasing interest in vegetated roofs and walls, the potential for buildings to contribute to the restoration of pattern at these various scales becomes increasingly possible and necessary (Kim 2004).

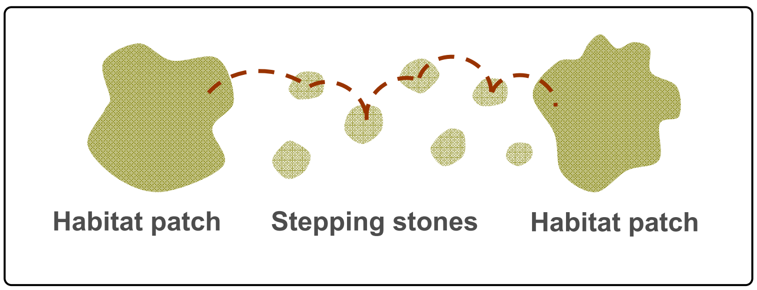


Figure 5.8. The role of stepping stones in creating connectivity between habitat patches. In an urban area, roof tops and vegetated built structures can compliment landscaped properties and act as stepping stones between urban forests.

Patterns and function at the scale of the building

At the smaller scale of the individual building (figure 5.7iii), local ecologies and habitats will be expressed by the structural form and pattern of their individual features. The roofs, walls and other exterior elements of buildings can be used to incorporate these features, which include the structural diversity and distribution of plants and plant communities, soil formation, stream-flow patterns and hydrology. At this scale, the more detailed patterns that reflect differences in microclimate at a site become apparent. In the human built environment, these microclimates, and the micro-ecosystems they produce will not only be influenced by the same elements influencing non-human dominated sites (e.g. topography, solar gain, wind, precipitation, air temperature), but they will also be highly influenced by the distribution of pervious and impervious built surfaces. Therefore at the building scale, the ability of a site to provide habitat for all of its inhabitants, both human and non-human, would be enhanced by balancing the microclimates humans need to live with the restoration of the microclimates needed for elements of native ecosystems to thrive. These microclimates or ‘conditions’ will be discussed further in the next section.

Although human-made patterns that represent non-human forms, or what Kellert (2005) terms ‘indirect or symbolic attributes of organic design’ (e.g. human constructed organic, curvilinear shapes, fractal patterning) have been shown to have biophilic benefits (Heerwagen 2003, Kellert 2005), they offer little or no ecological benefits. Furthermore, biophilic benefits have been shown to be greater when non-human elements, or what Kellert (2005) terms ‘direct attributes of organic design’ (e.g. real plants vs. artificial plants) are used (Wilson 2006). The approach in this thesis therefore proposes that whenever possible, non-human elements of native ecosystems should be considered, instead of artificial representations, in order to maximize both ecological and biophilic functions.

Green Façades as Stepping Stones

The City of Malmö, Sweden encourages developers in their Western Harbour district to cover all walls with plants, make the roofs of all buildings in their development green roofs and to plant native species. This widespread use of vegetated façades can provide stepping stone habitat for birds, insects, and any other organism to which the façade is accessible (figure 5.9a).

In 1985, the City of Stuttgart, Germany became the first city worldwide to establish a green roof policy and implementation plan. It promotes green roof development by greening public buildings, offering financial incentives for homeowners and regulating green roofs in local development plans (Lawlor et al. 2006). As of 2006, 105,000 m^2 of public roofs were vegetated, providing a mosaic of stepping stone habitats within the urban core (Lawlor et al. 2006) (figure 5.9b).

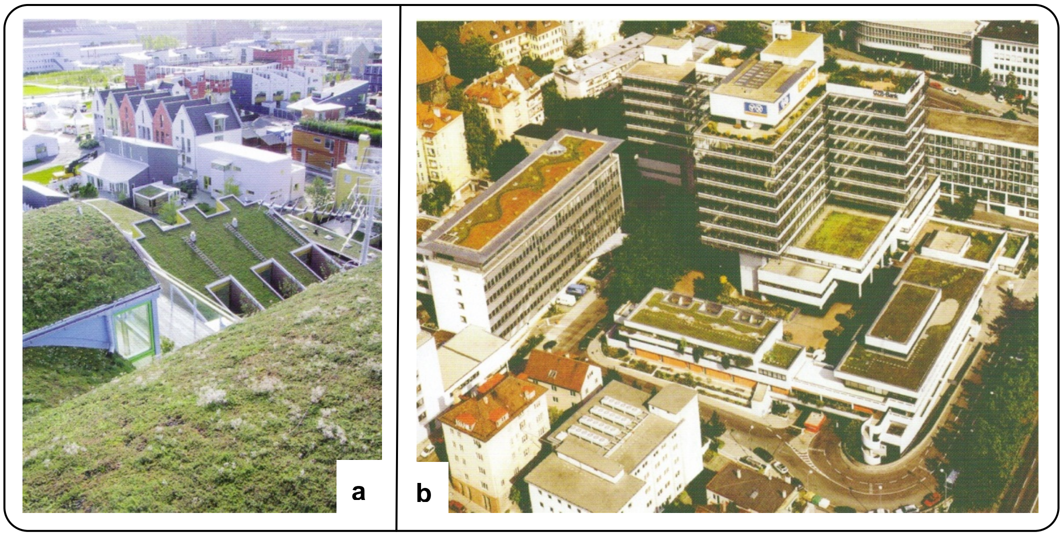


Figure 5.9. Green roofs in (a) Malmö, Sweden; and (b) Stuttgart, Germany (from Earth Pledge 2005).

5.2.3 The relationship between conditions, ecosystem functions and ecosystem health

A certain range of conditions are required by both non-human species and humans for their communities to thrive. These communities also produce a variety of conditions depending on their structure and pattern. When the conditions produced are congruent with those required, ecosystems are better able to uphold their functions and are more likely to be healthy systems.

At the larger scale of the neighbourhood and watershed, those basic conditions required by the non-human aspects of ecosystems, but most influenced by the human aspects, will be soil availability and connected growing space. Where those conditions are available, larger scale functions are more likely to be upheld, and will then be dependent on climate patterns (e.g. temperature, moisture) and resulting ecosystem types and successional stages. At this larger scale, the ‘conditions’ reflected in a landscape are therefore actually patterns resulting from smaller scale conditions.

At the smaller scale of the building, the function of providing habitat will primarily be driven by microclimatic conditions that determine growth and structural form, i.e. what can grow in a setting and how well it grows. Different ecosystem types (e.g. meadows, forests) consist of different species and will therefore require different microclimatic conditions to develop. For example, a meadow will require more open, sunny areas, while many forest plant species, depending on which successional stage they predominantly participate in, require shadier, moist conditions. By the massive nature of buildings, they will invariably produce a variety of microclimates that will be suitable to different plant communities. Through their built structures, humans can therefore help produce the conditions that will encourage diverse native plant communities.

Native plants can also help to produce the conditions desired by humans. These conditions can be thought of as fulfilling three types of functions:

- Physical comfort
  - In terms of physical comfort, the conditions produced will be highly dependent on the ecosystem type. For example, a meadow with low-lying vegetation and widely interspersed trees will have drier, more open conditions with localized shading, whereas a forest ecosystem will likely produce shadier, moister conditions depending on over storey height. These conditions will change over time, not only during the day with the movement of the sun, but also seasonally. What trees provided shade and cooling in the summer, may allow light to filter through leafless branches in the winter. Seasonal variation of native ecosystems thereby creates opportunities for variations in building design.

- Resource supply
  - Although native plants can contribute to local food supply, growing space will likely be used more efficiently if it is shared between native plants and urban agriculture. Merging the functions of providing habitat for non-human species with proving local food production for humans may perhaps be more successful where native plants prefer partial shade conditions, such as in the forests of the Pacific Northwest, thereby leaving sunnier microclimates available for urban agriculture.

- Biophilic benefits
  - The integration of buildings with their native ecosystems, as proposed in this study, can also produce conditions that offer biophilic benefits (table 5.3). One of these benefits relates to the diversity of native plants potentially supported by the variety of microclimatic conditions produced by buildings. When incorporated at the larger scale of the neighbourhood, these conditions benefit not only those people directly in contact with them at the small scale of the individual building, but they also benefit people from afar, by, for example being able to view them from a window (Kaplan 2001).

Table 5.3. The conditions produced by the key features of biophilic buildings (from Heerwagen & Hase 2001).

Key Dimensions	Attributes, Qualities and Conditions
Prospect (ability to see into the distance)	- Brightness in the field of view (windows, bright walls) - Visual distance - Ability to get to a distant point for a better view - Horizon/sky imagery (sun. distant mountains, clouds) - Strategic viewing locations - view corridors
Refuge (sense of enclosure or shelter)	- Canopy effect (lowered ceilings, screening, branchlike forms overhead) - Variation in light levels (darkness suggests refuge) - Enclosing surfaces (walls, partitions, screens) - Penetrable barriers and surfaces for views out
Water (indoors or in views)	- Glimmering or reflective surface (suggests clean water) - Moving water (also suggests clean, aerated water) - Symbolic forms of water
Biodiversity	- Varies vegetation indoors and out (large trees, plants, flowers) - Windows designed and placed to incorporate nature views - Outdoor natural areas with rich vegetation and animals
Sensory Variability	- Changes and variability in environmental colour, temperature, air movement, textures, and light over time and space
Biomimicry*	- Design derived from nature - Use of natural patterns, forms, textures - Fractal characteristics (self-similarity at different levels of scale with random variation in key features, rather than exact repetition)
A sense of Playfulness	- Incorporation of décor, artifacts, objects, spaces whose primary purpose is to delight, surprise, amuse
Enticement	- Discovered complexity - Information richness that encourages exploration - Curvilinear surfaces that gradually open information to view

* Heerwagen and Hase use the term ‘biomimicry’ to refer to what Heerwagen has called ‘bio-inspired’ organic design in other literature (e.g. Heerwagen 2003). Here, biomimicry therefore refers strictly to shape and form.

The City of Malmö, Sweden

A case study that contributes to ecosystem health and functions by balancing the conditions required by local biodiversity with those produced by humans is the City of Malmö, Sweden. The city developed a system of ‘green points’ from which developers in its Western Harbour district are required to choose at least 10 out of 35 measures to apply to the design of their development. The goal of the ‘green points’ system was to encourage the development of a “habitat-rich” city district. To achieve that, some of the points include building a nest box for every dwelling unit, integrating shelves into house fronts suitable for swallows to nest on, covering all walls with climbing plants, making all roofs green roofs, having at least 50 species of native plants in the courtyard, and providing $1m^2$ of pond for every $5m^2$ of concrete area (Kellert et al. 2008). The result is a mosaic of habitats including green roofs and walls, wetland retention ponds and courtyard gardens (figure 5.10). Monitoring indicates that nine different species of seabird have already begun breeding in the development, three species of bats feeding and several species of fish, molluscs, mussels and crustaceans occupy the saltwater canal (Fry 2009).

Figure 5.10. Western Habour water systems and 'green point' design measures, Malmö, Sweden (TCPA 2004).

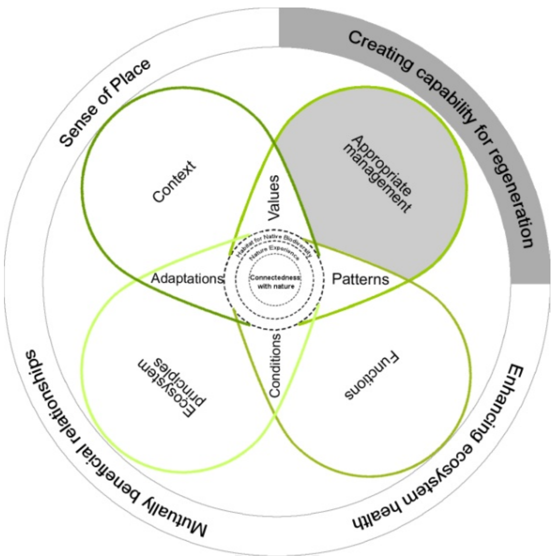
Incorporating nesting sites into buildings

Johnston and Newton (2004:42) also offer suggestions of alternative ways to incorporate nesting sites into buildings (table 5.4). Examples include incorporating traditional nest boxes into walls, removing bricks, creating gaps and providing ledges.

Table 5.4. Examples of how to integrate nesting sites for specific species into buildings (TCPA 2004, adapted from Johnston and Newton (2004)).

Nesting site	Species	Action
Open-fronted box	Flycatchers, robins, wagtails, blackbirds	Replaces bricks
Hole-entrance box	Tits	Needs to be removable
Quarter sphere	House martins	Under eaves and terraces
Small cavities	-	Remove facade brick(s)
Gaps between roof	Swifts, bats	Small gap or special tiles
Purpose made bricks	Bats	Replaces bricks
Ledges	Kestrels	Design-in at high level

5.3 Regenerative Capability



It is humans that need managing, not the planet.

David Orr (Willers 1999:7)

Humans are a defining and dominant part of urban ecosystems and as a result play a significant role in the processes that occur there. Conservation and preservation, the act of setting aside land and protecting existing natural areas from human development or exploitation are important for wildlife as they provide refuge and opportunities for interactions with other native and non-human species. However, with an ever increasing human population there appears to be only so much space left to preserve, particularly in urban areas (Rosenzweig 2003). The idea of re-integrating humans with their native ecosystems as proposed by this study suggests that segregating humans and other species is not necessarily an effective method of ensuring either of their well-being. Humans inherently need other species for emotional well-being as well as to maintain life supporting ecosystem processes. Moreover, at this point in time with the degree of damage already done, non-human species also need humans to participate in and speed up the healing and restoration process before irreparable damage is done and more species are lost.[3] If

[3] In Holmes' (2006) article Imagine the Earth without people, where the author asks what would happen if all humans disappeared tomorrow, it is suggested that for some ecosystems it may already be too late due to the stronghold of

humans are to become integrated with the rest of nature, then we must learn how to provide for the positive coexistence of both other species and ourselves in the same space. As proponents of restorative, reconciliation, and regenerative ecology suggest, we must learn to share our habitats deliberately with other species (McHarg 1971, Rosenzweig 2003, Kellert 2005).

The term ‘regeneration’ implies continuous renewal, and in the context of this thesis, it refers to that of ecological processes and their biodiversity, along with human prosperity. As Haggard (2002:24) points out, the related term ‘regenerative’ can be applied to architecture and infrastructure that “improves the living and working conditions for both natural and human communities by healing the earth *through* development.” It consists of not only self-sufficient development that provides for the “continuous replacement, through its own functional processes, of the energy and materials used in its operation” (Lyle 1994:10), but also that which participates in and allows for the renewal of the functions of local non-human ecosystems (Eisenberg & Reed 2003).

Typically, however, development and human involvement in a landscape are extensive and as a result detrimental as we often tend to over-utilize and over-manage non-human nature. Building sites (the land around a building but especially the land they displace) are frequently void of the patterns and functions typical to the site before development by humans – forests no longer grow where they once did, water no longer follows natural contours, and native soils are replaced by gravel and fill (Lyle 1994, Day 2002). Consequently regeneration can only occur once restoration has paved (or rather de-paved) the way. Restoration will help to initially repair systems, while appropriate management and regenerative community design will help to continually renew them (Clewell et al. 2005). By participating in the ecological functions of the land they displace, buildings can therefore act as vehicles for the restoration, and ultimately the regeneration process (Reed 2007) (figure 5.11).

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invasive species. It is also argued that although they may crumble in a few hundred years, remnants of most human-made structures will last thousands of years due to the persistent nature of their materials.

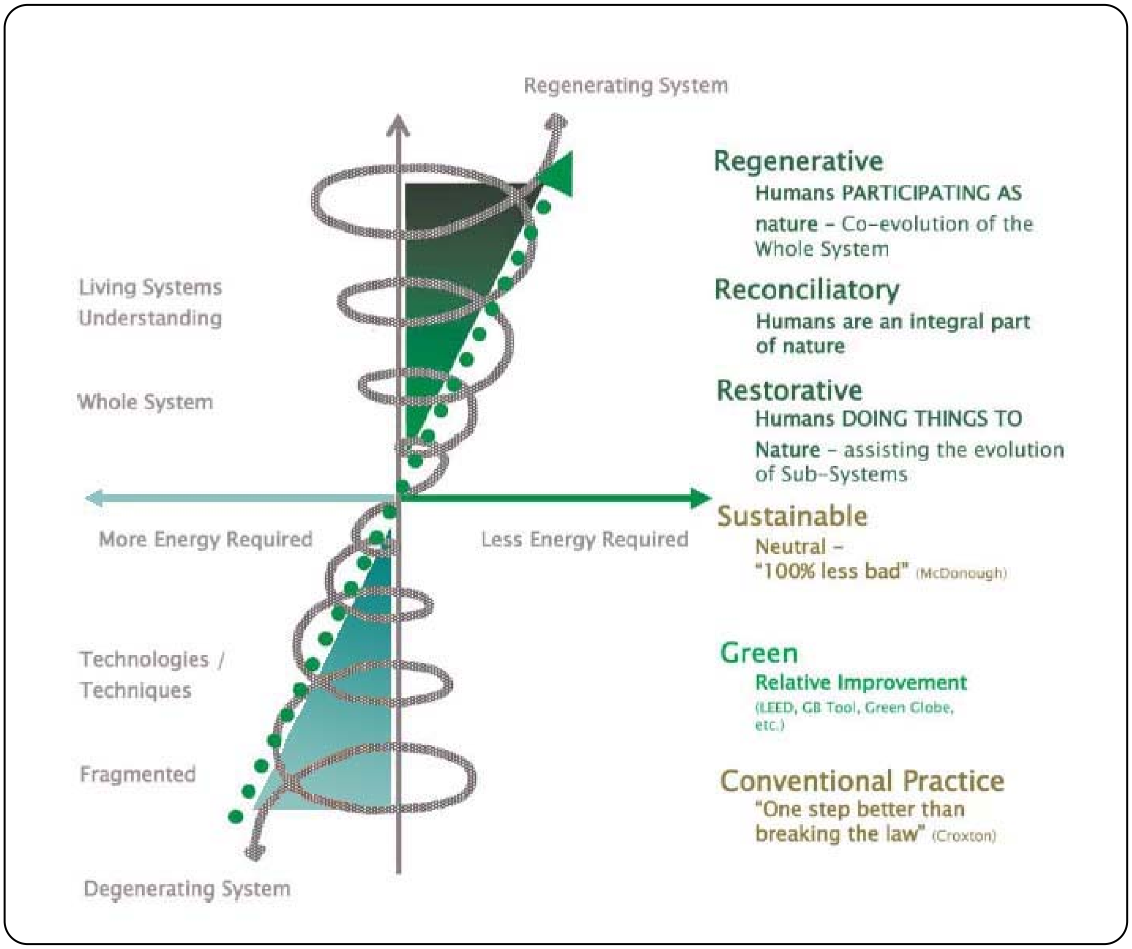


Figure 5.11. Trajectory of environmentally responsible design towards restorative and ultimately regenerative design (from Reed 2007).

5.3.1 Appropriate management

The term management can be defined as "the use of means to accomplish an end" (Merriam-Webster 2007) or the "practice of control" (Collins 1986). Ecologically speaking, humans have assumed various degrees of management of the world's ecosystems (MEA 2005) – various extents to which they have controlled ecosystem processes, more often than not, for means that benefit humans. Land has been managed for thousands of years by humans, historically for sustenance and more recently for resource use purposes (Ponting 1992). Actions have ranged from over-management (severely altering the ability for ecosystems to function) to adaptive management (making changes to the management plan based on the reaction of the system to past actions) to no management (allowing the system to regenerate without human involvement) (Christensen et al. 1996, Apostol 2006). By their current design, buildings and their infrastructure typically reflect the former category of over-management, permanently monopolizing the landscape. It is therefore perhaps the actions of humans that are in need of management, rather than the systems they are intended to control (Christensen et al. 1996, Orr 1999).

A concept quickly gaining acceptance as the appropriate form of management in ecological fields is that of 'ecosystem management'. The ecosystem approach to management is a strategy for the integrated management of land, water and living resources that promotes both the conservation and sustainable use of biodiversity (Shepherd 2004). Its major goals are the restoration and maintenance of the structural diversity of ecosystems while accommodating human use and it promotes the use of ecological rather than political boundaries (Grumbine 1994, Christensen et al. 1996). It also recognizes the need to focus on the hierarchical connections between various spatial and temporal scales of ecosystems and highlights the potential for humans to contribute to ecological integrity across these scales through interagency cooperation and involvement of local knowledge and expertise.

Whereas ecosystem management brought discussions of humans and development into ecological circles, its principles can be applied to the built environment to help bring the discussion of ecology and biodiversity to the architectural domain.

As discussed in the previous sections, the recognition that ecological boundaries traverse political ones can lead to a greater understanding of ecological context at both the local and larger scales. At the local scale, this would imply some degree of cooperation between property owners and inhabitants, whereas at the larger scale of the watershed it could involve multiple municipalities and policy-makers. From a design standpoint, this would require coordination not only with owners but also between the various jurisdictions of planners, landscape architects, and architects. Ecologists would also necessarily play a large role in such an integrated design process. By helping to bring native ecosystems to individual properties and buildings, ecologists and designers have an opportunity to encourage ecological literacy and environmental advocacy at the level of the local citizen, upon whose involvement any management efforts of this kind are dependent (Grumbine 1994, Horwitz et al. 2001).

5.3.2 The relationship between ecological values, management and regenerative ability

Over the past 30 years, Western societal values regarding non-human nature and human management of it have changed significantly in an overall ecologically positive direction. Where non-human nature was once habitually valued solely as a resource to be exploited, it is now increasingly viewed as having intrinsic and instrumental value (Dunlap et al. 2000). This shift has caused a widespread adoption of 'ecosystem management' methods that consider the value and functioning of the system as a whole, in addition to individual species (Shepherd 2004).

With regard to the built environment, values too have shifted from what used to be an exclusively domionionistic and negativistic view of nature in conventional building towards an appreciation of nature for its utilitarian value when integrated with buildings. Ecosystem-based design now has the opportunity to further shift these values beyond seeing nature as something to be used to more inclusive naturalistic and biospheric values. Such a shift, however, will also require a shift in the way we manage nature in the built environment. In order to create a regenerative relationship, non-human nature needs to be allowed to renew itself. This may require a shift in specific values – aesthetic ones being of particular importance, especially in residential areas where much pride is taken in 'controlling' nature to produce 'neat' properties (Nassauer 1993). Furthermore, the successful restoration of native ecosystems and acceptance or preference for native plants will likely take a large shift in the assumption that 'native' implies messy and abandoned (Nassauer 1995, Sauer 1998).

Nassauer's (1995) theory of "cues to care" and Sheppard's (2001) theory of a "visible stewardship" can be applied to buildings to support the argument that 'messier' native plants and features of native ecosystems can be accepted and perceived as attractive when integrated with buildings. The idea behind 'cues to care' is that people find attractive something that indicates human intention and care for the object (Nassauer 1995), whether it be a landscaped property or in the case of this study, a building integrated with its ecosystem. Similarly, objects that reflect a ‘visible stewardship’ are those that “show people’s care for and an attachment to” those objects (Sheppard 2001:159). It is likely that buildings that incorporate native plants and features of native ecosystems have done so intentionally and will be more likely to be recognized as such, whereas a native landscape can more easily be misinterpreted as uncared for. Buildings can therefore potentially overcome what are presumably cultural biases against so-called messy ecosystems because of the obvious care that had to be taken to produce such a design.

Prairie Crossing Conservation Community – Grayslake, Illinois

An example of meeting both human needs and human values while also meeting restoration goals is the Prairie Crossing Conservation Community located just outside of Chicago, Illinois. Prairie Crossing demonstrates that native landscape preservation and environmentally conscientious values can successfully be balanced with suburban living (Prairie Crossing, n.d.). Native prairie and wetland habitats were restored within a development consisting of 359 single family homes and 36 condominiums (figure 5.12). Its success appears to be its emphasis on comfort and aesthetics needing to not be compromised for environmental protection and enhancement. Perhaps also key to its success is the involvement of individual community members in the maintenance of the natural heritage and community experience, for example through environmental quality workshop and energy conservation contests (Prairie Crossing Homeowners Association, n.d.).

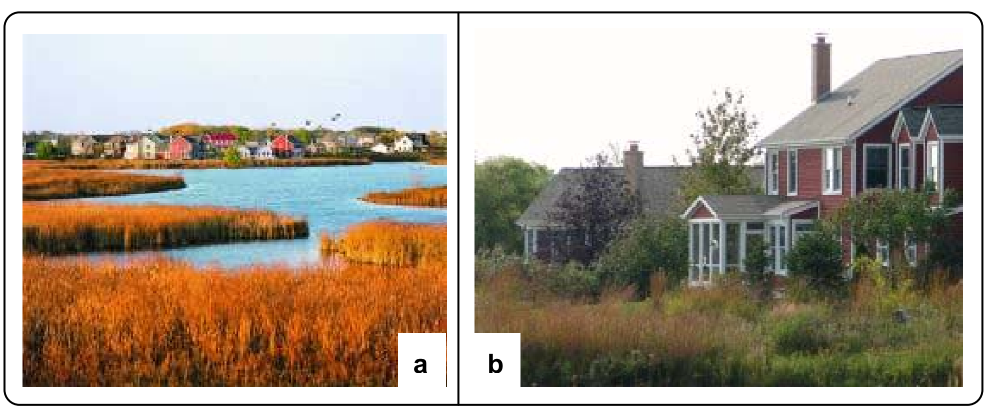


Figure 5.12. (a) Restored wetlands; and (b) prairie at Prairie Crossing, IL (from Prairie Crossing, n.d.).

5.3.3 The relationship between patterns, management and regenerative ability

As discussed earlier, for human systems to become regenerative, the non-human systems of which they are a part must first be restored and themselves regain regenerative ability alongside human development. The approach proposed in this thesis suggests that this restoration can at least be partially accomplished by incorporating the forms and patterns of native ecosystems into human built structures so as to dissolve current physical, functional and aesthetic disparities between the two. Since all human environments and their ecosystems are terrestrial, soils and growing space act as their foundation. As such, the necessary human uses of growing space need to be merged with the growing needs of native ecosystem plants.

There are therefore three patterns to understand and merge together when managing for regenerative ability – patterns of:

- biodiversity and habitat
- urban agriculture
- communities and infrastructure

Since this study is focusing on working with existing infrastructure patterns, the first two patterns will drive discussion.

Given that it has been argued that human systems cannot thrive in the absence of thriving non-human systems, the first priority should therefore be to understand and restore native biodiversity and habitat patterns. Patterns of successful regenerative communities “must be founded on biodiversity” (Thayer 2003:188), with opportunities for urban agriculture and infrastructure subsequently interwoven.

As recurrently suggested throughout previous sections, since ecosystems have no hard boundaries, restoring native biodiversity and habitat patterns and ultimately the regenerative abilities of a local ecosystem will require a focus on various scales (Grumbine 1994, Kay & Schneider 1994, Christensen et al. 1996). The restoration needs to be understood within the context of its immediate smaller ecosystem, or micro-ecosystem with localized conditions of the building scale, but perhaps more importantly also within that of its bioregion or macro-ecosystem to display existing patterns and the ways in which it relates to nearby systems in its watershed. Incorporating individual properties and stakeholders into the bigger picture of a management plan brings ecosystem processes down to a personal level, helping foster the human-nature relationship (Allison 2004). It also encourages a more appropriate and cohesive pattern at the larger scale. As Thayer (2003:191) states, “one cannot manage a watershed, only “many” can, and the “many” required to manage whole watersheds must talk to each other, see through each other’s eyes, meet in real time and space, share common goals, build trust, and mutually undertake the work of keeping the watershed functioning.”

Adam Joseph Lewis Centre for Environmental Studies – Oberlin College, Ohio

A case study that merges habitat with agriculture is the Adam Joseph Lewis Centre for Environmental Studies at Oberlin College in Oberlin, Ohio. The Centre was conceived as an integrated building – landscape system whose landscape features include a variety of ecosystems native to Northern Ohio (Oberlin College, n.d.). Wetlands, an emerging deciduous forest, and dry land community ecosystems were created adjacent to the building. Native saplings were planted in 2000 but will require 50-75 years to mature (figure 5.13). Understorey plant species typically found in the native deciduous forest, such as witch hazel and spice bush, were planted against the north side of the building which provides cool, shady conditions similar to those found under large trees (Oberlin College, n.d.).

Over one third of the building site is dedicated to edible landscaping that includes fruit trees, strawberries, blueberries and raspberries, and raised-bed organic vegetable gardens (figure 5.14). The gardens are maintained by students, staff and the Oberlin community (Orr 2004).

Figure 5.13. Ecosystem timeline at the site of the Adam Joseph Lewis Centre (from Oberlin College, n.d.).

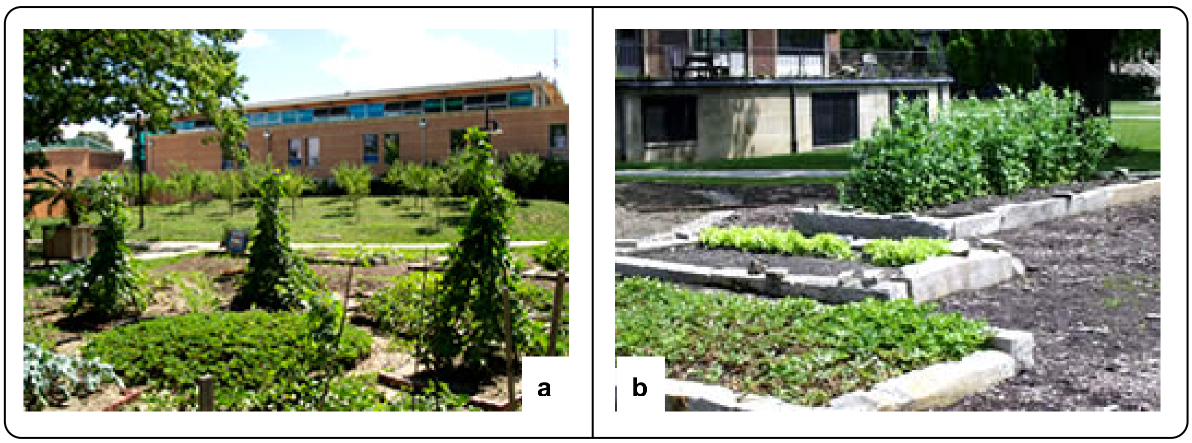
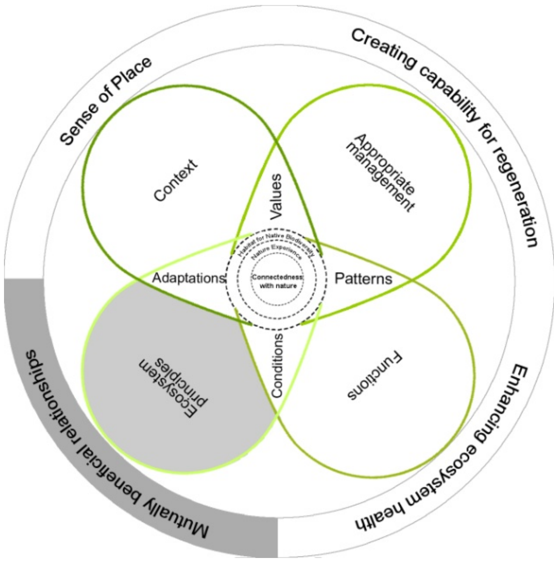


Figure 5.14. (a) Community demonstration fruit and vegetable garden north of the AJLC; (b) Raised beds (from Oberlin College, n.d.).

5.4 Mutually Beneficial Relationships



We have learned much from each of you. Our first inkling of what we are was shaped by communion with you Mr. Bear, and you Mr. Wolf, and you Ms. Salmon; indeed with all of you. We first came to know many of you as our teachers—the mirror by which we might better understand ourselves.

David Orr (2006:1571)

Humans, like all other species modify their environment for their survival. The distinction however is in the nature and scale of the modifications. Humans are not the most populous of the species (most insect species are far more numerous) nor are they the most abundant in terms of biomass (they are outweighed by termites ten to one). They are also one of the youngest species (figure 5.15) but despite this, have still managed to influence every ecosystem on earth (Vitousek et al. 1997, Sanderson et al. 2002, MEA 2005). Through the processes of their life activities, of which urban development is a large part, humans have transformed between one third and one half of the earth's entire land surface and as a result have been a primary driver of habitat and biodiversity loss (Vitousek et al. 1997). Humans therefore clearly play a key role in the earth's ecosystem processes which consequently have tended to be quite one-sided to their benefit. One of the goals of the approach proposed in this thesis is to return this unbalanced relationship between humans, their habitats, the earth's ecosystems and its some 5-100 million other species to a mutually beneficial and supportive one using buildings as key drivers of change.

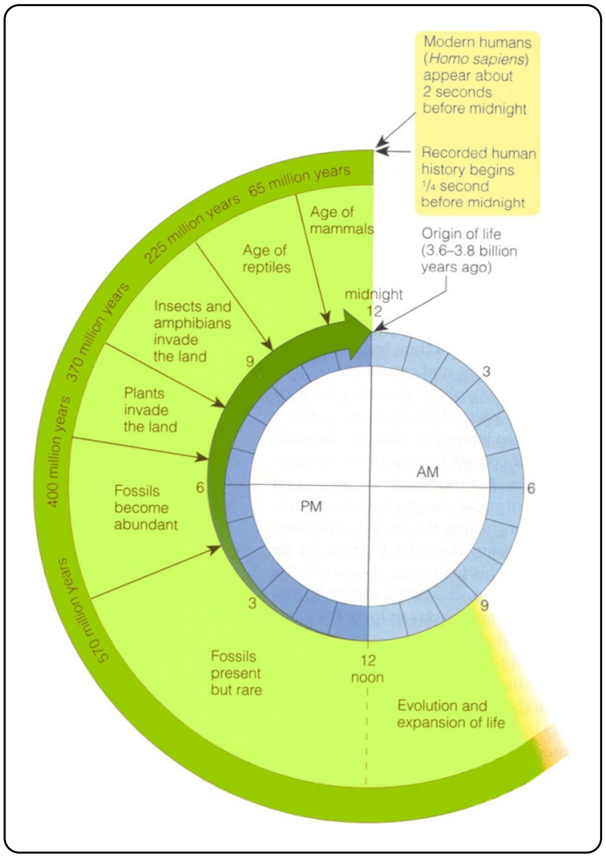


Figure 5.15. If the origin of life on earth is compressed into a 24-hour time scale, our species (Homo sapiens sapiens) appeared less than one second before midnight, with agriculture beginning one quarter of a second before midnight, and the industrial revolution having existed for only seven thousandths of a second (adapted from Miller 1997).

Because their influence is so widespread, and because humans are perhaps alone in their ability for reflection and foresight, they have a responsibility to take action on the earth's decline. Humans can no longer consider themselves exempt from the laws of nature, community, decency and courtesy (Orr 2006). As stated by Sanderson et al. (2002), "human beings are stewards of nature, whether we like it or not".

As stewards, however, there remains much to learn in the ways of living in partnership with one's ecosystem cohabitants. It is beginning to be recognized that humans stand out not only for their ability for foresight and reflection, but because they are the only species that does not act in the best interest of the ecosystem (Orr 2006). Other species instinctively act as though their survival depends on the survival of others around them, and that it is in their best interest not to jeopardize their fellow system members. It has been suggested then, that sustainability is only achievable if humans can re-learn how to act in ways indicative of non-human processes (Benyus

2002, Kibert et al. 2002a). Only then will mutually beneficial relationships that consider the whole system be possible.

So far, evidence presented within this thesis has suggested that opportunities exist for buildings to interact positively with their local and native ecosystems. This section builds on that premise by suggesting that such interaction need be reflective of the ways in which non-human species interact, i.e. through mutually beneficial relationships. The human built environment can therefore potentially be designed to *act like* its ecosystem in order to more effectively *interact with* it.

5.4.1 Ecosystem principles

The strategies required to create mutually beneficial relationships with other members of one's ecosystem can be described as ecosystem principles. Ecosystem principles state in general terms how life works and why living systems survive as they do. The framework proposed here suggests that for human systems to be integrated and interact with their ecosystems, they must also act like those systems by adhering to ecosystem principles.

The ecosystem metaphor, presented in the form of ecosystem principles has recently been investigated in fields such as biomimicry, and industrial and construction ecology (Korhonen 2001, Benyus 2002, Kibert et al. 2002a, McDonough & Braungart 2002, Graham 2003, Biomimicry Guild 2007, Perdersen Zari & Storey 2007) [4]. Interestingly, traditional ecology and

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[4] It is important here to distinguish between natural 'laws' and ecological or ecosystem 'principles'. A *law* of nature is universal across scientific disciplines and describes either the way the physical, non-living world *is* or how non-living phenomena *must occur*. Lawton (1999) outlines these universal laws as:

1. The first and second laws of thermodynamics.
2. The law of conservation of matter.
3. Darwin's law of natural selection.
4. Physical and physiological laws – i.e. the set of principles that govern diffusion and transport of gases and liquids, mechanical properties of skin and bone, aerodynamics, hydrodynamics etc. that define limits to the performance of individual living organisms.
5. The observation that organisms interact with one another.

biology literature does not typically discuss how ecosystems work in terms of generalized principles, but rather individual studies tend to focus on the details of specific ecosystem aspects. The study of ecosystems as complex systems however, is a more recent wholistic approach that characterizes the properties of such systems in more general terms (Kay 2002). Collaboration between ecologists and designers has since become increasingly common in an attempt to (1) understand ecosystem ecology and its applicability to the built environment, and (2) express this understanding in the form of principles that can be used to inform the creation of a more sustainable built environment (Kibert et al. 2002a, Kibert 2005).[5]

Due to the complex nature of ecosystems, attempts to characterize their properties have resulted in a range of outcomes varying in scope and detail. Although no official consensus yet exists on how the principles should be organized, similar core concepts tend to emerge when lists are compared (table 5.5).

A primary theme that becomes apparent in this comparison is that ecosystems can be described either by how they *are* or by how their components *act and interact*. For example, several authors (Kay 2002, Graham 2003, Capra 2005) describe ecosystems as being hierarchically nested - they exist within one another at various scales. Their living components, on the other hand, cycle and reuse materials which themselves will move across these scales. Consequently, the fact that organisms reuse and cycle materials can only be fully understood by knowing that they do so across ecosystem scales. The fundamentals of what ecosystems are, or what the Biomimicry Guild (2007) calls the conditions under which nature operates, are therefore the premise for what occurs within them. These basic properties of ecosystems, in general, are that they:

As ecology deals with a special class of systems (living systems), then it can be stated that ecology can also have its own unique set of generalizations regarding living systems components and their interactions with both living and non-living components. An *ecological or ecosystem principle* is therefore a generalization that can be made regarding living systems and the interactions between living and non-living components, which are subject to the universal *laws of nature*.

[5] A clarification of the difference between ecological principles and design principles may be useful. Ecological principles are the foundation science upon which design principles and implementation strategies are based. Ecological principles state how life works, while design principles are statements of how design *should* work, based on the ecological principles. See Kellert (2005:97) and Graham (2003:224-227) for examples of lists of design principles.

- exist in dynamic non-equilibrium
- are subject to limits and boundaries
- are hierarchically nested (scales)
- are emergent and self-organizing
- are often unpredictable

From these basic properties of ecosystems, those that are perhaps the most applicable when considering how buildings can interact with their ecosystems are the notions of limits, boundaries and nested scales. Consequently, these concepts permeate the other three cornerstones as evidenced in previous sections.

The Biomimicry Guild (2007) has further classified the principles that describe how ecosystem components act and interact into two categories:

- The way in which resources are shared between organisms (how organisms create conditions conducive to the survival of other organisms)
- The way in which organisms adapt and evolve

As illustrated in table 5.5, this classification incorporates, in one form or another, those principles described by the other authors. These categories are therefore also the manner by which the principles are incorporated into the framework in this study.

Table 5.5. Comparison of ways in which the living processes of ecosystems (principles) have been described.

Biomimicry Guild (2007) *Life:*	**Kay (2002)** *Properties of SOHO systems:*	**The Natural Step (2000)**	**McDonough & Braungart (2002)**	**Graham (2003)** *Characteristics of ecosystems:*	**Capra (2005)** *The concepts that describe the patterns and processes by which nature sustains life:*
How ecosystems ARE					
Follows nature's operating conditions					
• Dynamic non-equilibrium	• Existing in a quasi-steady state, away from equilibrium				• Dynamic balance
• Subject to limits and boundaries	• Having multiple system states bounded by certain maximum and minimum limits				
	• Hierarchically (holarchically) nested			• Hierarchical organization	• Nested systems
	• Occasionally undergoing dramatic and sudden changes in unpredictable ways			• Emergent • Unpredictability	
	• Self-organizing			• Self-organization	
***How ecosystem components ACT* & *INTERACT* with each other**					
Creates conditions conducive to life					
Uses benign manufacturing • Self-assembly • Water-based chemistry • Life-friendly materials					
Optimizes resource use • Multi-functional design • Fit form to function • Recycle all materials		• There is value in order and structure • Nothing disappears • Everything spreads	• Waste Equals Food	• Consumes resources no faster than the rate at which it can replenish them • Creates systems that consume maximum energy-quality • Creates only byproducts that are nutrients or raw materials for resource production	• Cycles • Flows
Leverages interdependence • Self-organizing • Foster cooperative relationships • Recycle all materials	• Self-organizing • Non-linear			• Self-organization	• Networks • Interdependence

(cont'd)

Table 5.5. (cont'd)
Comparison of ways in which the living processes of ecosystems (principles) have been described.

Biomimicry Guild (2007) *Life:*	**Kay (2002)** *Properties of SOHO systems:*	**The Natural Step (2000)**	**McDonough & Braungart (2002)**	**Graham (2003)** *Characteristics of ecosystems:*	**Capra (2005)** *The concepts that describe the patterns and processes by which nature sustains life:*
Adapts and Evolves					

Is locally attuned and responsive
• Resourceful and opportunistic
  • Free energy
  • Simple, common building blocks
  • Shape rather than material
  • Cellular and nested
• Feedback loops
  • Antenna, signal, response
  • Learns and imitates
		• Plants create structure and order by using energy from sunlight.	• Nature Uses Current Solar Income		• Development and learning

Uses cyclic processes • Feedback loops • Cross-pollination and mutation	• Employing both positive and negative feedback loops • Open systems • Maintained by energy gradients across their boundaries			• Positive and negative feedback	
Is resilient • Diverse • Redundant • Decentralized and distributed			• Nature Celebrates Diversity	• Diversity and resilience • Enhances biological and functional adaptability and diversity	• Diversity

In applying the framework to the design process, the ecosystem principles act as a filter through which the design strategies are developed and tested for their consideration of the whole system, and ultimately their sustainability. If truly designed ecosystematically, the principles should inherently be incorporated throughout all stages of the design and can also be used as a check between subsequent rounds of the design process to highlight whether it is truly working as a system integrated with its local ecosystems, as well as what can be improved upon. This use of the principles analysis throughout the design cycle is reflected in the most recent evolution of the biomimicry methodology (Biomimicry Guild 2007) and can be applied in the form of questions that will help draw out the design's ecosystemic qualities (table 5.6). Although the questions are presented in a linear way, the analysis itself is not linear and may be accomplished in various sequences.

Table 5.6. Transforming ecosystem principles into design principles through the asking of questions.

Principles	**Questions to ask of a project based on the ecosystem principles**
Life creates conditions conducive to life by: Optimizing rather than maximizing Leveraging interdependence Using benign manufacturing	• Are the quantity and quality of the resources used (energy & materials) optimized? • Does it utilize free, renewable energy sources? • Are resources used to achieve multiple functions? • Does the form reflect the function it is trying to achieve? • How are resources cycled through the system? • Is cooperation between system members encouraged? • Is the design self-organizing (determines and is determined by its processes) and designed to operate at various scales? • Does the construction use life friendly materials that don't harm the system in their manufacturing, use, and disposal? • Does the construction use water-based chemistry? • Does the construction process allow self-assembly of components and materials rather than forcing elements to shape?
Life adapts and evolves by: Being locally attuned and responsive Using cyclic processes Being resilient	• Does the design rely on local energy and materials? • Does it perceive changes in the availability of resources and adapt accordingly? • Does it adapt in diverse ways? • In what ways does such diversity increase its resilience?

5.4.2 The relationship between conditions, ecosystem principles and mutually beneficial relationships

The ways in which the previously described conditions are produced in non-human nature can be described by ecosystem principles. All organisms (including humans) influence their surroundings through the processes of their life activities (Vitousek 1997). The conditions produced, particularly by non-human species, tend to not only not harm their ecosystem, but rather enhance its ability to function. Therefore by adhering to the ecosystem principles, humans and their products can also potentially create conditions that are conducive to the survival of other organisms.

Optimization

In non-human dominated ecosystems, the flow of energy and the use of materials are optimized by keeping the resources within the system for subsequent uses. Nature produces stores of energy beginning with the production of plant material from renewable solar energy and employs feedback loops that keep as much energy cycling within a system for as long as possible, making effective use of energy quality (Kibert et al. 2002a). In other words, the products of one organism's consumption (what humans often term "waste") are food for other organisms (McDonough & Braungart 2002). In this way, the whole system is optimized rather than individual components, substituting effectiveness for inefficiency. In addition to their cycling, resources are also used more effectively in the presence of functional diversity within and across scales, i.e. when different species occupy different niches so as to better allocate resources, which results in different functions being upheld (Diaz & Cabido 2001, Peterson 2002). These optimization strategies help ensure that there are enough resources to sustain the entire system.

Humans and their built environments tend to differ from non-human dominated ecosystems in the way they use resources through the linear use of materials (using them once and throwing them away), by not matching energy quality with its function, by not capitalizing on free energy, and by not incorporating functional diversity in their structures and components (McDonough & Braungart 2002, Kibert et al. 2002b). Industrial ecology however, has begun to incorporate the appropriate use of energy quality and the cycling of materials into the design of industrial systems (Ayres & Ayres 2002, Kibert et al. 2002a). Buildings that are integrated with their native ecosystems also optimize the use of energy and materials by using native plants to meet both human and non-human functional needs (e.g. by providing growing space and habitat, as well as insulation, shelter, and biophilic benefits).

Interdependence

The optimization of energy use and the division of function reflects the necessity for organisms to foster cooperative relationships whether implicitly through resource appropriation and competition or explicitly through symbiosis. These interdependent relationships are manifested through processes that both determine and are determined by the system, i.e. they cause the system to be self-organizing (Kay 2002). For example, the species and their distribution that make up a forest are determined by local physical conditions like soil nutrients and sunlight, as well as by larger scale availability of seeds, both of which's availability is in part determined by the species and distribution of the plants. Therefore ecosystems organize themselves across different scales (Peterson 2002).

In order to become more like non-human dominated ecosystems, urban systems and the built environment need to take better advantage of the possibilities for cooperation at and between the various scales. Buildings that are integrated with their ecosystems will necessitate interdependence not only between human and non-human members, but also between human neighbours and adjacent neighbourhoods, in order to create connectivity and encourage native seed propagation.

Benign manufacturing

All organisms modify their environments, however the degree to which the processes harm or benefit the greater system varies between human and non-human species. The substances produced by a non-human species' life processes generally exist in concentrations that can be cycled at rates normal to healthy ecosystems. Those substances that occur at higher concentrations and can be considered toxic to other species (e.g. venom) are only produced at the scale of the individual (for example for self-defense), whereas if they are stored or transported at the system level, it is done only in concentrations that can be broken down by the system at normal rates (The Natural Step 2000, Benyus 2002). Also, the materials produced by the life processes of non-human species, even chemical toxins like venoms, are produced at temperatures and pressures and with a water-based chemistry that those producing them are able to live with. They are also composed of elements in a chemical structure that is designed to break down and be re-introduced in useable forms, albeit at various time scales (Vogel 1998). In other words, substances produced by non-human species are done so in a way that does not harm their environment or their ability to survive and self-assemble (Benyus 2002).

The methods that humans employ to process resources on the other hand, often concentrate substances at levels not found in nature at the same scales (for example metals, and the structure of carbon in plastics) and are therefore difficult if not impossible for organisms to break down. They are also often produced using "heat, beat, and treat" methods, forcing products to shape rather than allowing them to form through natural affinities. Therefore, for human systems to become more like those dominated by non-human species, their manufacturing processes need to convert to ones whose products are created in environments that favour their assembly and that we ourselves would be comfortable living in, and are capable of being returned in useable form to the biospheric material cycles. An example is the use of native plants as building materials – they self-assemble using water-based chemistry and readily break down into useable forms from which the rest of the system can benefit.

Dockside Green – Victoria, British Columbia

An example of a project that reflects the above ecosystem principles is the Dockside Green development in Victoria, British Columbia. Dockside Green is a harbourfront mixed-use development with commercial, residential, live/work, and light industrial uses. The project entails the reclamation and redevelopment of a 15 acre brownfield site into three distinct neighbourhoods, a central gathering place, and a greenway. It is designed to function as a system in which form, structure, materials, mechanical and electrical systems will be interrelated and interdependent. Upon completion, it will have a district energy system based on a biomass gasification plant that will use wood scraps from local industry to produce heat and electricity for every building in the development, with excess heat sold to neighbouring businesses (Macaulay 2009) (figure 5.16). In addition to these cooperative relationships, the project also optimizes its water use by processing 100% of its sewage onsite (figure 5.16). It will use the treated grey and black water, together with rainwater, for toilet flushing and for landscaping and water features throughout the site. By matching water quality with function, the demand for potable water from municipal systems is reduced by 60-65% (Dockside Green, n.d.).

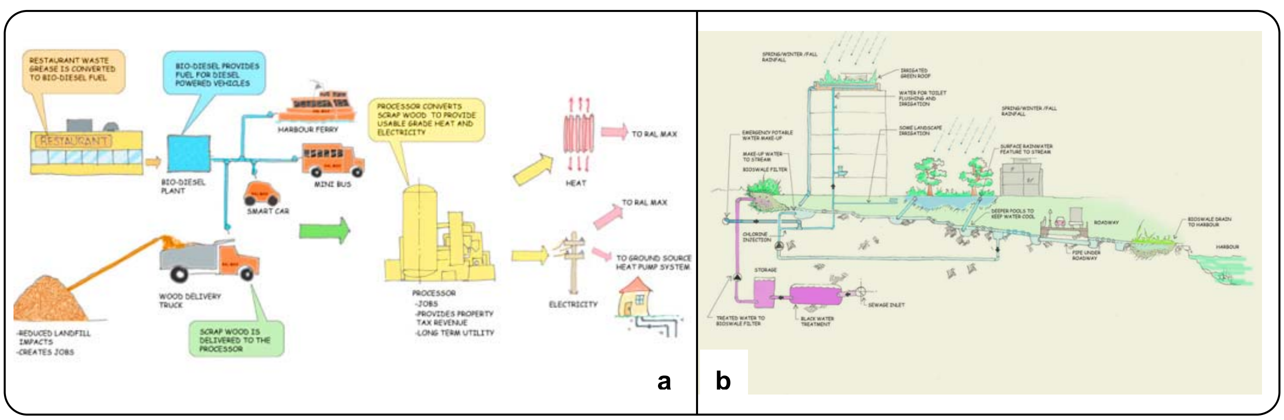

Figure 5.16. (a) Biogas energy generation system at Dockside Green; (b) Water system optimization at Dockside Green (from Dockside Green, n.d.).

5.4.3 The relationship between adaptations, ecosystem principles and mutually beneficial relationships

Non-human nature is able to thrive over the long-term because it is dependent upon and responsive to local resources and the conditions they produce. It employs strategies of feedback and diversity to ensure its continued capacity to exist within these local conditions. These basics of continuous survival can be thought of as ecosystem principles. By using ecosystems as a model and adhering to these principles, humans and their activities (including building) can potentially be better equipped to cope with the inevitable changes occurring throughout their communities.

Locally attuned and responsive

Non-human organisms obtain all their energy and material resources locally though interactions with their system members and as a result determine and are determined by local microclimate conditions (Smith & Smith 2000, Kay 2002). When these conditions are within an optimal range, the needs of all species are balanced so as to most effectively keep the system working.

Human systems and the built environment can be better equipped to deal with change if they were to have an understanding of the local dynamics of their place, their community members and the relationships that occur amongst them, and were able to incorporate this knowledge into the processes that shape them. By incorporating locally available resources, human communities would likely be more in tune with changes to resource state and availability, helping them to adjust their activities so as to reflect the change but maintain the relationship in some form.

Cyclic processes

The cycling of resources and information is what drives and maintains ecosystems (Kay 2002). The information is in the form of local conditions and is driven by feedback loops that convey the information to members of the ecosystem. It is awareness of local conditions, acting on this feedback and learning from the actions that describe how an organism, and hence their ecosystem adapt. Holling (1986) has described the adaptive process as a cycle that consists of four phases (figure 5.17)[6]:

1. *Growth (also called exploitation) (r)*

   Resources are readily available and rapid growth ensues.

2. *Conservation (K)*

   Slow rate of change as resources are increasingly unavailable, locked up in existing structures.

3. *Release (also called creative destruction or collapse) (Ω)*

   Rapid phase of disturbance where 'locked' up resources are suddenly released producing other kinds of opportunity.

4. *Renewal (also called reorganization) (*α*)*

   The system rapidly reorganizes itself while some of its members are lost, others persist or new ones arrive to produce a structure either similar to its previous one, or an new configuration.

[6] The growth and conservation phases describe the stages of succession in terrestrial ecosystems where young systems are rapidly colonized by pioneer (r) species and slowly replaced by climax (K) species.

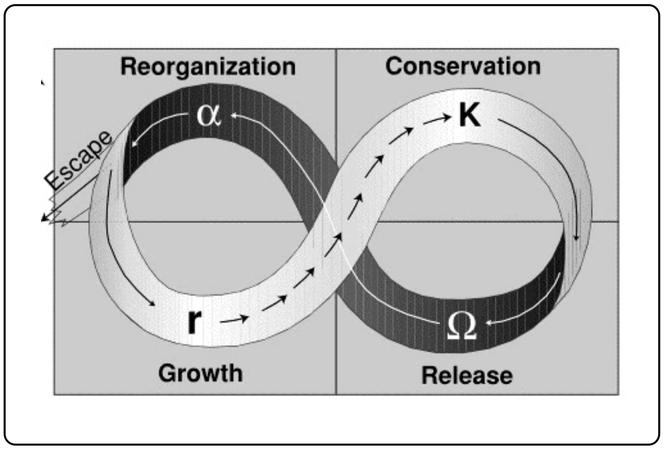

Figure 5.17. The dynamics of an ecosystem's adaptive cycle (from Peterson 2002).

Typically, the built environment severely alters this cycle by initially intervening and acting as the cause of disturbance or release (figure 5.18). A building that is permanent to its site will typically act as a continual cause of disturbance, restricting the development of the growth and conservation phases of its ecosystem (where succession would normally take place). Alternatively, buildings that are integrated with and help to restore their ecosystems will become a part of the renewal phase and encourage their ecosystem's natural progression through growth and development.

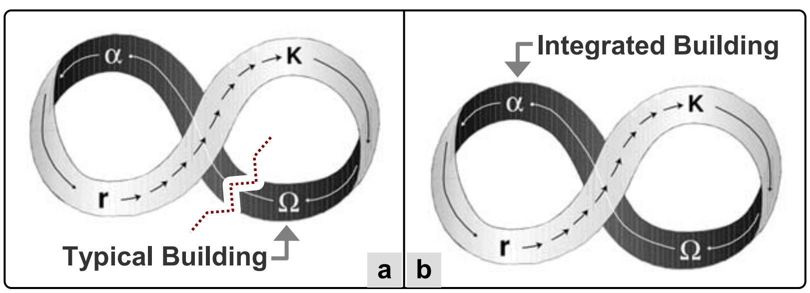

Figure 5.18. The point of intervention during an ecosystem's adaptive cycle by (a) the typical built environment; and (b) a building that is integrated with its ecosystem.

A building can also be considered to have its own adaptive cycle with phases that correspond to those of ecosystems (figure 5.19). The information intensive design phase organizes its structure to best prepare it for its construction and operation, and with adaptive buildings, also its deconstruction. As argued throughout this thesis, both the designer and the user have a responsibility to ensure that the building is in tune with and responds to its ecosystem. This feedback could be in the form of adaptive management, where, as Peterson (2002:140) points out, would mostly be incorporated in the design phase as they "both require learning from past experiences and anticipating the future while knowing full well that the world cannot be completely understood."

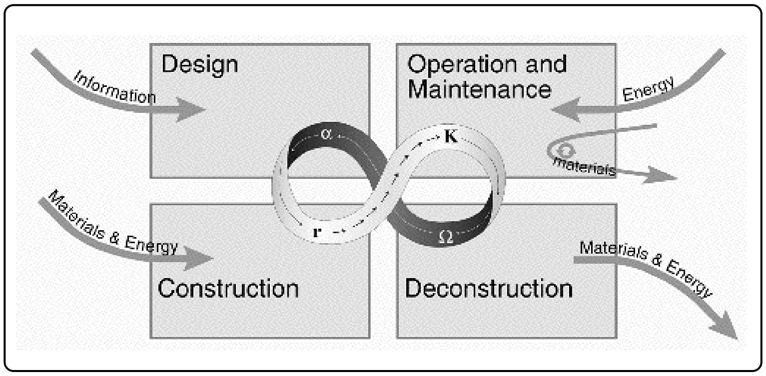

Figure 5.19. The dynamics of a building's adaptive cycle (from Peterson 2002).

Resilience

Ecological resilience is a measure of the amount of change a system can undergo before that change forces it to an alternate state (Peterson 2002). Alternatively, it is the ability of a system to absorb a disturbance without major changes to its structure, functions and feedbacks (Walker, et al., 2002). Resilience is a function of both diversity (since the more mechanisms a system has to respond with, the more likely it is to do so successfully), and adaptive capacity (the ability of the system to learn and change) (Holling 1986, Kay 2002). Ecosystems are more resilient when they are able to learn of change and adapt appropriately with a variety of responses as well as redundancy in responses to a disturbance across various scales (Peterson et al. 1998, Diaz & Cabido 2001, Peterson 2002). This ability to recognize constant change in local conditions, evolve diverse strategies to deal with it, and learn from these strategies for next time is the overlying driver of healthy ecosystems.

Humans can develop and maintain resilience in their systems by incorporating learning mechanisms and developing diverse opportunities for responding and adapting to changing conditions at various scales. For example, a neighbourhood that is looking at producing all of is own energy experiments with both property and neighbourhood scale sources, and adjusts its dependence on each based on their availability (e.g. use more solar on sunny days, wind power on stormy, grey days, and micro-hydro on rainy days).The diversity of energy sources allows them to adjust both their amount and form of consumption based on the local availability of resources.

Östratornskolan – Lund, Sweden

An example of a project that has incorporated these principles of adaptation and evolution is the Östratorn School in Lund, Sweden. The school's resources have been designed with systems in mind using the concept of eco-cyles, considering the origin, use and destination of food, materials, water and energy (Graham 2003) (figure 5.20). The food and water eco-cylces are particularly representative of the ecosystem principles because of their interconnection with each other and the larger community. Human waste is sold as fertilizer to local farmers who grow food for the school, and the locally attuned cycle continues.

Several measures were also taken with Östratornskolan to enhance the project's adaptability in the future (Graham 2003) (table 5.7). A 'black box' was built into the entrance of the building that contains information on the products and materials in the building and measures to be taken with their construction, maintenance, and demolition (figure 5.21). This provides future occupants and contractors with information regarding the original intent of the building and its components, and enhances the likelihood that the building's materials will be re-used properly. The lack of finishes and composite materials also enhances the potential for reuse and recycling. In terms of being able to physically adapt, none of the interior walls are structural so as to maximize flexibility of configuration and use of space. Each building's ventilation system adapts to the seasons and on an as-needed basis when controlled by the occupants. They control the ventilation through the use of a timer or opening and closing windows. This type of control can be seen as negative feedback since the result of the occupants actions (e.g. more ventilation, air gets cooled) reduces the air temperature and the need for more cooling.

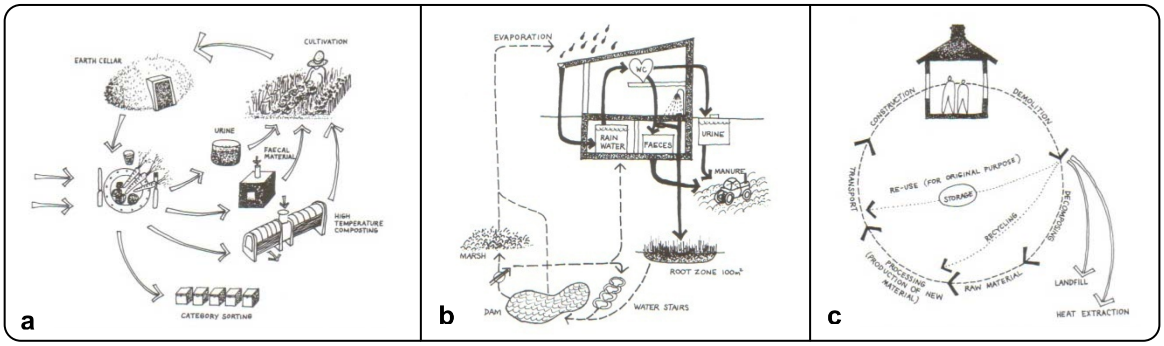

Figure 5.20. Östratornskolan's eco-cycles: (a) food eco-cylce; (b) water eco-cycle; (c) materials eco-cycle (from Graham 2003).

Table 5.7. Östratornskolan's adaptive strategies relate to the adaptive cycle stages of a building as described by Peterson (2002).

Adaptive cycle stage	Adaptive strategies
Design	Assessment of environment and potential uses
Construction	Interior walls non-load bearing & demountable No finishes/composite materials
Operation & Maintenance	No finishes/composite materials Occupant controlled ventilation
Deconstruction	Black box

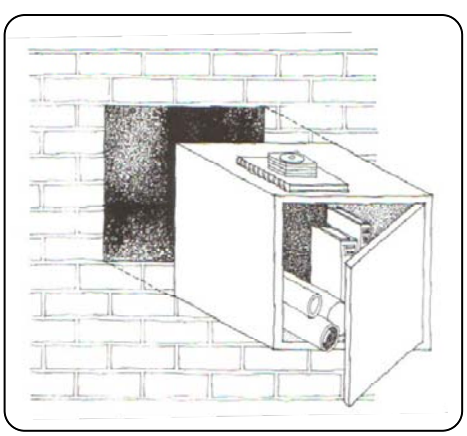

Figure 5.21. The 'black box' at Ostratornskolan containing information about the design and construction of the building for future occupants, designers and workers (from Graham 2003).

Chapter 6

Discussion & Conclusions

Making the connection: buildings, native biodiversity & nature experience

I may not have gone where I intended to go, but I think I have ended up where I needed to be.

Douglas Adams (1988)

6.1 What is nature-based design?

A key question posited at the outset of this thesis was *What is nature-based design*? In response to this question, the framework proposed in this study acts as a summary of those elements that describe the essence of nature-based design. Although the core concepts, with their linkages and interconnections, are described graphically in the framework, they are presented here in linear point form for the purposes of summarizing.

Results of the investigation show that nature-based design is an ecosystem-based design that:

1. Uses ecosystems as ***context*** so a building can ***interact with*** its native ecosystem

VALUES	Is driven by biospheric and natural aesthetic values
CONDITIONS	Creates conditions conducive to the survival of other organisms
PATTERNS	Weaves human networks with native ecosystem patterns
ADAPTATIONS	Becomes better suited to its native ecosystem by allowing natural processes of change to occur
CONTEXT	Uses buildings to reflect biospheric values in the form of awareness of the various scales of its ecological address and care for native ecosystems
FUNCTIONS	Balances the functional requirements of native biodiversity with those of humans
MANAGEMENT	Uses buildings to overcome aesthetic biases and dissolve physical, functional and aesthetic disparities between buildings and their ecosystems
ECOLOGICAL SENSE OF PLACE	Fosters an ecological sense of place by reflecting an awareness of and care for native ecosystems
ECOSYSTEM HEALTH	Encourages native ecosystem functioning
REGENERATION	Deliberately shares human habitat with other species by allowing the renewal of native ecosystems

2. Uses ecosystems as ***models*** so a building can ***act like*** an ecosystem

CONDITIONS	Creates conditions conducive to the survival of other organisms
ADAPTATIONS	Becomes better suited to its native ecosystem by allowing natural processes of change to occur
PRINCIPLES	Uses ecosystem principles to test its ability to act like an ecosystem
MUTUALLY BENEFICIAL RELATIONSHIPS	Acts like an ecosystem to more effectively interact with its ecosystem

Ecosystem-based design is, therefore, ultimately design that creates habitat for humans and for native biodiversity. An ecosystem-based building is therefore one that exhibits connections with non-human nature, acting as a vehicle by which to enhance connectedness with nature among its human users.

6.1.1 Does a project interact with its ecosystem?

In addition to the questions posed in section 5.4.1. to determine if a design *acts like* an ecosystem, the previous summary of the framework concepts can also be directly translated into questions to determine if a design *interacts with* its ecosystem. By asking these questions throughout the various stages of the design process, one can assess the degree to which the design interacts with its ecosystem based on whether the answers to the questions are 'yes'. Therefore, the questions to ask of a project to examine if it interacts with its ecosystem are:

VALUES	Is the design driven by biospheric and natural aesthetic values?
CONDITIONS	Does the design create conditions conducive to the survival of other organisms?
PATTERNS	Does the design weave human networks with native ecosystem patterns?
ADAPTATIONS	Does the design become better suited to its native ecosystem by allowing natural processes of change to occur?

CONTEXT	Does the design reflect biospheric values, awareness of ecological address and care for native ecosystems?
FUNCTIONS	Does the design balance the functional requirements of native biodiversity with those of humans?
MANAGEMENT	Does the design dissolve physical, functional and aesthetic disparities between buildings and their ecosystems?

ECOLOGICAL SENSE OF PLACE	Does the design foster an ecological sense of place by reflecting an awareness of and care for native ecosystems?
ECOSYSTEM HEALTH	Does the design encourage native ecosystem functioning?
REGENERATION	Does the design deliberately share human habitat with other species by allowing the renewal of native ecosystems?

These questions, along with those posed in table 5.6 of section 5.4.1., can be used to evaluate if a design is ecosystem-based.

6.2 Contribution

Based on its two major objectives (*to describe the meaning of 'designing with nature' in architectural theory*, and *to explore how nature-based design can be interpreted to encourage human connectedness with non-human nature, while addressing the two major losses caused by conventional building*), this thesis offers two new contributions to the field of environmentally conscious architecture:

1. It offers a graphic model in the form of a framework that summarizes the essence of an evolving field, that of nature-based design.

2. It describes the potential link between building design, native biodiversity, nature experience and connectedness with nature.

6.2.1 The framework

Emerging commonalities

The research has shown that there is indeed a range of ways in which nature has been drawn upon to inform building design, with each of the approaches having a variety of dominant themes as the foundation of their theory. As shown in chapter three, there was also, however, considerable overlap of those themes, indicating that although each approach has been given a different name, it has much in common with other approaches. This delineation is useful not only because it provides a snapshot of an evolving field, but because it also allows one to place themselves within it by seeing how their own personal interests or philosophies overlap with those of the approaches.

Analyzing the ecological approaches for their dominant themes, and comparing them with the design approaches was also valuable in that it provided verification that ecological theory does indeed figure prominently as a basis for the design theory. In a culture where 'green-washing' is becoming increasingly prevalent, it is reassuring to establish that claims of an ecological foundation are warranted.

Although the concepts presented in the framework are themselves not new, the way in which they are organized does contribute a new perspective on the field of nature-based design.

Refining the term 'nature'

On account of the many ways that the approaches draw on nature to inform design, one would expect different interpretations of what 'nature' is. This, however, appears to be the concept that is the most agreed upon, at least at first glance. The research showed that the concept of the ecosystem is that aspect of nature most used as a point of reference. The distinction is made, rather, in the way in which it informs design by acting as (1) models, for how the built environment can be *based on* and *act like* an ecosystem, and as (2) context, for how the built environment can be *based in* and *interact with* its ecosystem. This distinction is important as it appears that this is where much confusion lies surrounding nature and design. Once the distinction is made, one can better assess the pro and cons of each.

Although the term 'ecosystem' is by no means a simple concept, its use as a replacement for the word 'nature' helps to reduce any ambiguity and cultural loading associated with the latter term. Ecosystems, at their various scales, are also how nature is referred to in science and ecology. Use of the term 'ecosystem' in place of 'nature' in design thereby brings the two disciplines of design and ecology one step closer by beginning to bridge the language gap.

Depending on how ecosystems are drawn upon (either as models or context) they can provide two very different types of experience, each with the ability to encourage a different type of connectivity with nature. This source of inspiration – whether as model or as context – will be an important factor in predetermining the degree to which the design is able to connect its users with non-human nature. It is therefore a distinction that could be very useful to designers when laying out their goals at the onset of the design process.

Bridging the gap

The core concepts of the framework have their roots in a variety of disciplines, including architecture, landscape architecture, and various streams of ecology and environmental psychology. The framework uses common terms and language familiar to all of these disciplines, making it more accessible to a wide range of users. The discussion of each element of the framework is also valuable for the way in which it provides insight into what may have been a familiar topic but now from a new perspective.

6.2.2 Buildings, biodiversity, nature experience & connectedness with nature

One of the most significant and consistent observations from the thesis is that although a building and its site exist at a relatively small scale, they cannot be properly designed with nature without knowledge and incorporation of their larger bioregional context. The two notions of *scale* and *place* thereby emerge as drivers of an ecosystem-based design, linking buildings with native biodiversity, nature experience, connectedness with nature and thus an ecological citizenship.

Scale

The findings in the second half of the thesis revealed that in order to address the loss of native biodiversity, nature experience and ultimately connectedness with nature, buildings need to be designed for at two scales: that of the immediate site and individual building, as well as at the larger neighbourhood or community scale. Only when both scales are considered can context be accurately reflected, functions balanced and patterns merged.

Place: native vs. non-native

The research also suggested that through the act of building, designers have a responsibility to restore not only non-human nature, but in particular *native* biodiversity. Not only is native biodiversity that which was originally displaced by building, but it is also that which reflects the representative natural character of a place. By incorporating aspects of its native ecosystem and thus features that are recognized as characteristic to a particular place, a building can create ties to and enhance connectivity to place. This, in turn can enhance commitment and care for those places, thus encouraging pro-environmental behavior and an ecological citizenship. Figure 6.1 describes this chain of thought linking buildings, native biodiversity, nature experience and connectedness with nature.

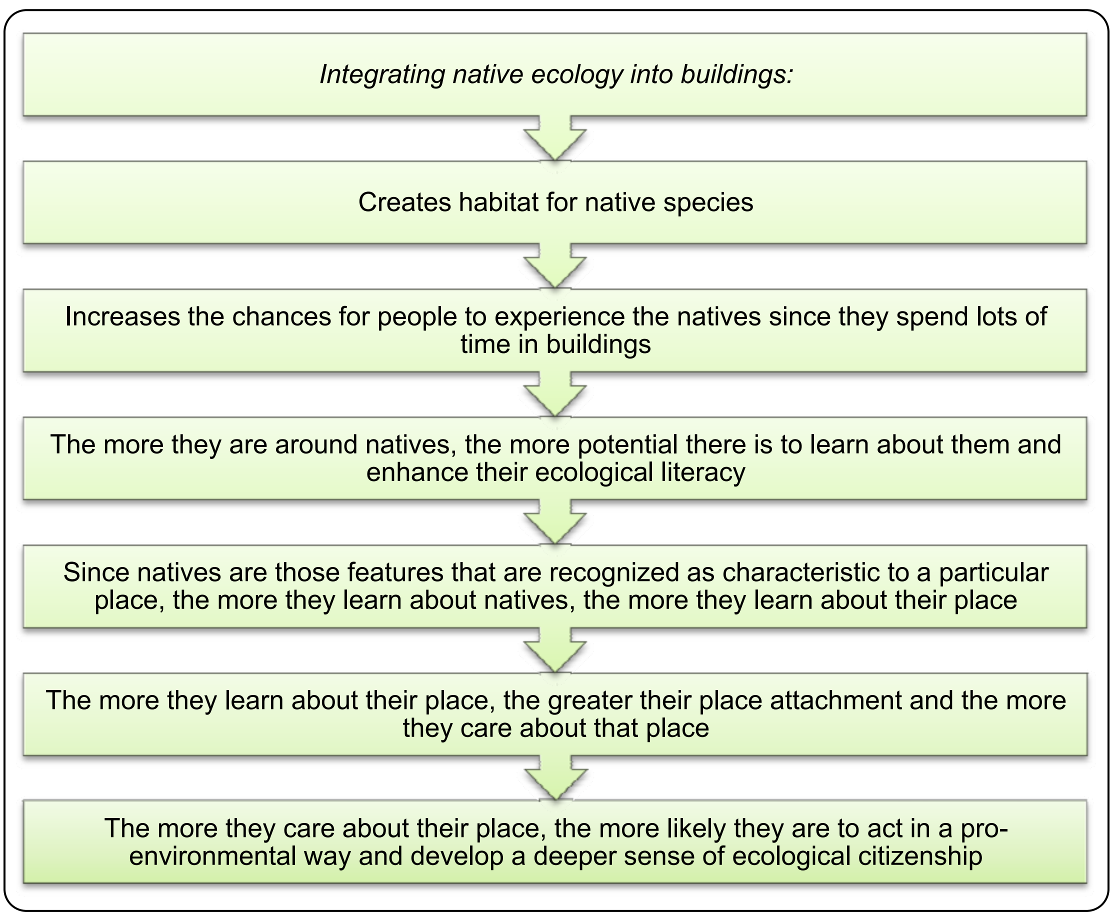

Figure 6.1. The chain of thought linking buildings, native biodiversity, nature experience and connectedness with nature.

6.3 Implications for the future of nature-based design

6.3.1 Noteworthy approaches

The development of the framework has shown that each approach reviewed in this thesis (green building, ecological design, biophilic design, biomimicry, industrial, construction and building ecology, and regenerative design) has something of value to offer nature-based design. Certain approaches, however, emerge as being more influential in the development of an ecosystem-based design that encourages human connectedness with non-human nature:

- Biomimicry's strengths are for industrial and material design, however it is valuable to nature-based building design for its development of the ecosystem principles used to test how a building can act like an ecosystem. It also makes a valuable contribution through its methods, urging designers to 'go outside' and experience non-human nature firsthand.

- Ecological, regenerative and biophilic design are particularly valuable for their focus on place, native ecosystems, scale and making nature accessible.

The notion to make building design integrated with its ecosystem and contribute habitat and nature experience is therefore already accepted – the individual concepts have indeed already been proposed – but have not yet become mainstream. Why is that? Is it because of the difficulty of incorporating synergies, such as those described by the ecosystem framework, within an assessment framework? Perhaps if assessment tools were structurally organized to incorporate the framework proposed in this study, resulting buildings might be better equipped to encourage a greater connectedness with nature. The results of this thesis therefore suggest that, although it would no doubt be challenging, building assessment tools could greatly benefit by taking inspiration not only from the framework proposed in this study, but from the approaches highlighted above.

6.3.2 Ecological education for designers and vice versa

The research supports the notion that ecological education would be beneficial to designers, as would design education for ecologists and biologists. Although the framework uses language familiar to both ecologists and designers, the different interpretations can sometimes still be confounding to the other. Continuing education courses that teach the fundamentals of ecology to designers (e.g. the *Biomimicry and Design* course offered by the Biomimicry Guild or the *Beyond Green* workshop offered by the Royal Architectural Institute of Canada), and the basics of design to ecologists (e.g. the *Biologists at the Design Table* course offered by the Biomimicry Guild), can help to further merge the fields. Incorporating such types of courses into university curricula is perhaps an even more effective way of narrowing this knowledge gap in future generations of nature-based designers and consultants.

6.4 Further investigations

As this research focused on the foundation of design theory, there remain many questions to be answered regarding interpretation of the theory and its application as a process. Some of these were introduced throughout this study but remain to be explored in further depth. Possibilities for subsequent research include:

- An investigation into how different designers have interpreted and manifested the core concepts in existing buildings
- A deeper investigation into the framework as a process, particularly with respect to the implications for the various members of the design team, as well as the building owners and users
- Translating the framework into a building assessment tool
- A comparison of specific design solutions and their ability to provide native habitat and nature experience
- Investigating which social and economic factors constrain/promote wider application of the framework's core concepts to buildings
- An investigation into the potential gains or losses of ecological value by raising the structure of the forest floor to roof level or rotating it to a vertical axis
- The technical issues involved in providing for native biodiversity in different types of ecosystems

6.5 Conclusions

This project is just a beginning for understanding the multitude of elements required to re-integrate humans into their native ecosystems and how to involve key aspects of human habitats - buildings - in that process.

The built examples given illustrate that this re-integration is already underway, sometimes using common, everyday strategies and other times employing more creativity and innovation. This, along with the fact that the ecosystem framework is composed not of new ideas, but rather of established concepts suggests that the building design and construction industry may be closer to an ecosystem-based design paradigm than popular building assessment tools would suggest.

The comprehensive yet concise organization of the framework makes it particularly valuable to those in search of an introduction to not only environmentally conscious, but more specifically nature-based building design. To the author's knowledge, this study is the first of its kind to provide not only such distinctions between existing design approaches, but also to draw attention to the role these approaches play in connecting buildings, biodiversity and human experience.

This thesis is also envisioned as being of value to the seasoned designer who is perhaps wondering how newer approaches, like biomimicry for example, fit in with their existing design philosophies. It is hoped that it also highlights the importance and usefulness of getting to know your non-human neighbours, regardless of profession.

Although this study focuses on the scale of the individual building and regional community, results of an ecosystem approach would undoubtedly also impact the larger global community. In theory, an ecosystem approach to building seems very possible, however, in reality, there are a lot of challenges and conflicts associated with such a paradigm shift. These range from social and economic forces affecting the individual, all the way up to global pressures on the human population. The approach developed in this thesis is trying to operate within that state of development, while acting as a driver towards a new way of valuing life.

Results of this study have shown that there is an abundance of information on the relationship between ecology and architectural design, and how this wealth of ideas can be both inspiring as well as intimidating. It is hoped that the framework developed here has pulled together the best of those ideas in a way that clarifies their meaning and importance. There is amazing potential for architecture to take a leadership role in the way we associate ourselves with other aspects of nature. In echoing the thoughts of James Wines, architect and "design outlaw on the ecological frontier" (Zelov 1995), it's not just about architectural evolution, but about a psychological revolution.

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