



Living Architecture Performance Tool
Biodiversity White Paper

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1.1 THE GREEN INFRASTRUCTURE FOUNDATION (GIF)

The Green Infrastructure Foundation (GIF) is a tax-exempt, charitable organization affiliated with Green Roofs for Healthy Cities (GRHC). It is dedicated to promoting public awareness of the diverse benefits of green infrastructure like green roofs, green walls and urban forests as part of the built environment.

- GIF is a well-recognized source of information, technical assistance, case studies, evaluation tools and policy models for green infrastructure for both public sector and private sector decision-makers.
- GIF supports the efforts of other organizations that focus on related areas such as low-impact development, green buildings, eco-industrial development and other sustainable development initiatives.
- GIF's programs and activities are designed to promote the positive contributions green infrastructure can make in communities while addressing barriers to green infrastructure such as local, state and federal regulations, the lack of awareness among policymakers and their constituencies, and the lack of technical knowledge about green infrastructure among contractors and consultants.

1.2 LIVING ARCHITECTURE PERFORMANCE TOOL OBJECTIVES

Over the last two decades, thousands of building owners and professionals have been incorporating an increasing number of vegetative technologies on building envelopes and within the interiors of new and existing structures. Voluntary standards such as LEED and Sustainable Sites, combined with a variety of local government public policies, have supported the growth of these living architecture technologies. The United States Environmental Protection Agency (EPA) has been increasingly involved in supporting local and regional efforts to develop effective policies and implementation strategies.

Living architecture is defined by the integration of inorganic, non-living structures with organic, living systems to achieve superior ecological, social and economic performance. Living architecture currently includes well known technologies such as green roofs, green facades and living walls.

There are multiple performance benefits provided by living architecture which cut across social, economic and environmental spheres. The complexity of their performance benefits are both a strength and a weakness. While these technologies can simultaneously address many critical needs in our buildings and communities, it is difficult to describe the interacting costs and benefits of these technologies in standardized way. A siloed, one-size-fits-all approach to the design and operation of these systems ignores or undervalues the range and scope of benefits that living architecture provides. An example of this is an analysis that concludes that white roofs are the best way to reduce the urban heat island effect, only because all of the benefits associated with green roofs and walls – i.e. the ability to reduce the urban heat island, support biodiversity, cleanse the air, generate employment, etc. – are discounted from the valuation. This complexity is both a challenge and an opportunity.

The main factors that contribute to the complexity of living architecture are as follows:

- **Diversity of benefits.** In comparison to other green building technologies, living architecture provides a wide range of benefits, which are often quantified independently and according to different metrics.
- **Variety of spatial scales on which benefits are accrued.** The many benefits of living architecture are also realized at different spatial scales, from individual buildings, to neighbourhoods and districts, and even across entire watersheds. Some benefits, such as urban heat island mitigation, or preventing a combined sewer overflow event, will only be realized when a certain threshold of implementation is reached.
- **Compound benefits.** When combined, multiple living architecture technologies can provide greater overall benefit than when used in isolation.
- **Climate and micro-climate.** Living architecture performance benefits are often dependent on the weather and climate environment of the region they are situated in. For example, in some regions, rainfall patterns are often sufficient to maintain vegetation whereas this is not possible in arid and semi-arid regions, which must provide irrigation support during certain periods of the year. Performance benefits may also be impacted by micro-climatic effects, such as the amount of available shade or sun.
- **Diversity of technologies.** The benefits of living architecture vary considerably from one technology type to another. For example, an interior living wall that is integrated with the mechanical system and acts as a bio-filter serves to remove pollutants from indoor air whereas an ordinary interior living wall or an exterior living wall may not.
- **Diversity of design, product and maintenance practices.** Through design, product and maintenance practice variation, there are often dramatic differences in the performance of different technologies in the same category. For example, a green roof can retain 100% of the annual stormwater runoff, or as little as 10%, depending on its components such as the growing media composition, types of plants, and drainage layer type. Improper maintenance may also result in inconsistent performance.
- **Private vs. public benefits.** Some of the benefits accrue to the building or property owner who makes the investment in living architecture, while other benefits accrue to the general public or the surrounding area. Quantifying these benefits and identifying their beneficiaries adds to the complexity of living architecture.
- **Second-tier impacts.** Many benefits are related to second tier impacts. For example, green walls can reduce the urban heat island effect, which in turn reduces energy consumption for air conditioning for buildings experiencing reduced ambient temperatures. This can act as a feedback loop, providing further benefits.
- **Trade-offs.** Costs in some areas can create benefits in other areas. For example, while irrigation of green roofs consumes water, it may also reduce water consumption elsewhere in a building. Less water may be required in the cooling tower due to the reduced cooling requirements from the contributions of the green roof.

These complexities have resulted in a number of barriers to the full standardization and realization of the performance benefits of living architecture. There are a number of related challenges that the Living Architecture Performance Tool aims to address. These include:

- ***Inconsistent policy.*** Policymakers are often keen to create regulatory and financial incentives for living architectural system implementation due to their many public benefits. However, they don't have a performance based system that can be used as a reference, which they can then support with policy measures. In the absence of a performance standard framework, the adoption of multiple design, construction and maintenance standards by different local jurisdictions over time will not serve the industry well. One of the initial driving forces behind the USGBC's LEED program was the fact that governments adopted the voluntary standard and tied it to procurement policies and incentives for new buildings. A similar system needs to be in place for living architecture systems – to guard against the manufacture, design, installation and maintenance of systems that may underperform, and to highlight best practices to help ensure maximum performance benefits for public and private building owners.
- ***Insufficient product testing.*** The influx of new products, particularly in the field of living walls, is a welcome trend, but in the absence of clear performance standards can leave many consumers without the necessary means of selecting a system and/or design that will meet their needs. For manufacturers, a third party certification of product performance will give them an advantage in the marketplace against firms that are unwilling to test their products for performance benefits.
- ***Lack of benchmark for quantifying the performance of projects.*** Increasingly, water and energy utilities, with support and encouragement from the EPA, are beginning to embrace green infrastructure as a means to reduce energy consumption and the urban heat island, manage stormwater runoff to prevent combined sewer overflows and improve water quality, as a complement to traditional grey infrastructure approaches. Yet without clear performance measures, many projects fail to meet their intended design objectives or have difficulty quantifying their long-term financial benefits.
- ***Representation of living architecture in voluntary standards for green buildings and sites.*** Voluntary performance standards, such as the USGBC's LEED and Sustainable Sites could benefit from a more clearly articulated reference standard for living architecture technologies. This would help to address credits which are seen by the industry as dysfunctional in some environments, like removal of irrigation systems, and strengthen the application of existing credits.

The lack of a comprehensive framework of clear performance benefit metrics for living architecture systems threatens their long term application to green buildings and sustainable sites, thereby jeopardizing the many benefits they provide building owners and the broader community.

1.3 THE LIVING ARCHITECTURE PERFORMANCE TOOL

Part of the success of the USGBC's LEED rating system is that it made the complexity of green building understandable and therefore actionable. Over past two years Green Roofs for Healthy Cities and the Green Infrastructure Foundation have been working with a variety of stakeholders to develop a performance framework called the Living Architecture Performance Tool (LAPT) in order to begin the important work of addressing the challenges described above. It is an ambitious effort which will require ongoing development over five years or more, but like LEED, it has the potential to be transformative.

The focus of the LAPT is to develop consensus-based performance criteria and metrics for all major types of living architecture, beginning initially with green roofs, green facades and living walls, and then in later phases incorporating other technologies which integrate living and non-living building systems. The objectives in developing the LAPT are as follows:

- To further the integration of living systems in buildings and to articulate the ecosystem services they provide.
- To improve the public and professional understanding of the value and multiple benefits of fully incorporating living architecture into the built environment.
- To encourage continuous improvement among living architecture professionals through a widely recognized standard of practice and feedback mechanisms from implemented projects.
- To build upon, inform and align with the on-going development of other high-performance rating systems, including Leadership in Energy and Environmental Design (LEED), Sustainable Sites Initiative (SITES), Roofpoint, and the Living Building Challenge.
- To help set the agenda for ongoing research activities and encourage greater collaboration among research groups.
- To establish performance metrics, benchmarks and design parameters that can be used by utility managers and government leaders to develop supportive policies and programs.
- To facilitate more uniform testing and evaluation of new products and implementation approaches against the performance metrics wherever possible.
- To help guide funding and investment decisions that accurately reflect the performance characteristics of living architecture systems and applications.

1.4 WHAT TYPES OF LIVING ARCHITECTURE EXIST?

There are many different living architecture systems, and new technologies are being developed every year. The major technological categories of living architecture currently include:

Green Roofs (Vegetative Roofs, Eco-Roofs, Garden Roofs)

A contained green space on top of a human made structure below, above, or at-grade. Green roofs typically utilize high quality waterproofing, a root barrier, drainage layer, filter fabric, engineered growing media and plants. Green roofs encompass a wide variety of project types and approaches.

Extensive green roof systems utilize less than 6" (15 cm) of growing medium and have more limited plant species and minimal maintenance requirements.

Intensive green roof systems use more than 6" (15 cm) of growing medium and can sometimes support small trees and shrubs and typically require more ongoing maintenance than extensive systems.

Roof systems can often accommodate both approaches based on the building's loading capacity or the budget for the roof system. Such *semi-intensive* systems are defined as those with at least 25 per cent of the planted area as either extensive or intensive.

Green Walls (vertical gardens, living walls, bio-walls)

Green walls are a class of living architecture that provides for vegetation on the vertical plane and are typically attached directly to the building envelope on both interior and exterior surfaces.

There are four different types of green walls: living walls, green facades, interior green walls (biowalls) and living retaining walls.

Living walls include vertical hydroponic membranes and inorganic fabric systems. Many living wall technologies are modular in design, with various types of compartments, and pre-grown units of growing medium and plants that are connected to a racking system, which is then attached directly to the building envelope. Modules can be made of plastic, polystyrene, synthetic fabric, clay, or concrete, and generally support a diverse range of plant life. Regardless of the system used, living wall systems are visually striking and have a major biophilic impact.

Green facades are systems in which vines and climbing plants or cascading ground covers grow up or down on supportive structures attached to walls. Plants growing on green facades are generally rooted in soil beds at the base, or in elevated planters at intermediate levels or even on rooftops. Green facades can be attached to existing walls or built as freestanding structures that support the ability of plants to grow and climb. Two primary sub-types of these systems are modular trellis panels, and wire, rope or cable net materials. Modular trellis panels typically use preformed lattices made of stainless steel that fix to the building envelop and lock into each other, and the ground. Rope or cable net systems use flexible stainless steel to create a mesh that plants are able to climb.

Interior green walls (biowalls) incorporate plants on walls within buildings. Interior green walls can be designed to pull indoor air through their leaves and root systems to improve indoor air quality by removing contaminants, or they may simply enhance aesthetic values within indoor spaces.

Living retaining wall systems are specially designed to stabilize a slope while also supporting vegetation. They provide structural strength that resists lateral forces and protects slopes from erosion. They are often modular in construction, with interlocking units that may be comprised of metal, plastic, mats, or woven willow plants. The intent of living retaining wall systems is to eventually become fully covered with plants so the underlying support structures disappear from view.

Other forms of living architecture

There are a growing number of living architecture systems and strategies that fit within these definitions. While the Living Architecture Performance Tool was initially conceived to address green roofs and walls, it quickly became evident that similar metrics should be used to describe the performance of any form of living architecture, and would have greater value in doing so.

For example, various living systems are developed and operated to manage, clean or re-use stormwater and/or wastewater. These include various designs (constructed wetland, living machine, biotopes, natural pools and spas), that clean water for human contact or improve indoor living conditions (air quality, humidity, temperature). The term “living architecture” implies integration with a built form, and all of these elements may be developed on or within built structures, or immediately adjacent to built structures.

A **Biofiltration system or Biotope** is a landscape element designed and engineered to receive and improve the quality of a particular water flow, such as surface water runoff, building process water, or from some other source. Such systems are generally low-input, relying on gravity rather than pumps, and include a cross-section of mineral material (gravel, sand), engineered soil/organic material, and plants. The combination of materials soils and plants filters and cools the water as it flows through. Rain gardens and bioswales also use this approach to receive, retain, and filter rainwater.

A **living machine (Eco-Machine, ecological engine, etc.)** is an intensive bioremediation system typically used to treat wastewater. Specific aquatic and wetland plants, bacteria, algae, protozoa, plankton, snails and other organisms are used in the system to provide specific cleansing or trophic functions. It can also produce beneficial byproducts, such as reuse-quality water, and habitat for ornamental plants and the production of plant biomass. These plant byproducts, in turn, can be used in building materials, animal feed or to produce energy from biomass combustion or anaerobic digestion.

A **constructed wetland** is an artificial wetland, marsh or swamp created as new or restored habitat for native and migratory wildlife. Wetlands can also receive anthropogenic discharge such as wastewater, stormwater runoff, or sewage treatment, or be used for land reclamation after mining, refineries, or other ecological disturbances. In many jurisdictions, constructed wetlands are required as mitigation for natural wetlands lost to land development.

These general classes of living architecture will be used as the basis for development of the Living Architecture Performance Tool. Some of the performance metrics developed in the LAPT will not apply to all of these types of living architecture, and will continue to evolve over time based on ongoing research and application of the performance tool.

1.5 THE APPROACH TO THE LIVING ARCHITECTURE PERFORMANCE TOOL

An important early step in the development of the LAPT is the commissioning of white papers in major subject areas related to living architecture. With funds raised from various sources, the goal

of the white papers is to define the state of performance metrics and their application to various types of living architecture. White paper development will be conducted by research groups and guided by technical committees convened by GRHC and GIF and subject to extensive peer review. An executive committee will then work to bring the white paper findings together into a comprehensive framework.

Multi-stakeholder committee discussions have already taken place in the context of different Technical Committees, which will be expanded to include more stakeholders. Technical committees will report to the Executive Committee who responsibilities include coordinating all of the work of the Technical Committees into a coherent and cohesive framework. Technical committees will oversee the development of the White Papers in their respective subject areas and conduct outreach to additional stakeholders. Possible White Paper topics are as follows:

Water Committee

Stormwater Quantity Management
Stormwater Quality Management
Water Capture, Reuse and Irrigation

Energy Committee

Energy Efficiency and Conservation

Life Sciences Committee

Biodiversity
Growing Media Sciences
Plant Sciences and Food Production
Ecosystem Integration and Life Cycle Impacts

Health and Well-Being Committee

Biophilic Design Potential
Air Quality
Noise Reduction
Materials/Components

Planning/Implementation Process Committee

Integrated Design Process
Management, Operations, and Stewardship
Research and Education

The White Papers will constitute the basic elements that allow for the development of the LAPT. Some will be relatively straightforward to produce while others will likely require a greater level of effort. Each of the proposed White Papers will follow a standardized format that will facilitate future synthesis into a cohesive framework. This paper is the third white paper to be developed, on the subject of Energy Conservation and Generation.

2.1 BIODIVERSITY – WHAT IS IT AND WHY IS IT IMPORTANT?

Biodiversity is short for biological diversity, and in its most simple form, is diversity through three biological levels: species, ecosystems and genes. There is a broad scientific consensus regarding a positive link between biodiversity and ecological system function (Hooper et al., 2005). These ecological systems (see chart; Costanza et al., 1997) provide goods and services that have an estimated value of \$125 trillion a year (Costanza et al., 2014) and include providing us with food, clean water and air, protection from environmental disturbance, maintenance of healthy soil for agriculture, and raw materials like fuel and lumber (Costanza et al., 1997).

Table 1 Ecosystem services and functions used in this study

Number	Ecosystem service*	Ecosystem functions	Examples
1	Gas regulation	Regulation of atmospheric chemical composition.	CO ₂ /O ₂ balance, O ₃ for UVB protection, and SO _x levels.
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
4	Water regulation	Regulation of hydrological flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
5	Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
6	Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes, storage of silt in lakes and wetlands.
7	Soil formation	Soil formation processes.	Weathering of rock and the accumulation of organic material.
8	Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification.
10	Pollination	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
11	Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
12	Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
13	Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing.
14	Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.
15	Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
16	Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, and other outdoor recreational activities.
17	Cultural	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

*We include ecosystem 'goods' along with ecosystem services.

To date, nearly 1.5 million species worldwide have been described and named by the mainstream scientific community. However, recent estimates have suggested a final species count could reach between 10 and 30 million (Ricklefs, 2001), with particular uncertainty surrounding the estimates of microorganisms like bacteria, viruses, protists and archaea. Scientists have a better understanding of how many stars there are in the galaxy than how many species there are on earth (1992 Global Biodiversity Strategy). This illustrates the complexity of biodiversity and the challenge of preserving it. Solutions must be creative, holistic and diverse. To that end, policy-makers, designers and city-builders have an opportunity to design living architecture to encourage and preserve biodiversity in the places it is most at risk: urban areas.

2.2 URBANIZATION AND BIODIVERSITY

By 2050, the world's population is predicted to rise to 9 billion, with two-thirds of those expected to live in urban areas. Urbanization negatively impacts biodiversity through:

- the destruction and fragmentation of habitat
- the transformation of land and removal of natural vegetation communities
- increased air, water, and soil pollution
- altered urban microclimates; the urban heat island effect creates hotter and drier conditions with altered nutrient cycling and perturbations in population dynamics
- disrupted ecological pathways (migration, seed dispersal, gene flow)
- introduction and dominance of invasive species
- overexploitation of resources
- changes in hydrology and soil biogeochemistry

Many of the most rapidly urbanizing areas of the world are located in biodiversity 'hotspots', areas of significant biodiversity importance, and in developing countries. There is an opportunity to develop plans and strategies to preserve biodiversity in these areas and mitigate some of the adverse effects of their urbanization.

Urban habitats are distinct and tend to be characterized by high species richness, but this is influenced by the presence of a high number of non-native and even invasive species. There is a trend towards the homogenization of urban habitats across the world, and species like the common urban rat (*Rattus norvegicus*) and the city pigeon (*Columbia livia*) are now found in cities across the world. In many cities, up to half of all species in the urban core are non-native (McKinney, 2002; Dunn and Heneghan, 2011; McDonald et al., 2013). The loss of native species is becoming more of an issue as the global urban population grows. A decrease in some native species can lead to further species loss and it is important to preserve species that have become, or are becoming rare in their natural ranges due to the pressures imposed by urbanization.

2.3 LIVING ARCHITECTURE AND BIODIVERSITY

As the human population continues to grow and urbanize, we continue to transform land, destroying and fragmenting habitat. Traditional biological conservation largely focuses on ‘non-use land’- areas set aside for conservation and protection like reserves, or areas where degraded ecosystems are restored or rehabilitated. However, Rosenzweig (2003) has argued that the global land area available for conservation and restoration is not enough to stop the current (and future) rate of species extinction. He instead proposes ‘reconciliation ecology’, where anthropogenic habitats are modified and diversified to support a greater range of plant and animal species, without compromising land use.

Urban environments, with their concentration of people and limited existing habitat, offer tremendous opportunity to be remade using the principles of reconciliation ecology. Francis and Lorimer (2011) argue that while ‘top-down’ and expensive attempts to the built and natural environments like those involving infrastructure and networks of parks can help, they are not an ideal or cost-effective solution. They argue that green roofs and walls offer a less expensive opportunity for ‘bottom-up reconciliation’, where the actions of individuals and organizations at a local level can add up to reconcile the built and natural environments.

The existing paradigm of living architecture (or for that matter, green building) has not paid a lot of attention to biodiversity. Roofs are generally extensive, dominated by sedums and feature shallow substrate depths; they are often designed for minimal cost, aesthetics, ease of maintenance, and stormwater attenuation (Connop et al. 2013). Despite this, the benefits of biodiverse living architecture designs can be broad and varied.

2.4 LITERATURE ON LIVING ARCHITECTURE AND BIODIVERSITY

While the topic of biodiversity as it relates to living architecture is one that is relatively new, research into the topic is becoming more common, especially regarding green roofs.

In a recent literature review on green roof biodiversity, Cook-Patton and Bauerle (2012) describe the potential benefits of green roof biodiversity based on existing studies:

- Increased plant productivity, structural complexity, and consistency of coverage will improve rooftop insulation, reflectance and cooling via evapotranspiration
- Increased complexity of vegetation will increase rainwater retention
- Increased productivity and constancy of coverage will improve uptake of pollutants that can be used for plant growth (e.g., CO₂, N and P), and reduce the need for fertilizer
- Increases in plant productivity will increase arthropod abundance and richness
- Diverse green roofs will support more specialized and rare species than less diverse green roofs
- Increasing diversity will improve the temporal stability of resources and better sustain dependent animal communities (e.g., pollinators)
- Diverse communities will receive less damage from specialist herbivores or pathogens

- Increased constancy of coverage and occupancy of niche space will prevent intrusion of undesirable weed species
- Diversity will increase the aesthetic benefits of green roofs

Cook Patton and Bauerle argue that diverse plantings are the key: more efficient resource use and positive interactions among plant species improve green roof performance, while diverse green roof plantings support more diverse fauna. Additionally, diverse green roofs are more resilient in the face of environmental stress and change: a key consideration when designing for a changing climate (Cook-Patton and Bauerle, 2012). There is limited research examining these benefits as they relate to green walls and facades, but many of them are based on general principles of urban ecology and could conceivably be applied to green walls and facades.

The literature on living architecture suggests that there are two broad approaches when designing for green roofs with diverse plantings: planting for diversity from the start or designing to create the conditions for biodiversity and allowing for colonization of wild plants.

- **Planting for diversity from the start** - Initial planting could involve planting a diverse array of complementary species and irrigating until establishment. Kohler (2006) suggests that long-term species richness on green roofs can be increased with a minimal amount of irrigation and maintenance, as well as enhanced initial plantings. There are arguments for using both native and non-native plants. Native plants on green roofs can help replace habitat lost by urban development, encourage biodiversity and help provide ecological niches for avian and arthropod species that depend on these plants (Bousselot et al, 2009). Cook-Patton and Bauerle's review of research (2012) found evidence that native plants in urban environments are beneficial because they are more likely to support native wildlife and replace vegetation destroyed by development, as well as less likely to become invasive. However, green roofs are often very different habitats than the surrounding area: drier, windier, sunnier, less nutrient rich and prone to dramatic temperature fluctuations. This necessitates the use of hardier plants, some of which could be non-native. Lundholm (2006) argues for a 'habitat template' approach, using a diverse array of plants adapted from regions with shallow substrates and extreme soil-moisture conditions. He suggests using plants adapted to cliffs and rocky outcrops, because they are adapted to similar conditions found on many green roofs. Other habitat analogues that could work on extensive green roofs include dry prairie, California grassland, alvars and sand barrens.
- **Designing for colonization** – Many designers take the approach of creating the conditions for biodiversity without planting from the start. Rare plants and lichens often establish spontaneously on older roofs (Brenneisen, 2006; Kohler, 2006). The conditions that encourage this spontaneous colonization can be created by establishing a variety of microhabitats and microclimates.. Ishimatsu and Ito (2011) compare this approach to the spontaneous colonization of brownfields by wild plant communities. They suggest recreating the conditions of brownfields on 'brown' or 'biodiverse' roofs by using a variety of substrate materials to create different drainage regimes. Substrate materials include crushed brick and stone, lightweight granular waste material, natural soil and areas of bare

gravel. Brenneisen (2003) suggests that carefully removing and reusing the top 15cm of natural soil from the area surrounding the building - with its seed bank and soil microorganisms intact - will lead to more biodiverse green roof environments. Madre et al.'s study of green roofs in Northern France (2004) concludes that many of the wild plants that spontaneously colonize green roofs are native, and that they can provide valuable habitat for fauna in urban environments. They determine that substrate depth is the principal factor determining the diversity of these colonizing communities, arguing that deeper substrates provide more consistent soil moisture and temperature conditions. It can be argued that this is the approach that requires the least maintenance, because plants that colonize, survive and thrive in the harsh conditions of extensive green roofs are generally hardy and drought-tolerant.

Vegetation diversity on green roofs can also help create habitat for fauna on green roofs. Many invertebrate and avian communities have been documented on a wide variety of green roofs in several countries. (Coffman and Davis, 2005; Brenneisen, 2006; Kadas, 2006).

A literature review conducted by Fernandez and Gonzalez-R (2010) determined green roofs are valuable habitat for birds, with the primary determinant of their value being the availability of food. Diverse plantings (including flowering plants) and a wide variety of invertebrates improves the temporal availability of food, supporting birds. Green roofs in denser urban areas were found to be used by birds more often than in suburban areas or adjacent to agricultural areas; Dunnett and Kingsbury (2004) argue that this is because of the relative scarcity of food and green space in these built up areas. Fernandez and Gonzales-R (2010) also found that the availability of shelter and cover from predators, as well as the presence of water increases bird use. Baumann (2006) found that ground-nesting birds breed on green roofs, if the appropriate vegetation to nest is present.

Rare native species have also been found using green roofs as habitat. For example, the rare black redstart (*Phoenicurus ochruros*) has been found using green roofs in London as sites for foraging and nesting. This has mobilized conservation organizations to promote habitat, and providing habitat for black redstarts on green roofs has been incorporated into the London Biodiversity Action Plan (Ishimatsu and Ito, 2013). While insect diversity has been a more common focus of research, there is less research regarding the use of green roofs by birds, and their habitat value as part of ecosystems.

Invertebrates found include insects like beetles, ants, bugs, flies, bees, spiders, and leafhoppers (Coffman and Davis, 2005). Rare and uncommon species of beetles and spiders have also been recorded on green roofs in several countries (Brenneisen 2006, Grant 2006, Kadas, 2006). Gedge and Kadas (2004) positively correlated species richness in spider and beetle populations with plant species richness, as well as variations in topography. It has been demonstrated that insect species diversity does not differ significantly between green roofs and adjacent ground level sites (MacIvor, 2011), suggesting that green roofs could replace lost habitat, at least when it comes to insects.

Colla et al. (2009) found that green roofs provide valuable habitat for bees away from agricultural areas where pesticide contamination and diseases are common; native bees in urban areas might face less competition for floral resources from managed and introduced bee populations. Including

suitable nesting substrate and providing native flowering species could serve to encourage bees; a more diverse array of plants improves the temporal availability of resources. Bees and other pollinators decrease the need for active seeding and tending, lowering maintenance costs. Increased bee diversity could also aid in urban agriculture systems on green roofs, improving crop productivity. Green roofs as habitat for bees is an important research topic that should be explored further, especially with declining global bee populations and Colony Collapse Disorder threatening global agriculture.

In addition to macrofauna, microinvertebrates and microorganisms are important to the ecological function of green roofs, cycling nutrients, decomposing organic matter and forming the base of the food web. Organisms like springtails (Collembolla) have been found to colonize green roofs. Over time, their assemblages become more diverse, contributing to soil forming processes and supporting increased plant diversity (Schrader and Böning, 2006). McGuire et al. (2013) recently discovered a diverse microfungal community on green roofs in New York. While the role of fungal communities on green roofs has not been studied in depth, they likely play a large role in nutrient cycling, symbiosis and plant productivity. Determining the factors necessary for their healthy populations could have wide ranging effects on overall plant health, productivity and maintenance. Further research on these microfauna and their role in the maintenance of healthy soils is an area that should see further research in the future.

Green facades have also been found to provide a home for a wide variety of invertebrate species, providing an important food source for birds and bats. Established and larger plants may even provide roosting and nesting sites for birds (Dunnett and Kingsbury, 2004). Especially abundant are fauna that have a preference for thermophile or synanthropic vegetation - species adapted to urban settings, including those preferring warm temperatures (Köhler 1988). Birds also use green facades significantly more than bare walls for perching, nesting and feeding. Evergreen species like ivies are also valuable sources of food and shelter for birds in the winter (Chiquet et al., 2013), while some climbers (like *Hedera helix*) provide nectar as a food source, or have leaves eaten as food by larvae (Dunnett and Kingsbury, 2004). While further research must be conducted regarding the habitat value of living walls, one can assume its potential is greater than that of green facades due to the possibility of greater structural complexity and more diverse plantings.

While there have been a few studies tracking the biodiversity on green roofs over a number of years, more long term studies are needed to fully understand the contributing factors of biodiversity. Though there is a strong research basis for the value and determinants of biodiversity on green roofs, the realm of biodiversity on green walls and facades is relatively unexplored one. Of particular interest would be research on how to create the conditions for spontaneous colonization of green walls and facades, and if this is indeed possible. The relationship between various forms of living architecture on biodiversity at different spatial scales (city blocks, neighbourhoods, cities, regions) is something that could also be worthy of further study. Can individual green roofs, walls and facades connect and act as green corridors, linking fragmented habitat? What role can living architecture play in regional landscape planning and ecology?

3.0 REVIEW OF EXISTING RATING SYSTEMS

A number of rating systems currently exist that provide the framework for the design of buildings and landscapes. One of the goals of the LAPT is to build upon, inform and align with these various rating systems. These systems include:

LEED (Leadership in Energy and Environmental Design) - A set of rating systems for green buildings and neighbourhoods developed by the U.S. Green Building Council (USGBC). LEED is by far the most popular green building rating system used in North America today. Its popularity can be attributed to its simplicity, as well as its adoption and support by various organizations and government agencies.

Sustainable Sites Initiative – A set of guidelines and performance benchmarks used to evaluate the environmental performance of sites, including open spaces and sites with buildings on them. The initiative is a collaborative effort by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Centre at the University of Texas and the United States Botanic Garden.

Living Building Challenge – A green building certification program run by the International Living Future Institute, the program is the most advanced measure of sustainability for buildings. Certified buildings and sites can claim a very high level of environmental performance. As a result of its stringent criteria, very few buildings are certified Living Buildings.

Roofpoint – A green rating system developed by the Center for Environmental Innovation in Roofing to evaluate roofs based on long term energy and environmental benefits.

Certified Wildlife Habitat – A certification provided by the National Wildlife Federation for sites that feature the necessary elements to create habitat for wildlife. The certification is mainly geared toward residential gardens but has been applied to living architecture.

Green Globes – A green building certification developed by ECD Energy and Environment Canada, an arms-length division of JLL (a commercial real estate management and investment firm). Green Globes was designed to be a comparable but more cost-effective alternative to LEED, due to the fact that it is designed as a self-assessment and does not require the use of outside consultants.

Envision - A rating system used to evaluate the sustainability and performance of infrastructure on all scales. Envision is a joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure.

BREEAM (Building Research Establishment Environmental Assessment Method) - A comprehensive rating system for buildings run by BRE (Building Research Establishment). Formerly a UK government body, BRE is now a private organization that carries out research, consultancy and testing for the construction and built environment sectors in the UK. The scheme is especially popular in the UK and Europe, but is also used globally.

The overall approach these systems take to biodiversity is generally quite broad. Themes common to most systems include broad mentions to ‘preserving’ or ‘restoring’ site ecology. Living architecture is only given a brief mention. The gaps in these rating systems present an opportunity for the LAPT. The LAPT could complement and inform these rating systems and fill in their gaps by creating targeted, focused metrics for Living Architecture and Biodiversity.

Table A presents an overview of how these rating systems address topics related to biodiversity. The number of possible points or overall weight within the rating system is provided, as are case studies wherever possible. Each credit is assessed for its potential application to various forms of living architecture, based on case studies and the literature on biodiversity as it relates to living architecture. Living architecture assessed here includes extensive/intensive green roofs, interior/exterior green walls and green facades. ‘Other’ includes living retaining walls, biofiltration systems, living machines and constructed wetlands.

DRAFT

Table A - Credits in existing rating systems that relate to Biodiversity										
Rating System	Description of Credit	Points	Measurement Standard / Basis	Case studies (Where Credits Have Been Applied)	Relevance					
					Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Sustainable Sites v2	Preserve threatened/endangered species and their habitats	Req.	Federal/state threatened or endangered lists; IUCN red list of threatened species	2001 Market/38 Dolores (San Francisco) - Rooftop butterfly habitat	Y	Y	?	?	?	Y
	Develop an active management plan to deal with invasive species and minimize their impact on the surrounding ecosystem	Req.	Federal/state noxious weed laws; regional invasive plant lists (created through a vetted, transparent process and accepted by regional stakeholders)		Y	Y	?	N	?	Y
	Use appropriate, non-invasive plants that improve landscape performance and reduce resource use	Req.	No invasive plants on above lists. Plants must be nursery grown, legally harvested or salvaged from the site. Nursery grown plants must use an applicable regional standard. If one does not exist, they must use ANSI Z60.1-2004 American Standard for Nursery Stock	American University of International Service - Green roof on parking garage uses native plants. Phipps Centre for sustainable landscapes - Green roof uses native plants. SWT Design Campus - Green roof uses native plants.	Y	Y	Y	Y	Y	Y
	Preserve and restore plant biomass on site	1-6 out of 200 possible	Biomass density values are based on a literature review of leaf area index (LAI) for various vegetation types which included LAI for approximately 1,000 historical estimates of LAI summarized by biome/cover type in JMO Scurlock, GP Asner, and ST Gower, Worldwide Historical Estimates of Leaf Area Index, 1932-2000 (Oak Ridge, TN: Oak Ridge National Laboratory, 2001). Biomes based on The Nature Conservancy, Terrestrial Ecoregional Boundaries and Assessments Geodatabase (TNC) 4/6/09. Leaf area index is defined as the one sided leaf area per unit of ground surface area.		Y	Y	Y	Y	Y	Y
	Use native plants.	3-6 out of 200 possible	Plants native to EPA level III ecoregion or known to naturally occur <200 miles from the site	American University of International Service - Native plants on green roof. Phipps Centre for sustainable landscapes - Native plants on green roof SWT Design Campus - Green roof uses native plants	Y	Y	Y	Y	Y	Y

Rating System	Description of Credit	Points	Measurement Standard / Basis	Case studies (Where Credits Have Been Applied)	Relevance					
					Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
	Create a plan for sustainable site maintenance. This includes soil management, plant stewardship, integrated pest management, managing invasive species, etc.	Req.		<i>Bat Cave Draw and Visitors Centre, Carlsbad Caverns National Park</i> - has a comprehensive plan for maintenance personnel	Y	Y	Y	Y	Y	Y
	Conserve and restore native plant communities	4-6 out of 200 possible	Plants native to EPA level III ecoregion or known to naturally occur <200 miles from the site	<i>Cypresswood water conservation garden at Harris County WCID 132</i> - Created rain garden/stormwater bog to provide habitat to water loving insects, birds, plants	Y	Y	Y	N	Y	Y
	Monitor performance of sustainable site design - use third party/qualified and peer reviewed monitoring to improve body of knowledge on sustainability. Could include monitoring of the restoration of native plant species, etc.	4 out of 200 possible	Communicate findings through submittal to a discipline-wide professional magazine (e.g., Planning, Landscape Architecture), peer-reviewed scientific journal, professional national/international conference, or national/international public database.		Y	Y	Y	Y	Y	Y
LEED v4	Bird collision deterrance - mostly deals with using appropriate window/wall materials and minimize unnecessary interior/exterior lighting	1 out of 100 possible	Material Threat Factors table developed by the American Bird Conservancy		?	?	Y	N	Y	N
	Protect or restore habitat - restore 30% of previously developed portions of the site using native or adapted vegetation. Sites with >1.5 FAR can use green roofs if 'plants are native or adapted, provide habitat and promote biodiversity'.	2 out of 100 possible			Y	Y	?	N	?	Y
	Alternatively, contribute \$0.40 per sq ft of total site area to a recognized land trust or conservation organization	1 out of 100 possible	Within the same EPA Level III ecoregion or the project's state (or within 100 miles of the project [160 kilometers] for projects outside the U.S.). For U.S. projects, the land trust must be accredited by the Land Trust Alliance.		Y	Y	Y	N	Y	Y

Rating System	Description of Credit	Points	Measurement Standard / Basis	Case studies (Where Credits Have Been Applied)	Relevance					
					Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
	Restore pre-development native ecological communities, water bodies or wetlands in an area greater than or equal to 10% of the developmental footprint. Protect land by donating or selling land/conservation easement to a land trust/govt agency. Commit to managing land for 3 years or until restoration is completed, whichever is later	1 out of 100 possible			N	N	N	N	N	N
Roofpoint	N/A - Does not address biodiversity	N/A			N	N	N	N	N	N
National Wildlife Federation	Food (at least three) - Seeds from a plant, Berries, Nectar, Foliage/Twigs, Nuts, Fruits, Sap, Pollen, Suet, Bird Feeder, Squirrel Feeder, Hummingbird Feeder,	Req.		<i>Christian Reformed Church National HQ - Grand Rapids, MI.</i>	Y	Y	Y	N	Y	Y
Certified Wildlife Habitat	Water (at least one) - Birdbath, Lake, Stream, Seasonal Pool, Ocean, Water Garden/Pond, River, Butterfly Puddling Area, Rain Garden, Spring	Req.		<i>PS 41 - New York City</i>	Y	Y	?	N	N	Y
	Cover (at least two) - Wooded Area, Bramble Patch, Ground Cover, Rock Pile or Wall, Cave, Roosting Box, Dense Shrubs or Thicket, Evergreens, Brush or Log Pile, Burrow, Meadow or Prairie, Water Garden or Pond	Req.		"	Y	Y	?	N	?	Y
	Places to Raise Young (at least two) - Trees, Meadow or Prairie, Nesting Box, Wetland, Cave, Host Plants for Caterpillars, Dead Trees or Snags, Dense Shrubs or a Thicket, Water Garden or Pond, Burrow	Req.		"	x	x	?	N/A	?	x
Living Building Challenge 3.0	On-site landscape must be designed so that as it matures and evolves it increasingly emulates the functionality of indigenous ecosystems with regard to density, biodiversity, plant succession, water use, and nutrient needs. It shall also provide wildlife and avian habitat appropriate to the project's transect through the use of native and naturalized plants and topsoil. No petrochemical fertilizers or pesticides can be used for the operation and maintenance of the on-site landscape.	Req.		<i>Eco-sense residence, Highlands, BC - living roof with native plants.</i> <i>Phipps Conservatory, Pittsburgh, PA - uses native plants, restores native plant communities which provide habitat.</i>	Y	Y	?	N	N	Y

Rating System	Description of Credit	Points	Measurement Standard / Basis	Case studies (Where Credits Have Been Applied)	Relevance					
					Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Green Globes	Ensure that a minimum of 50% of the vegetated area will be covered with plants that are drought-tolerant, native or non-invasive, and with minimal turf grass	9 out of 1000 possible			Y	Y	Y	Y	Y	Y
	Install landscaped areas with at least 15 cm of aerated soil incorporating organic mulch	2 out of 1000 possible			N	Y	N	N	N	?
Envision	Protect biodiversity by preserving and restoring species and habitats. Protect/Improve/Restore or create	16 out of 700 possible			Y	Y	Y	N	Y	Y
	Use appropriate non-invasive species and control or eliminate existing invasive species.	11 out of 700 possible			Y	Y	Y	?	Y	Y
BREEAM	Minimize the impact on existing site ecology - based on plant species richness in broad habitat types. A table is provided with values for different habitat types. Ecological value is determined based on this table and the area of altered habitat. The point is awarded for no or minimal change on site ecology. Green roofs are only considered where a suitably qualified ecologist is responsible for advice on suitable plant species.	1 out of 100 possible	Plant species richness based on 2007 UK Countryside Survey		Y	Y	?	?	?	?
	Enhance site ecology - a suitably qualified ecologist provides a report with recommendations for protection and enhancement of site ecology. The recommendations are implemented and the ecologist confirms that this will result in an increase of plant species of ecological value.	2 out of 100 possible			Y	Y	Y	N	Y	Y
	Minimize the long term impact of a development on the biodiversity of the site and surrounding area - must appoint an ecologist, comply with all regulations relating to ecology, create a landscape and habitat management plan for at least four years. Points are awarded for meeting some/all of the following criteria: appointing a 'biodiversity champion', training staff on protecting site ecology, recording and monitoring steps taking to protect biodiversity, creating new habitat, minimize disturbance to wildlife.	2 out of 100 possible (3 for prisons)			Y	Y	Y	?	Y	Y

4.0 THE 'REGION' QUESTION

A major criticism of LEED and other rating systems is they fail to adequately address regional issues and differences related to performance. Sites can face very different conditions, depending on their climatic zone, habitat zone, degree of urbanization and even the jurisdiction they fall into. To ensure that the LAPT works and is an effective tool to evaluate performance across a wide variety of sites, it must account for the regional and unique circumstances every site faces while still holding up shared standards of performance.

An important consideration when classifying sites by region is the purpose of this classification. Sites could be classified differently based on different areas of performance evaluation. For example - when dealing with stormwater management, climate zones would likely be an appropriate measure; while ecoregions would be more appropriate when dealing with biodiversity.

There are several potential ways to classify sites by region already in use. Each contains different pros and cons:

- **Ecoregions** – Ecoregions are areas which contain distinctive assemblages of natural communities and species. The U.S. Environmental Protection Agency (EPA) has created Ecoregions of levels I, II, III and IV, with each successive level containing a finer grain of detail than the previous. Levels I, II and III are available for all of North America while Level IV Ecoregions are only available in the United States. EPA level III Ecoregions are used to distinguish regions within certain existing rating systems. For example, Sustainable Sites definition of 'native plants' is based on plants native to the Level III Ecoregion of a site, and LEED allows a project to obtain a credit related to preserving open space by making a contribution to a Land Trust located within the same Level III Ecoregion as the site.
- **Biomes** – Biomes are areas defined by similar plant life in relation to climatic conditions like temperature and rainfall, as well as soil conditions. While Biomes and Ecoregions often overlap, Biomes, however, do not account for genetic, taxonomic or historical similarities. Biomes (as classified by the Nature Conservancy) are used to distinguish regions within Sustainable Sites, where the number of credits awarded for restoring vegetation density to a site depends on the biome the site represents.
- **Climate Zones** – Climate classifications like the Köppen climate classification system are defined by patterns of average annual and monthly precipitation and temperature, as well as the seasonality of precipitation. While climate zones often overlap with ecoregions and biomes, they do not take into account natural species or communities of flora and fauna. Climate zones could be useful to classify sites when the temperature or precipitation patterns of a region are a consideration, such as stormwater management or reducing heating/cooling costs.
- **Degree of urbanization** – An urban-to-rural transect classifies sites on a continuum ranging from natural space and rural on one end, to dense urban areas on the other end. This could be useful when determining different impacts that living architecture could have depending on how urban the site is. For example, reducing the urban heat island is potentially a much more important consideration in denser urban areas than in rural areas.

The Living Building Challenge classifies all sites along a degree of urbanization transect; the location determines what standards must be met across many of its categories.

- **Political boundaries** - Political boundaries like States, Provinces or EPA regions are easy to determine and administer. Using political boundaries would allow the LAPT to adapt to and take advantage of diverse policy requirements and incentives from different levels of government. However, political boundaries do not align with ecological boundaries and are often arbitrary, reducing their applicability in many areas.

Once sites are classified by region, the next step would be to determine how to treat sites in different regions differently. There are several potential ways to approach this, and they may be used in combination with each other:

- **Regional priority credits** – Offer additional credits in certain areas that are important regionally. These could be in the form of additional points for existing credits (for example, additional points for conserving water in an arid area like Southern California) or entirely new credit categories (like preserving or creating habitat for a regionally important animal). LEED utilizes this approach, with the regional priorities determined by local chapters of the U.S. Green Building Council. There are up to six regional priority credits, and projects can earn up to four bonus points (in addition to the 100 regular points).
- **Different requirements for different regions** – Alter the requirements in certain credit areas to account for regional differences (for example, reduce stormwater management requirements in areas with historically low levels of infiltration). Sustainable Sites uses this approach – for example, credits are awarded for restoring plant biomass to different levels depending on the biome of the site.
- **Use tiered performance based measurements** – Measurements based on performance (for example, sites must manage stormwater from the 95th percentile of local rain events, or reduce heating or cooling costs by 20%) inherently take regional differences into account. By using percent or ratio based tiered targets instead of absolute numbers, one can account for regional variation. LEED uses this approach in certain areas. For example, it mandates an outdoor water use reduction by 30%, regardless of where the site is located.
- **Provide flexibility for unique circumstances** – When regional issues prevent a site from meeting a target, there should be flexibility to award a credit if the intent or aim of the credit can be met using an alternative strategy (for example, if managing stormwater on site would adversely affect local hydrology). Sustainable Sites uses this approach throughout their system.

5.0 METRICS

Metrics form the basis of which we can evaluate the performance of green infrastructure. The potential metrics described here are based on metrics used by existing rating systems, as well as factors that increase biodiversity as determined by the research community.

Compliance with metrics can be measured and confirmed using standards laid out by organizations like the American National Standards Institute (ANSI) or ASTM International. Standards relating to living architecture fall under two categories:

- **Test Methods** – A product or design is tested for performance or quality according to established criteria. All details regarding apparatus, test specimen, procedure, and calculations needed to achieve satisfactory precision and bias should be included in a test method. While the performance standard is established, how a product or design meets the standard is generally not prescribed. For example, a performance standard is established where a green roof would need to retain all water from 90% of rain events, without determining the type or depth of substrate used. The product or design undergoes a standard test procedure to determine whether this requirement is met. The test can be performed in a controlled environment or on site. On-site testing is generally the most expensive method to meet a standard.
- **Specification** – An explicit set of requirements to be satisfied by a product or design. These are based on research that shows that meeting these requirements will ensure performance to an established standard. Examples of specifications include, but are not limited to, requirements for: physical, mechanical, or chemical properties, and safety, quality, or performance criteria. For example, one could require a green roof to have a substrate depth of more than 6" (15 cm) because research has determined that greater substrate depth improves biodiversity. Evaluation of a site can be based on construction drawings/plans or a site visit.

Table B provides a number of potential metrics that could be applied to living architecture. The table includes the intent of the metric, how it could be measured, and a basis from research on biodiversity and living architecture, or from existing rating systems or guidelines.

Each potential metric is assessed for its application to various forms of living architecture. Living architecture assessed here includes extensive/intensive green roofs, interior/exterior green walls and green facades. 'Other' includes living retaining walls, biofiltration systems, living machines and constructed wetlands.

Table B - Potential Biodiversity Metrics								
Intent	Metric	Type and Measurement Guidelines	Potential Application					
			Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Façade	Other
Use a wide variety of native and or/naturalized plants, while using dense and more productive vegetation	Plant diversity index; Percentage of plants, planting areas or biomass that are native (alternatively, a requirement that only native and/or naturalized plants are used); Leaf area index or biomass density index	Design guideline and/or On-site testing and validation	Y	Y	Y	N	Y	Y
Provide for diverse growing media environments that are less prone to desiccation and temperature fluctuations	Average growing media depth; growing media depth, topographic and composition variety; presence of water (irrigation or occasional irrigation)	Design guideline	Y	Y	?	N	?	?
Provide a variety of microclimates and habitats for different species	The number (?) of niche spaces and landscape features on the site	Design guideline and/or On-site testing and validation	Y	Y	Y	N	Y	Y

5.1 PLANTING DIVERSITY, DENSITY AND APPROPRIATENESS

Intent	Use a wide variety of native and or/naturalized plants, while using dense and more productive vegetation
Metric	(1) Plant diversity index; (2) Percentage of plants, planting areas or biomass that are native (alternatively, a requirement that only native and/or naturalized plants are used); (3) Leaf area index or biomass density index
Measurement Method	(1/2/3) Design guideline or on-site testing and validation
Rationale	

Higher species diversity positively affects ecosystem functions like biomass production, stability and nutrient retention or absorption, leading to a more efficient use of limited resources (Tilman et al,

1997, 2001). More plant species makes ecosystems more resilient to pests and diseases (Santamour, 1990). Better and more diverse initial plantings can have an impact on long term plant diversity (Kohler, 2004). Work by Kolb and Schwarz (1993) indicates functionally diverse vegetation has a greater positive influence on the thermal properties of green roofs than monocultural types of vegetation (Oberndorfer, 2007).

Native plants on green roofs can help replace habitat lost by urban development, encourage biodiversity and help provide ecological niches for avian and arthropod species that depend on these plants (Bousselot et al, 2009). However, many native plants are unsuitable for green roofs because of the harsh environment and shallow substrate depth (Monterusso et al, 2005). Additionally, experimental evidence indicates that the functional, structural, and phenological properties of vegetation are more important than "nativeness" in promoting invertebrate biodiversity (Smith et al. 2006). Lundholm (2006) argues for a 'habitat template' approach, using plants adapted from regions with shallow substrates and extreme soil-moisture conditions. The use of native plants is a contentious subject, but there is consensus that it is important to use either native or naturalized plants.

Higher density of vegetation leads to increased water retention (Teemusk and Mander, 2007). Higher density of vegetation leads to more available food and nesting resources for fauna. Biodiversity in turn promotes increased plant productivity and an optimized use of resources (Marquard et al., 2009; Oberndorfer, 2007).

Using a wide variety of plants is a recommendation in the City of Toronto guidelines for Biodiverse Green Roofs. The use of native plants is a metric used by Sustainable Sites and the Living Building Challenge. Using denser vegetation is a metric used by Sustainable Sites.

5.2 GROWING MEDIA BIODIVERSITY POTENTIAL

Intent	Provide for diverse growing media environments that are less prone to desiccation and temperature fluctuations
Metric	(1) Average growing media depth; (2) Growing media depth, topographic and composition variety; (3) Presence of water (irrigation or occasional irrigation)
Measurement Method	(1/2/3) Design guideline or on-site testing and validation
Rationale	

Shallower growing media desiccates more quickly and suffers higher temperature fluctuations, making them harsher environments. Deeper growing media retains more moisture and suffers fewer temperature fluctuations, supporting a wider range of flora and fauna (Oberndorfer et al, 2007). Growing media depth is the principal factor determining the diversity of wild colonizing plants (Madre et al, 2014).

Varying growing media depth, using a deeper growing medium in structurally supportive areas and varying topography creates a wider range of conditions, allowing for a wider variety of

flora and fauna (Brenneisen, 2006). Species richness among spider and beetles is positively correlated with topographic diversity (Gedge and Kadas, 2004).

Natural soils work better to encourage biodiversity than technical growing media; when possible the top 15cm of soil should be carefully taken off brownfields or valuable vegetated areas and transplanted to roofs (Brenneisen, 2006). Using a variety of growing media including crushed brick, sand, gravel, granular lightweight waste materials and natural soils to create a variety of drainage regimes creates microhabitats on and below the soil surface that encourages colonization by a more diverse flora and fauna. (Ishimatsu, 2011; Oberndorfer et al, 2007, Brenneisen, 2006).

Small amounts of irrigation can also improve plant diversity, especially during initial planting periods (Kohler, 2004). However, irrigation is a contentious subject, and awarding credits for irrigation should be weighed against climate and regional water availability.

Using diverse growing media by varying depth, topography and composition is a recommendation in the City of Toronto guidelines for Biodiverse Green Roofs.

5.2 MICROCLIMATES AND MICROHABITATS

Intent	Use design features to create microclimates and microhabitats
Metric	Use design features like logs, perches or shade structures to create different microclimates and microhabitats to encourage niche flora and fauna
Measurement Method	(1) Design guideline or on-site validation
Rationale	

The creation of microclimates encourages a wider variety of flora and fauna (Brenneisen, 2006). Providing areas of sun and shade (Kohler, 2004), using landscape elements like logs and small pebbles or rocks (Ishimatsu, 2011), changing topography, and providing a water source are potential ways of creating these microclimates.

This is part of the National Wildlife Federation Certified Wildlife Habitat Program, and is a recommendation by the City of Toronto guidelines for biodiverse green roofs.

6.0 CONCLUSION

The next steps that need to be taken are the selection and refinement of metrics. Metrics could be combined, refined and modified to fit different forms of living architecture. The issue of how to deal with regional differences would then have to be approached, (this paper offers ways to approach this in section 4.0).

Following that, each metric must be weighted, with consideration given to how biodiversity is weighted within the entire system. The following chart shows how biodiversity is weighted within other rating systems. It is important to note that some credits contain many different facets, so this is far from a precise measurement.

Rating System	Biodiversity Weight
Sustainable Sites v2	9%
LEED v4	3% plus regional priority credits (if applicable in region)
Living Building Challenge	Difficult to quantify, but embraces biodiversity at a higher level by mandating landscapes emulate natural ecosystems
Roofpoint	N/A
Green Globes	1.1%
Envision	2.4%
BREEAM	5%
NWF Certified Wildlife Habitat	100%

While biodiversity should be an important consideration when designing living architecture, it needs to be weighted appropriately within a system that also considers a variety of factors including energy efficiency, stormwater management, etc.

Another important consideration is the need to develop a framework for monitoring and evaluating the biodiversity performance of living architecture following construction and/or certification. Plans for how to manage invasive species, pests and ecological succession are considerations for designers of living architecture. Planning for long-term health of floral and faunal communities could be a requirement of the LAPT, or an area where credits are awarded where a comprehensive plan is created.

This paper serves as a template for future white papers. Other white papers could follow the same structure and format (allowing for variation based on the uniqueness of each subject area). Once metrics are selected and consolidated in each area, links could be established between metrics, demonstrating the holistic and integrated nature of the LAPT.

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