Living Architecture Performance Tool

Stormwater Quantity Management

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 that 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 do not 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 that 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 that 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

A growing number of living architecture systems and strategies 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 by-products, such as reuse-quality water, and habitat for ornamental plants and the production of plant biomass. These plant by-products, 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 second white paper to be developed, on the subject of Stormwater Quantity Management.

2.0 STORMWATER: THE CURRENT APPROACH

By 2050, the world's population is predicted to rise to 9 billion, with two-thirds of those expected to live in urban areas (UNDP, 2008). Urban areas are constantly expanding and intensifying. Urbanization has many altering effects on hydrology, including an increase in impermeable areas like roofs and roads, construction of hydraulically efficient drainage systems to replace existing natural systems, compaction of soil, and removal and modification of vegetation (Elliott and Trowsdale 2005). Pervious surfaces with existing natural hydrology intercept, store and slowly deliver subsurface flow to receiving water bodies. In contrast, impervious or altered surfaces rapidly increase surface runoff directly to water bodies (See Figure 2.1). This increase of both runoff volume and peak flow stresses urban stormwater infrastructure, increases flooding risk, contributes to erosion along waterways, alters channel forms, and degrades receiving water bodies and habitats (Czemiel Berndtsson, 2009; Galster et al., 2006). In urban areas, runoff often contains high levels of pollutants, including hydrocarbons from roads, pathogens from animal waste, excessive nutrients from fertilizer, and sediment (Elliott and Trowsdale, 2005).

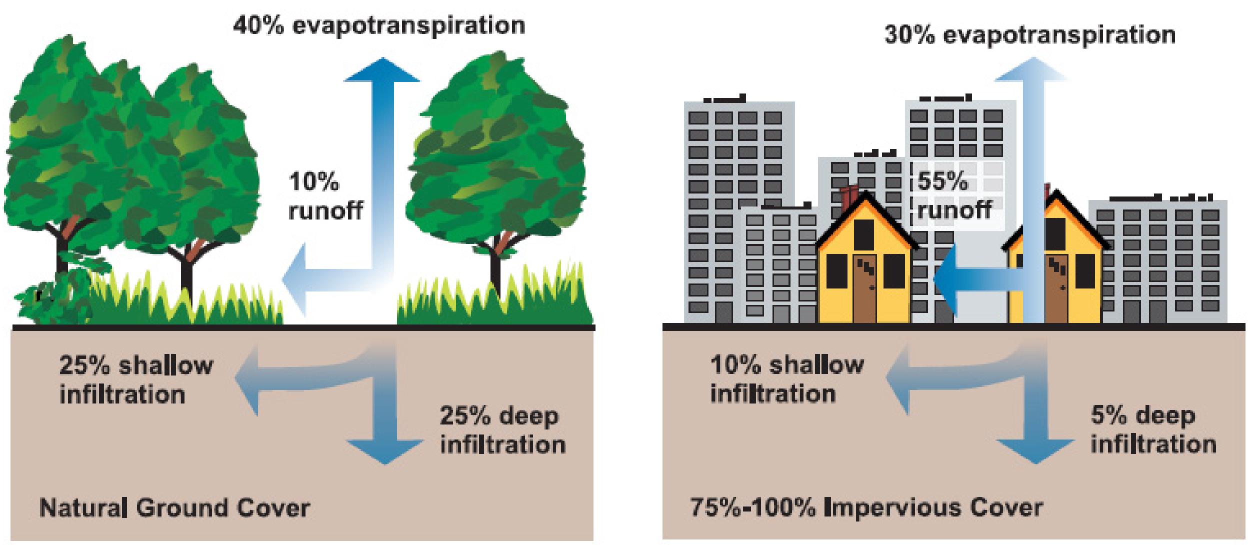

Figure 2.1, Source: US EPA (2003)

Combined Sewer Overflows

Many cities in North America - especially older ones - have combined sewer systems. These systems collect stormwater runoff, domestic sewage and industrial wastewater in the same pipe. This wastewater is conveyed to a treatment plant, where it is treated and then discharged into a waterway. However, during periods of heavy rainfall or snowmelt, the volume in a combined sewer system can exceed the capacity of the treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge untreated wastewater into nearby water bodies (See Figure 2.2). These Combined Sewer Overflow (CSO) events discharge wastewater that can include untreated sewage, toxic industrial by-products, and suspended solids. These pollutants are a significant source of water pollution in areas where combined sewer systems are common. This includes much of the Northeast, Great Lakes and Pacific Northwest regions of the United States.

There are 772 communities in the United States, home to 40 million people that are served by combined sewer systems (US EPA, 2014). Detailed data regarding combined sewer systems in Canada is not available, but most communities developed before the 1940s feature combined sewer systems, and are home to almost 7 million people (Chambers et al., 1997).

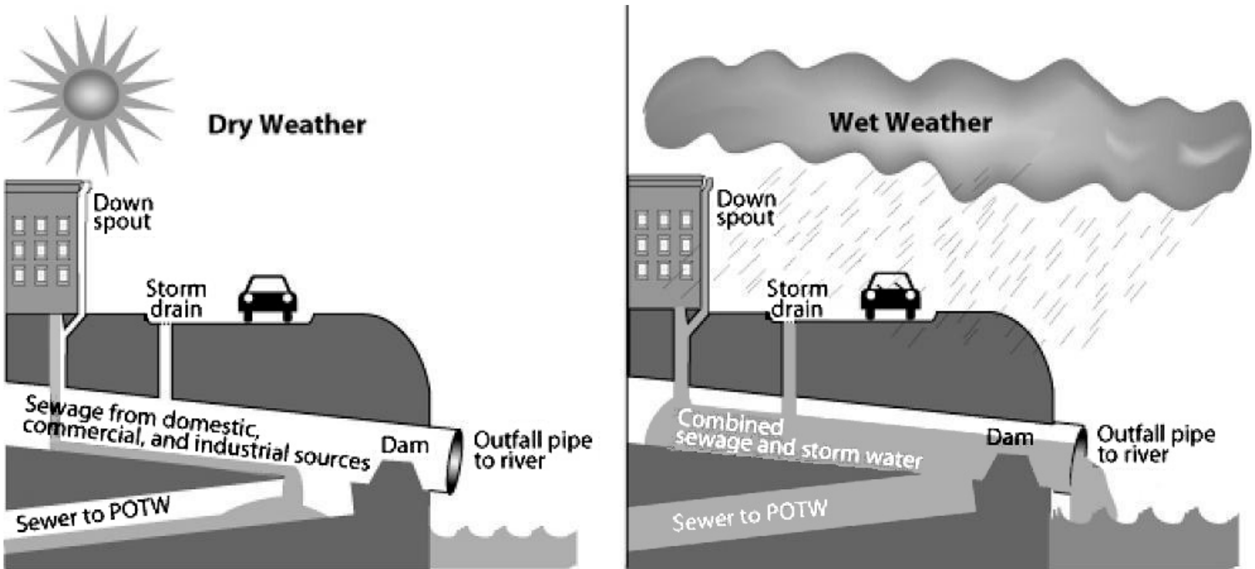

Figure 1.2, Source: US EPA (2004)

While many combined sewer systems overflow only during heavy rainfall or snowmelt, some systems overflow during every wet weather event.

In 1994, the United States Environmental Protection Agency (EPA) issued a policy statement requiring municipalities to control or eliminate CSOs. In 2000, Congress amended the Clean Water Act (1972) to require municipalities to comply with the 1994 policy statement issued by the EPA. When municipalities fail to comply with laws, the EPA can initiate an enforcement action to bring them into compliance and deter further violations. Many municipalities resolve violations by entering to a consent decree, which is a negotiated settlement between the EPA and the municipality. Several municipalities have entered into consent decrees to reduce combined sewer overflows, including Cleveland, Washington D.C., Pittsburgh, Cincinnati and Kansas City.

In 2012, the Government of Canada introduced its first regulations regarding the treatment of wastewater. The Wastewater Systems Effluent Regulations primarily address a minimum level of treatment for wastewater that must occur, but also require municipalities with combined sewer systems to record information on the frequency and quantity of combined sewer overflow events and develop a plan to reduce overflows.

Stormwater in a climate change-influenced world

Managing the quantity of stormwater runoff in urban areas becomes even more important in a world impacted by climate change. Climate change is expected to increase the unpredictability of weather and increase the incidence of extreme weather events. This includes an increase in the intensity of precipitation events and corresponding flooding risk, as well as increased incidence of drought.

There are a number of other second and third tier potential effects (Andrey et al., 2014):

- More intense rainfall events and increased rain on frozen ground are expected to increase the frequency and quantity of combined sewer overflows in the winter (Urban Systems, 2010; Genivar, 2011).
- Increased heavy flows will increase pumping requirements, increasing energy costs (Kerr Wood Leidal Associates Ltd, 2009) or in some cases, overwhelming pumping capacity.
- Pumping stations are at risk of electrical failure during periods of extreme summer heat due to overheating of building electrical systems (Genivar, 2011).
- More frequent winter thaw events can increase the flow of cold surface runoff in combined sewer systems, dramatically reducing the water temperature. These shocks can reduce the effectiveness of secondary and biological treatment (Plosz et al., 2009).
- The movement of debris can temporarily block drainage culverts and basins, causing localized flooding or erosion.

A study in 2009 found that a climate-changed influenced increase in rainfall intensity by 20% had the same impact on a combined sewer system as a 40% increase in impervious area. (Kleidorfer et al.). The potential for change on this magnitude must be met with a strategy to mitigate the effects of increased stormwater on our infrastructure.

2.1 Stormwater and Living Architecture

The widespread current approach to urban stormwater management treats precipitation as an undesirable by-product of urbanization. The traditional goal is to move stormwater away from the surface as quickly and efficiently as possible, using 'grey' infrastructure - impervious drains, culverts and channels routed to centralized storage and treatment facilities. Much of the existing grey stormwater infrastructure in North America is reaching the end of its life cycle. Additionally, many cities have outgrown their limited infrastructure and need to upgrade. Replacing or upgrading ageing and insufficient grey infrastructure within the status quo would require significant capital expenditure.

Fortunately, a recent conceptual shift towards treating precipitation as a resource that can be used is underway. Low-Impact Development/ LID (Canadian/American English), Sustainable Drainage Systems/SuDS (British English) and Water-Sensitive Urban Design/WSUD (Australian English) are terms used to describe a land-use and engineering approach that focuses on replicating natural hydrology. This approach aims to manage stormwater through evapotranspiration, infiltration, storage, detention and filtration of precipitation close to its source. There are two important principles involved in low-impact development: storm water is best controlled as close to the source as possible, and multiple technologies should be combined to create a more robust system than is possible with just one technology. In fact, the way LID elements interface with each other is very important, and that each element should perform at least one other function besides conveyance (Elliott and Trowsdale, 2007; Villarreal et al., 2004)

Many LID elements need to be integrated into an urban area during the design phase to replicate natural hydrology patterns, where runoff is as little as 10% (US EPA, 2003). Large areas of land are required for elements like stormwater detention/retention basins, wetlands, and biofiltration areas, which are often unavailable in existing built-up areas (Villarreal et al., 2004). However, there is an opportunity to reconcile the natural and built environments and manage stormwater quantities using living architecture. Living architecture technologies like green roofs and walls can help reduce the volume and peak of stormwater runoff, among other benefits. When they form the first part of a 'treatment train' and are combined with other forms of green infrastructure like rain gardens, permeable pavement and bioswales, they can form a new, decentralized method of managing stormwater. This decentralized network can be built as need arises or when existing infrastructure is being replaced, all without a large capital outlay. As more and more LID elements are put into place, they augment and increase the efficiency and effectiveness of traditional grey infrastructure. Past a certain threshold of implementation, they can prevent or reduce combined sewer overflows and dramatically improve watershed health (US EPA, 2012). The use of a low-impact stormwater management strategy is particularly attractive considering the policies to eliminate and reduce CSOs, and the increasing effects of climate change.

Villarreal et al. (2004) found that retrofitting communities using LID elements could create some conflict, where residents see 'usable' courtyards, gardens and lawns turned into 'unusable' swales and detention ponds. They argue that green roofs are superior in this aspect, because they make use of previously unused space. They also found that stormwater ponds could be extremely useful when combined with green roofs - both as a visual amenity and as a detention area. In a study of Augustenborg, an inner city suburb of Malmö, hydrograph simulations show that a detention pond is able to attenuate the peak of a 10-year storm, even with previously wet conditions.

2.2 Literature on Stormwater and Living Architecture

There is a large amount of literature outlining the value of using green roofs as an urban stormwater management strategy. Experiments conducted by Liaw et al. (2011) and a literature review conducted by Czemiel Berndtsson (2009) found that green roofs have demonstrated the ability to:

- Reduce the overall volume of runoff
- Attenuate peak runoff
- Delay the onset of runoff
- Delay the peak of runoff
- Extend the duration of runoff

Czemiel Berndtsson (2009) determined that the main benefits of green roof stormwater management are their ability to lower (attenuate) and delay the peak runoff. This is because green roofs detain a certain volume of water. Depending on the intensity and duration of the rain event, some of the water will slowly drain and some will be retained. Depending on several other variables, the retained water will evaporate or be transpired by plants. The total runoff reduction from green roofs corresponds to the volume of water evaporated or transpired.

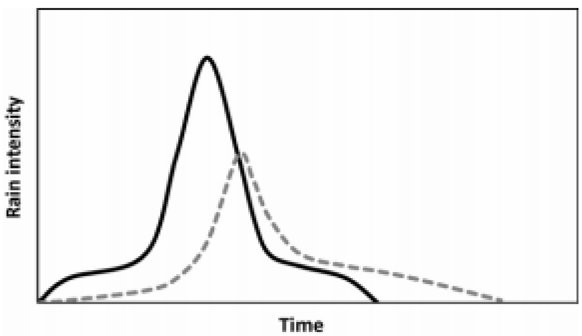

Figure 2.3 - Example runoff from a green roof (dashed line) generated by a given rain event (solid line). (Czemiel Berndtsson, 2009)

The findings of Mentens et al. (2005) found that widespread implementation of green roofs can have a significant impact on an urban watershed scale. Using the example of Brussels, they determined that implementing extensive green roofs (with a substrate depth of 100mm) on 10% of buildings could reduce total urban runoff by 2.7%. Given that the scope is the entire capital region, which includes parks and forests, this figure could be higher in a denser urban area with more existing impermeable surfaces. Similarly, Speak et al. (2013) found that greening 10% of Manchester's rooftops would result in a 2.3% in urban runoff. While these numbers may seem low, they illustrate that green roofs are only one part of the stormwater management toolbox, and they should be considered for their myriad other benefits, and are most effective when used in combination with other LID elements.

Czemiel Berndtsson's literature review (2009) found green roof stormwater performance depends on two main types of variables, design characteristics and weather conditions:

- ***Green roof design characteristics:*** number of layers and type of materials, substrate depth and composition, vegetation type and cover, roof geometry, slope and length, roof position (sun exposure, direction faced), roof age

- ***Weather conditions:*** length of proceeding dry period, season/climate (air temperature, wind conditions, humidity), characteristics of rain event (duration, intensity)

Green Roof Design Characteristics

A review of German studies conducted by Mentens et al. (2005) examined the annual reduction in runoff from green roofs versus traditional roofs. Using 628 measurements from 18 publications, most from Germany, they found that green roofs have significant potential to reduce the total volume of stormwater runoff. The study areas featured annual precipitation of between 533 mm and 1347 mm. Water retained ranged from 27%-81% on extensive green roofs (with a median depth of 100mm), and 65%-85% on intensive green roofs (with a median depth of 150mm). They found that the number of layers and depth of substrate are significantly correlated with the yearly runoff. Based on their collected data, the researchers developed a regressed equation to determine yearly runoff from a green roof, using precipitation and substrate depth as variables. The equation is

Annual Runoff (mm) $= 693 - 1.15P + 0.001P^2 - 0.8 \times S$, where P is annual precipitation in mm, and S is substrate depth in mm. [1]

Runoff reduction rates increase with both the depth and the water retaining capacity of the growing media (Guo et al., 2014). Soil moisture characteristics are an important variable in water holding capacity and by extension, runoff reduction. Bengtsson (2005) defines water retention capacity as the difference between field capacity and wilting point (plant available water), or about 30% of substrate volume. Runoff from green roofs does not occur until the growing media is at field capacity. The same green roof may provide higher runoff reduction but require more irrigation in arid/semi-arid areas than in humid areas. Incorporating a water storage layer into a green roof can enhance runoff reduction potential as well as reduce the need for irrigation. (Guo et al, 2014).

The role of growing media composition is unclear. Most studies have focused on depth of growing media, and literature comparing different types of growing media is extremely limited. The age of a green roof does affect the physical and chemical properties of green roofs over time, and Getter et al. (2007) found that organic matter and pore space dramatically increased in the media of a 5 year old roof, improving its water holding capacity from 17% to 67%. However, Mentens et al. (2005) found no relationship between age and retention capacity, further clouding the issue.

The role of vegetation is most important during periods of low water availability and high evapotranspiration. Lundholm et al. (2010). found that a diverse plant structure including different types of vegetation like grasses, forbs, and succulents was more effective than monocultures at managing stormwater. Grasses and forbs are more effective than succulents

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[1] This equation is limited to a specified rainfall range typical of Western and Central Europe (533-1347 mm/year). It is also important to note that while Mentens et al. (2005) were able to develop a regressed equation to determine yearly rainfall, other researchers (Speak et al, 2013; Stovin et al., 2012; Carter and Rasmussen, 2006) concluded that large variations in retention data made the use of regression models unfeasible.

at transpiring water out of the soil into the air, but are also less hardy during periods of drought and may require supplemental irrigation. The researchers claim that the best way to approach this delicate balance is to plant a combination of tall forbs, grasses and succulents to optimize the range of ecosystem services provided and maximize evapotranspiration and runoff reduction. This maximization of evapotranspiration contributes to another important goal of green roofs – to reduce the roof temperature, and by extension, heating costs and the urban heat island effect. The role of vegetation in stormwater retention was found to be most important during periods of low water availability and higher temperatures (i.e. when potential evapotranspiration rates are highest), and negligible in winter (Dunnett et al., 2008). However, Teemusk and Mander (2007) found that runoff was significantly lower for all studied events where plant coverage was denser, suggesting that the water was held and slowly released by the plants themselves.

Villarreal and Bengtsson (2005) found that slope did not affect the shape of the hydrograph – i.e. slope does not influence the response of the system to different rain events. They did find, however, that slope does affect water retention – the lower the slope, the greater the retention. Getter et al. (2007) and VanWoert et al. (2005) also found that slope and retention capabilities are correlated. Getter et al. found that lower sloped roofs retained 85% of rain, while higher sloped roofs retained 75%. However, Bengtsson (2005) found that slope does not significantly influence runoff distribution, suggesting that vertical percolation of water through the growing medium is the dominant force in the rainfall-runoff process. The data on slope is not completely clear, but the literature seems to support the argument that lower sloped roofs are at least somewhat more effective than higher sloped roofs at retaining stormwater.

Effect of Weather and Climate

The antecedent dry weather period is an important factor affecting the retention capacity of a green roof. Longer dry periods should allow the substrate to 'recharge' its potential for water storage (Stovin et al, 2012). While the antecedent dry weather period should theoretically be a good predictor of retention capacity, the interaction of other factors like season effects on evapotranspiration produces too much variation to identify clear trends (Speak et al., 2013).

Stovin et al. (2013) compared green roofs in different parts of the UK and found that annual runoff reduction was heavily dependent on climate. The hottest and driest areas retained 59% of annual runoff, while the coolest and wettest retained only 19%. It is important to note that these findings are limited to the UK, which has less significantly less variation in climate than North America and falls largely into only one Köppen climate classification zone. In a review of German studies, Mentens el al. (2006) found that the warm season results in higher evapotranspiration rates and by extension, faster water retention capacity recharge. Bengtsson et al. (2005) found the difference in seasonal retention to be large, with only 19% retained in February, compared with 88% in June. Villarreal and Bengtsson (2005) found that in dry conditions, runoff did not occur until 6-12 mm of rain, but runoff was almost immediate in wet conditions. Further studies on green roof performance during snowmelt would aid the further understanding of green roof performance in winter.

> Carter and Rasmussen (2006) found that green roofs are better at retaining water from smaller events than larger events, as the substrate quickly reaches its water holding capacity during larger events. The numbers ranged from 48% retention in larger storms (>76.2 mm) to 88% in smaller storms (<25.4 mm). Similarly, Simmons et al. (2008) found that small events (<10 mm) were all retained, while an average of 43% was retained during large events (28-49 mm).

Because factors affecting stormwater performance on green roofs are rarely the same, it is impossible to generalize the hydrology of green roofs. Wide variations in runoff reduction have been reported in various studies, and there is a lack of accepted design tools or models to predict stormwater performance of green roofs. This poses a major challenge to designing green roofs for stormwater management performance (Czemiel Berndtsson, 2009; Guo et al., 2014). Additionally, there is a lack of understanding of evapotranspiration rates, which are critically important to the 'recharging' of water holding capacity, and dependent on climate and season (Stovin et al., 2013).

The literature on stormwater management using green walls and facades is extremely limited. Green walls in Portland (Bajandas, 2014) and London (Dezeen, 2013) have recently been constructed with the goal of managing stormwater. In both cases, runoff from the roof is directed to the wall. Based on the literature on green roofs (Czemiel Berndtsson, 2009), it can be assumed that stormwater directed to a green wall system will be evaporated and transpired by plants and lead to reduced runoff. The additional substrate and plant material should also provide hydraulic resistance to delay the onset and peak of runoff. Green walls could be another important step in the LID treatment train if designed and implemented appropriately. It is important to note that these inferences are speculative and based on green roof literature. There is a need for further study of the potential of green walls to manage stormwater.

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. Because 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 is designed to be a comparable but more cost-effective alternative to LEED, because it is 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 stormwater management is almost exclusively performance based, requiring a percentage reduction based on the nature of the rating system and overall project. Many of the measurement standards used are based on surface hydrology, which may not be appropriate to use when discussing the stormwater management capabilities of living architecture like green roofs and walls (which do not have the same hydrological properties). Most rating systems do not offer a prescriptive approach to managing stormwater dealing especially with living architecture. 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 stormwater quantity management.

Table A presents an overview of how these rating systems address topics related to stormwater quantity management. 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 stormwater quantity management 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.

Table A - Credits in existing rating systems that relate to Stormwater Quantity Management

Rating System	Description of Credit	Points	Measurement Standard / Basis	Relevance					
				Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Sustainable Sites v2	Manage precipitation on site - retain the precipitation volume from the 60th percentile precipitation event through on site infiltration, evapotranspiration, and reuse	Req.	Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act (or local equivalent for projects outside the United States).	Y	Y	?	N	?	Y
	Manage precipitation on site - retain or treat the precipitation volume from the 80th-95th percentile precipitation event	4-6 of 200 possible	Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act (or local equivalent for projects outside the United States).	Y	Y	?	N	?	Y
	Design functional stormwater features as amenities - must use precipitation as the sole source of water and be visually and physically accessible from high-use areas of the site	4-5 of 200 possible		?	Y	?	N	?	Y
LEED v4	Manage precipitation runoff on site in a manner best replicating natural site hydrology processes. From the 95th-98th percentile of precipitation events (85th percentile for zero lot line projects with a FAR over 1.5) - OR -	2-3 of 100 possible	Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act	Y	Y	?	N	?	Y
	Manage the increase in runoff volume from the natural land cover condition to the post-developed condition	3 out of 100 possible		Y	Y	?	N	?	Y

Roofpoint	Install a self-sustaining (no irrigation except during establishment period and during extreme drought) vegetated roof covering 75% of the roof surface. (Can also use a non-vegetated water retaining roof or combine with a vegetated roof)		To qualify as a non-vegetated water retaining roof, the manufacturer must provide documentation that the roof can retain 90% of a 1" rain event over a 24 hour period, with no standing water remaining after 48 hours.	Y	Y	N	N	N	N
National Wildlife Federation	N/A	N/A	N/A						
Living Building Challenge 3.0	All stormwater must be treated on site and managed either through re-use, a closed loop system, or infiltration. Excess stormwater can be released onto adjacent sites under certain conditions.	Req.		Y	Y	?	N	?	Y
Green Globes	Meets municipal and/or watershed flood and erosion control targets	5 out of 1000		?	?	?	N	?	?
	Retains at least 50% of average annual rainfall volume as per a Site Water Balance Assessment	5 out of 1000		Y	Y	?	N	?	Y
Envision	Retain 100% of stormwater on greenfield sites. Retain between 30%-100% of stormwater on greyfields, 20%-100% on brownfields	4-21 out of 700 possible	TR-55 or other continuous simulation modeling methods. For greenfields, the target water storage is based on pre-development conditions. For greyfields and brownfields, the target water storage capacity using TR-55 CNs has been established for various climates across the US to represent pre-development conditions.	Y	Y	?	N	?	Y

BREEAM	All stormwater credits (achieving some credits preclude a project from achieving others, only 5 credits can be achieved regarding surface runoff)	3.85% of total system based on weighting							
	The peak rate of runoff from the developed site is no greater than that of the pre-development site. Relevant maintenance agreements for the ownership, long term operation and maintenance of all specified SuDS (Sustainable Drainage Systems) are in place.	1 credit out of 132 (0.77%)	Based on 1 and 100 year rain events, should allow for climate change, in accordance with current best practice planning guidance.	Y	Y	?	N	?	Y
	Drainage design measures are specified to ensure that the post development run-off volume, over the development lifetime, is no greater than it would have been prior to the assessed site's development for the 100-year 6-hour event, including an allowance for climate change (see criterion 14). 2. Any additional predicted volume of run-off for this event is prevented from leaving the site by using infiltration or other Sustainable Drainage System (SuDS) techniques. - OR - When there is a justification as to why the above criteria cannot be met, Drainage design measures are specified to ensure that the post development peak rate of run-off is reduced to the limiting discharge.	1 credit out of 132 (0.77%)	The limiting discharge is defined as the highest flow rate from the following options: The pre-development 1-year peak flow rate; OR The mean annual flow rate Qbar; OR 2L/s/ha.	Y	Y	?	N	?	Y
	There is no discharge from the developed site for rainfall up to 5mm. Appropriate levels of pollution prevention treatment are to be provided, based on SuDs techniques.	1 credit out of 132 (0.77% of total system based on weighting)		Y	Y	?	N	?	Y
	Simple buildings only There is a decrease in impermeable area of 50% - OR - Runoff from rainfall depths up to 5mm are managed on site	2 credits out of 132 (1.55%)	Simple buildings - do not contain air conditioning, refridgeration, escalators, commercial kitchens, etc.	Y	Y	N	N	N	Y
	Simple buildings only There is no increase in impermeable area - OR - If there is an increase in impermeable area, all hard standing areas and building extensions should be permeable or provided with on-site SuDS to allow full infiltration of additional volume, and manage runoff from rainfall depths of up to 5mm on site	1 credit out of 132 (0.77%)		Y	Y	N	N	N	Y

4.0 The 'Region' Question

A major criticism of LEED and other rating systems is they fail to address regional issues and differences related to performance adequately. Sites can face very different conditions, depending on their climatic zone, habitat zone, degree of urbanization and even the jurisdiction they fall under. 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 that 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 95^{th} percentile of local rain events, or reduce heating or cooling costs by 20%) inherently consider regional differences. 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 living architecture. The potential metrics described here are based on metrics used by existing rating systems, as well as factors that contribute to increased stormwater quantity management as determined by the research community.

Table B provides an overview of potential metrics that could be applied to living architecture. The table describes the metric, its measurement basis, and its potential application to different types of living architecture. Living architecture assessed here includes extensive and intensive green roofs, interior and exterior green walls and green facades. 'Other' includes living retaining walls, biofiltration systems, living machines and constructed wetlands. The metrics are then described in detail, with a rationale grounded in literature and/or a presence in other rating systems like LEED, Sustainable Sites, etc.

Table B - Potential Stormwater Quantity Management Metrics

			Potential Application					
Intent	**Metrics**	**Type and Measurement Guidelines**	**Ext. Roof**	**Int. Roof**	**Ext. Wall**	**Int. Wall**	**Faç-ade**	**Oth-er**
Reduce the volume of runoff, and delay the start and peak of runoff by increasing the water retention capacity	Total annual runoff reduction, delay of start and peak of runoff, depth and composition of growing media, presence of water storage layer	Performance based modeling using TR-55 or similar software (adapted for green roof hydrology), design guideline or on site validation	Y	Y	?	N	?	Y
Reduce the total overall runoff by maximizing evapotranspiration; use an optimal vegetation mix and increase water contact with plant root zone	Leaf area index, plant diversity index, mix of grasses, succulents and forbs, hydraulic resistance time	Design guideline or on-site testing and validation post-construction	Y	Y	?	N	?	Y
Integrate with other low-impact development devices	Integration with bioswales, rain gardens, artificial wetlands, etc.	Design guideline	Y	Y	Y	?	Y	Y

5.1 Improved Water Retention

Intent	Reduce the volume of runoff, and delay the start and peak of runoff by increasing the water retention capacity
Metric(s)	(1) Total annual runoff reduction (2) Time delay of start and peak of runoff during a baseline storm event (3) Depth of growing media (4) Presence of water storage layer (5) Water holding capacity of individual components or completed assembly
Measurement Methods	Annual runoff modeling using software programs like TR-55 (adapted for green roof hydrology) (1/2); Design guideline or on-site validation (3/4); Product testing (5)
Rationale	

A review of German green roofs conducted by Mentens et al. (2005) found that found that the number of layers and depth of substrate are significantly correlated with the yearly runoff. The researchers developed a regressed equation to find the annual runoff retention of a green roof based on precipitation and substrate depth.

Guo et al. (2014) also determined that the depth and water retaining capacity of green roofs increased the runoff reduction. Additionally, they found a water storage layer enhances runoff reduction potential while also reducing the need for irrigation.

While software modeling is an established practice when attempting to determine the energy savings potential of living architecture, stormwater modeling is still quite limited. The wide variations in runoff reduction from different studies make it difficult to make generalizations, and there are a lack of accepted models for runoff reduction on green roofs (Czemiel Berndstsson, 2009; Guo et al., 2014). It can also be argued that green roof hydrology is very different than surface hydrology – infiltration is a negligible part of the equation (Miller, 2013). Because of this, green roof specific models would have to be developed, or surface hydrology models like TR-55 would have have to be adapted and refined to accurately measure the water retention capabilities of green roofs.

5.2 Improved Evapotranspiration

Intent	Reduce the total overall runoff by maximizing evapotranspiration; use an optimal vegetation mix and increase water contact with plant root zone
Metrics	(1) Leaf area index (2) Plant diversity index, or optimized plant mix (3) Hydraulic resistance time
Measurement Methods	(1/2) Design guideline or on-site validation; (3) Product testing of individual components or completed assembly
Rationale	

Teemusk and Mander (2007) found that runoff was significantly reduced when vegetation density was higher, suggesting that denser plants lead to increased evapotranspiration and water holding capacity.

Lundholm et al. (2010) found that a diverse plant structure including different types of vegetation like grasses, forbs, and succulents was more effective than monocultures at managing stormwater. Grasses and forbs are more effective than succulents at transpiring water out of the soil into the air, but are also less hardy during periods of drought and may require supplemental irrigation. The researchers claim that the best way to approach this delicate balance is to plant a combination of tall forbs, grasses and succulents to optimize the range of ecosystem services provided, maximize evapotranspiration (and by extension, runoff reduction) as well as minimize the need for supplemental irrigation.

Miller (2013) argues that green roofs differ from other green infrastructure in that runoff reductions are not based on infiltration, but rather on evapotranspiration. Therefore, a viable strategy to reduce runoff is to optimize evapotranspiration – this can be accomplished by maximizing the time that water is in contact with the substrate and plant roots. This contact time can be manipulated by controlling the transmissivity of the layers, creating a tortuous path for drainage, and providing for water storage areas within the green roof.

5.3 Integration with other Low-Impact Development (LID)

Intent	Use living architecture as the first step in a low-impact stormwater 'treatment train'
Metric	Integration of living architecture with other forms of low-impact development like bioswales, rain gardens, constructed wetlands, etc.
Measurement Method	Design guideline
Rationale	

Villareal et al. (2004) argue that the way LID elements interface with each other is very important, and that each element should perform at least one other function besides conveyance. Green roofs are arguably the most space-efficient form of LID because they use existing 'wasted' space (the same argument could be made of living walls or green facades). When they form the first part of a 'treatment train' and are combined with other forms of green infrastructure like rain gardens, permeable pavement and bioswales, they can form a new, decentralized method of managing stormwater. This decentralized network can be built as need arises or when existing infrastructure is being replaced, all without a large capital outlay. As more and more LID elements are put into place, they augment and increase the efficiency and effectiveness of traditional grey infrastructure. Past a certain threshold of implementation, they can prevent or reduce combined sewer overflows and dramatically improve watershed health.

6.0 STANDARDS

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.

The following standards are relevant to establish a standard test method or specification to determine the performance of a product or design as it relates to stormwater management performance:

ASTM E2397-11 - Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems

This practice covers a standardized procedure for predicting the system weight of a vegetative (green) roof system and addresses the weight of the green roof system under two conditions: (1) weight under drained conditions after new water additions by rainfall or irrigation have ceased (this includes the weight of retained or captured water), and (2) weight when rainfall or irrigation is actively occurring and the drainage layer is filled with water. The first condition is considered the dead load of the green roof system. The difference in weight between the first and second conditions, approximated by the weight of transient water in the drainage layer, is considered a live load.

ASTM E2396-05 – Saturated Water Permeability of Granular Drainage Media

This test method covers a procedure for determining the water permeability of coarse granular materials used in the drainage layers of green roof systems and addresses water permeability under the low-head conditions that typify horizontal flow in green roof applications.

ASTM E2398-05 – Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems
This test method covers the determination of the water and media retention of synthetic drain layers used in green roof systems. This standard is applicable to geocomposite drain layers that retain water and media in cup-like receptacles on their upper surface. Examples include shaped plastic membranes and closed-cell plastic foam boards.

ASTM E2399-05 - Standard Test Method For Maximum Media Density or Dead Load Analysis of Green Roof Systems
This test method covers a procedure for determining the maximum media density for purposes of estimating the maximum dead load for green roof assemblies. The method also provides a measure of the moisture content and water permeability measured at the maximum media density.

ASTM D4491 – Standard Test Methods for Water Permeability of Geotextiles by Permittivity
This test method covers the procedure for determining the quantity of water that can pass through a geotextile perpendicular to the surface of the geotextile.

ASTM D4716 – Standard Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head Geotextile
This test method covers the procedure for determining the volumetric flow rate of water per unit width of a geotextile specimen per unit gradient in a direction parallel to the plane of the specimen.

7. 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.

Objectives must be determined – is overall volume reduction the main objective, or is it a reduced flow rate and delayed flow? Potential metrics must be evaluated as to their ability to measure performance related to the objectives, as well as the cost of measurement and accuracy for the stated objectives. Can multiple goals be met with one metric or do there need to be several? Are they design guideline based or performance based? This is a crucial step, and multiple priorities (alignment with objectives, cost, and accuracy of measurement) will need to be balanced.

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 stormwater quantity management is weighted within the entire system. The following chart shows how stormwater quantity management 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	**Stormwater Quantity Management Weight**
Sustainable Sites v2	5.5%
LEED v4	3% plus regional priority credits (if applicable in region)
Living Building Challenge	Difficult to quantify, but embraces stormwater management at a higher level; mandates all stormwater is treated and managed on site
Roofpoint	4.3%
Green Globes	1%
Envision	3%
BREEAM	3.85%

Another important consideration is the need to develop a framework for monitoring and evaluating the stormwater quantity management performance of living architecture following construction and/or certification. Plans for how to maintain drainage systems are considerations for designers of living architecture. Planning for long-term stormwater management effectiveness could be a requirement of the LAPT, or an area to award credits where a comprehensive plan is created.

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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