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Green Infrastructure as Water Sensitive Urban Design Strategy for Sustainable Stormwater Management

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Abstract: The world is struggling against extreme droughts, heavy rain, and heat waves because of climate change. These abnormal climate cause urban flood, urban heat island, and water pollution and shortage and these natural disasters not only threaten citizen's health and amenity but also negatively affect cities economically, environmentally, and socially. Thus, this paper discusses about green infrastructure as water sensitive urban design strategy to prevent and mitigate damages of natural disasters by climate change in terms of sustainable stormwater management in urban areas. To do this, this paper reviews concept, context, and current trends of green infrastructure, and examines relations between green infrastructure and sustainable stormwater management. After then, some case studies of green infrastructure are selected to investigate design methods, environmental performances, and benefits of green infrastructure in terms of sustainable stormwater management.

Keywords: Green Infrastructure, Water Sensitive Urban Design, Sustainable Stormwater management, Climate Change

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1. Introduction

The world is struggling against extreme droughts, heavy rain, and heat waves because of climate change. These abnormal climate cause urban flood, urban heat island, and water pollution and shortage and these natural disasters not only threaten citizen's health and amenity but also negatively affect cities economically, environmentally, and socially. Furthermore, frequency and scale of damages by droughts, heavy rain, and heat waves will be increased for some period by climate change (OECD, 2010). Our society also cannot be exceptional when we consider unusual weather in recent years in Korea. Therefore, this paper will discuss about green infrastructure as water sensitive urban design strategy to prevent and mitigate damages of natural disasters by climate change in terms of sustainable stormwater management.

2. Method

Firstly, this paper reviews concept, context, and current trends of green infrastructure, and examines relations between green infrastructure and sustainable stormwater management. Secondly, some case studies of green infrastructure as water sensitive urban design strategy are selected. However, they are limited to buildings and small-scale sites to be applied in urban area because green infrastructure's scope is very broad. Therefore, these selected case studies can be categorized into 1) building landscape - green roofs; roof farms; cisterns 2) site landscape – rain gardens; constructed wetlands; bioswales; bioponds 3) street landscape – stormwater planters; curb extensions; permeable pavement. All of case studies also are limited in North America area because green infrastructure for sustainable stormwater management were initiated and are being applied in there. Therefore, the following cases are analyzed. 1) Building landscape – ASLA headquarters green roof, Washington D.C. 2) site landscape – Mount Tabor Middle School rain garden, Portland, Oregon; Sidwell Friends School, Washington D.C.; Tanner Springs Park, Portland, Oregon 3) street landscape – SW 12th Avenue Green Street, Portland, Oregon; Taylor 28, Seattle, Washington. Thirdly, this paper examines sustainable design methods, environmental performances, and benefits through selected case studies.

3. Green Infrastructure for Sustainable Stormwater Management

Green infrastructure means different things to different people depending on the context in which it is used. Green infrastructure was theorized by Benedict and McMahon in the United States even though the President's Council on Sustainable Development identified green infrastructure as one of five opportunity areas for sustainable community development, defining it as "the network of open space, airsheds, watersheds, woodlands, wildlife habitat, parks, and other natural areas that provides many vital services that sustain life and enrich the quality of life" (p. 64). Benedict and McMahon have offered the most commonly cited definition of green infrastructure: "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations (p.6)". This definition was later elaborated in a book-length work (Benedict, 2000; Benedict and McMahon, 2003, 2006). Green infrastructure, according to Benedict and McMahon, encompasses both natural and restored ecosystems and features, which together form a system of "hubs", "sites", and "links." Hubs include anything from managed preserves to publicly owned lands to community parks, and they serve as anchors to green infrastructure networks. Sites are smaller than hubs and include local areas intended for nature-based recreation or enjoyment. Links – such as floodplains and greenbelts – tie the system together and are "critical to maintaining vital ecological processes" (Benedict and McMahon, 2006). Such connectivity, say Benedict and McMahon, is the key to green infrastructure.

By stressing the interconnectivity of green infrastructure, Benedict and McMahon hope to craft a principled, integrated, long-term approach to sustainable community development. They argue that green infrastructure can be implemented at any scale, from the household to the regional level. They stress the need for a comprehensive framework for sustainable development grounded in careful planning and wise public investment. Implemented properly, green infrastructure benefits both nature and people, respecting the needs and desires of landowners and stake holders while protecting vital natural resources (Benedict and McMahon, 2006).

However, as Benedict and McMahon concede (2003), “green infrastructure means different things to different people depending on the context in which it is used (p. 5).” To some, green infrastructure refers simply to “natural features” in urban areas, including trees, wetlands, streams and open (or green) spaces. Others think of green infrastructure in terms of planning, practices and policies. They emphasize the conservation of natural resources combined with the re-engineering of the urban environment to promote natural hydrological cycles. Such definitions are compatible with the arguments of Benedict and McMahon, but they are less grand in scope, less ambitious in their claims (Klaver, 2010).

However, recently it is defined, green infrastructure has moved closer to the center of both public and intellectual discourse on stormwater and wastewater management. Traditional measures of stormwater control have become too damaging, inefficient and costly to persist. Green infrastructure offers alternatives that are more sustainable, more efficient and less costly. As Wise puts it (2007), “the future of stormwater has arrived, and that future is green. Green infrastructure, that is (p. 15).” In the United States, the transition from the gray infrastructure of sewage and drainage systems to a green infrastructure has been driven in part by the U.S. Environmental Protection Agency (EPA). According to Richards (2009), green infrastructure manages stromwater “through infiltration (water soaking into the ground), capture and reuse (water being stored in a rain barrel or cistern for later use in watering plants or flushing toilets), and evapotranspiration (water being used by trees and plants).” These three processes infiltration, reuse and evapotranspiration constitute the basis of green infrastructure.

However, on a smaller scale, the green infrastructure approach to stromwater control is based on landscape design. Sustainable landscape design mitigates urban flooding and water pollution by protecting and restoring the capacity of a site to cleanse and temporarily store water. Sustainable landscape design can hold water on-site using both built (e.g. porous paving and green roof) and natural (vegetation and soil) site components that intercept, infiltrate, and evaporate stromwater. Stormwater can also be harvested and stored in cisterns or other containers for reuse on the landscape or in buildings. Existing sources of stromwater runoff and water pollution, such as parking lots or heavily fertilized lawns, should be identified in the site inventory, and design strategies developed to capture and cleanse the water on-site. Vegetation, soil, and the diverse community of microorganisms that live within the soil can bind and break down many water pollutants. Sites can take advantage of these natural cleansing mechanisms by using design strategies such as biofiltration areas that slow runoff and filter it through vegetation and soil. At the outset of a project, goals and performance targets should be established for reducing stromwater runoff and avoiding the outset use of materials or products that pollute water resources. New design opportunities arise when project teams view stromwater not as a waste product, but as a valuable resource that can be utilized to improve the function and beauty of the site (Venhaus, 2012).

According to Wise (2007), these practices do more than reduce stromwater runoff: they “also foster community cohesiveness by engaging residents in planning, planting, and maintaining highly visible stormwater infrastructure that beautifies and adds value to neighborhoods (p. 16).” As the literature suggests, transitioning away from gray infrastructure toward green infrastructure to manage stromwater and wastewater runoff involves a welter of practices at multiple scales. No single sustainable landscape design components can restore the natural hydrological cycle at a given location.

Rather, each city must crafts a comprehensive plan of stromwater and wastewater management that applies green infrastructure theory from the household to the regional level. An expansive body of literature exists to support such efforts, and a growing number of case studies have amply demonstrated the advantages of moving toward green infrastructure (Klaver, 2010).

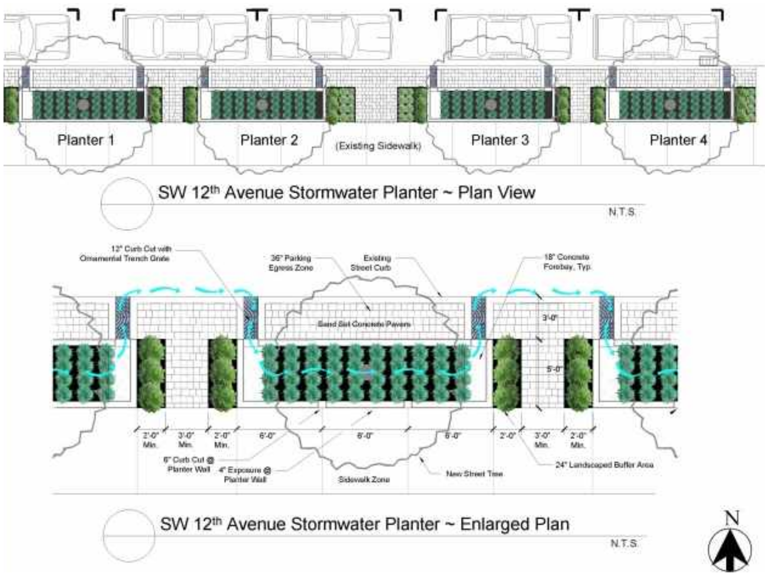
4. Case studies

4.1. SW 12th Avenue Green Street

4.1.1. Design Overview

The SW 12th Avenue Green Street project, located adjacent to Portland State University in downtown Portland, is unique to Portland and the United States in the way the pedestrian zone of this street has been transformed to sustainably manage street stormwater runoff. As part of the City of Portland's commitment to promote a more natural approach to urban stormwater management, this "green street" project converts the previously underutilized landscape area between the sidewalk and street curb into a series of landscaped stormwater planters designed to capture, slow, cleanse, and infiltrate street runoff. Built in the summer of 2005, this street retrofit project demonstrates how both new and existing streets in downtown or highly urbanized areas can be designed to provide direct environmental benefits and be aesthetically integrated into the urban streetscape. Though this green street project maintains a strong functional component, it is the ability of the landscaped stormwater planters to be integrated into the urban fabric that has the design community, developers, policy makers, and local citizens excited about the SW 12th Avenue Green Street (ASLA, 2006; Margoris et al., 2010).

Figure 1. SW 12th Avenue Green Street Plan (image courtesy of Sustainable Stormwater Management Program)



4.1.2. Sustainable Stormwater Management

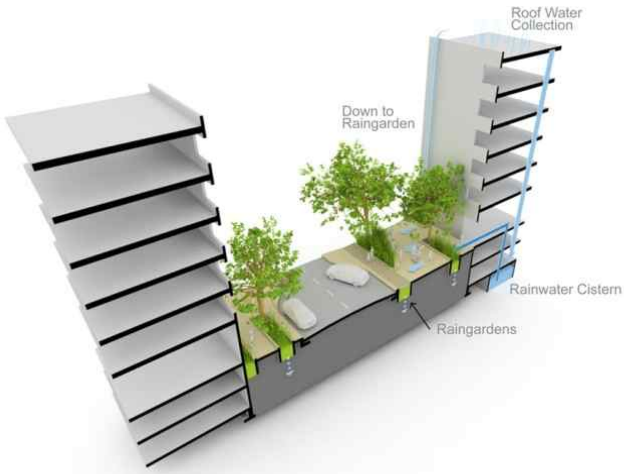
The system of embedded planters is designed to handle 60% of SW 12th Avenue's street runoff, a total of 180,000gallon (681,374 L) annually, for the three-lane street with parking. Stromwater runoff from 8,000 square feet (743m2) flows along the existing curb until it reaches the first of four 4ft x 17ft (1.2 x 5.2m) stromwater planters, with a combined area of 272sf (25.3m2). A 12inch (30.5cm) cut in the curb channels the runoff into the first stromwater planter, which then collects to a level of up to 6in (15.25cm). Once the 6in height is reached, water exits through the planter's second curb cut, along the street, and into the next planter. Only when all the planters exceed, capacity will excess water flow into the storm-drain system. It is expected that the water will infiltrate into the ground at rate of 4in/hr (10.16cm/hr).During construction, basin were dug to 9inch (22.9cm) below the sidewalk grade and filled with native soils, amended with an equal mix of sand, compost, and screened loam. Native Rushes (Juncus patens) were planted in row 18inch (45.7cm) on center to allow space for a leaf rake to remove accumulated sediment and debris. During rain events, the native Grooved Rush (Juncus patens) in each water planter slows water-flow and retains pollutants. The rush's deep penetrating roots absorb water and are also drought-tolerant enough to survive the dry summer. Tupelo trees (Nyssa sylvatica), planted in the middle of each planter, were chosen for their tolerance to wet-dry conditions, and for their spectacular fall color. The infiltration basins are cleaned of pollutant-loaded sediment periodically. Since installation in July 2005, the first basin in the series has been cleaned every two months, while the others have not yet needed cleaning. Pea gravel placed just below the level of the sediment layers informs excavators when they have reached the bottom of the layer (ASLA, 2006; Margoris et al., 2010).

4.2. Taylor 28 Steetscape

4.2.1. Design Overview

Taylor 28 is the first residential, mixed-use development within the transforming Denny Triangle neighborhood. The project sets a precedent for a new urban design standard that transfers underutilized roadway into the public realm. The new pedestrian-focused neighborhood enhances the quality of the urban experience and contributes to a healthier Puget Sound by minimizing stormwater runoff and input to Seattle's overburdened combined sewer overflow pipe system. Prior to development, Taylor Avenue included two travel lanes and back-in angled parking on both sides of the street. The project's design maintains the same vehicular volume (two travel lanes) but eliminates the inefficient angled parking. The final design resulted in a reduction in vehicular width of 20 feet (6 m) while still maintaining some parallel on-street parking. This design concept has been approved by the city of Seattle for the entirety of Taylor Avenue, which stretches several blocks north and south of the project site. Taylor 28 was designed to catalyze the neighborhood development by creating great public space and attracting more residents through a combination of apartments and retail. The design team worked closely with key city of Seattle staff to achieve outcomes that crossed typical boundaries between zoning, planning, streets, and utilities to address layout, maintenance responsibilities, rainwater harvesting and reuse, and stromwater collection and distribution (Venhaus, 2012).

Figure 2. Taylor 28 Streetscape Water Circulation Diagram (source: MITHUN)



4.2.2. Sustainable Stormwater Management

The project is designed to manage stormwater up to a twenty-five-year storm event. Stomwater management strategies, such as permeable concrete, infiltration planters, and on-site rainwater harvesting, achieve zero discharge for both on-site and right-of-way runoff at the sidewalk level. The majority of the stormwater is managed with a 16,000 gallons (60,567 L) rainwater cistern that provides water reuse for nonresidential toilet flushing and is also the sole water source for all on-site and right-of-way landscape irrigation. In the winter, when irrigation is not necessary, the cistern supplies water for toilet flushing within the building. The dual-use cistern allows the site to maintain a balance between an adequate water supply and available cistern capacity. This rainwater reuse strategy, in addition to efficient low-flow fixtures, saves up to 122,000 gallons (461,820 L) of potable water per year (Venhaus, 2012, p. 167).All runoff from the pedestrian zone is directed to one of 8 rain gardens, which in size from 100 square feet (9 m2) to about 800 square feet (74 m2). The profile of each includes an infiltration gallery, which in some cases extends beyond the perimeter of the planting area above. Two areas of permeable concrete pavement (1,000 square feet total) are located along the curb edge to capture rainwater that could not flow directly into the rain gardens. This water is piped back to the rain gardens for infiltration. All rain falling on the building roof enters the hybrid cistern/detention tank, which meets the City’s detention requirement for a 25-year storm. Stored water is used for non-residential toilet flushing and landscape irrigation in summer. A“smart” irrigation system uses water stored in the cistern to irrigate all landscape areas, both onsite and in the public right-of-way (Venhaus, 2012).

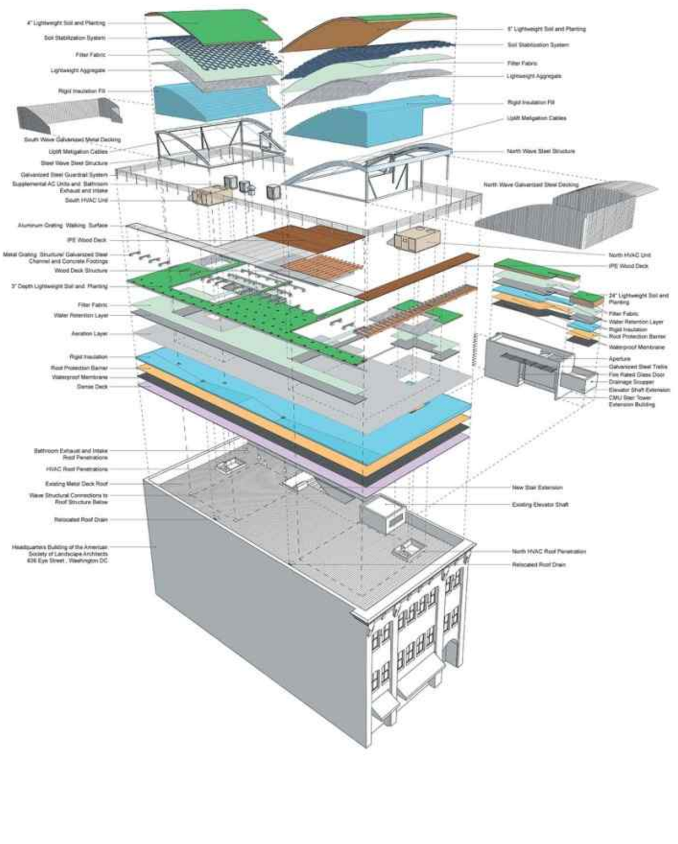
4.3. ASLA Headquarters Green Roof

4.3.1. Design Overview

Environmental stewardship is a core value of the American Society of Landscape Architects (ASLA).

For that reason, the headquarters green roof was conceived as a demonstration project and includes ongoing monitoring and research components related to stromwater retention, temperature, water quality, plant performance, and building energy savings. The location of the project in an urban area that faces significant issues related to combined sewer outflows and a degraded watershed makes the demonstration value of the project particularly important and effective. In 2004, ASLA began to investigate installing a green roof on its 12-year-old, 3-story headquarters building in Washington, D.C. The building's original rubberized membrane roof had already begun to develop pinhole leaks, and a structural engineering study showed that the roof had additional load capacity to accommodate an extensive green roof. ASLA wanted the roof to serve as a demonstration project, but access was limited to a wall-mounted ladder and hatches. The roof also held two 6ft-by-8ft HVAC units, located toward the center of the roof, and three smaller HVAC units. Because maximizing the "green" area and environmental benefits were a high priority, the original program did not envision significant usable space. During the course of the design process, designers developed a concept that maximized both green space and usable amenity space. The project scope and budget were expanded. The roof design includes two elevated "waves," covered with a green roof system. The waves create an intimate, semi-enclosed space on the roof and completely hide the HVAC units, which were relocated as part of the project. An existing stairway was extended to the roof level to provide access for viewing and maintenance. Aluminum grating over sedum was used for the central roof area and access path to provide more green coverage while accommodating use. Intensive plantings were incorporated above the new stairwell structure and elevator shaft, which had significant additional structural load capacity. The design also includes experimenting with different plantings and soil depths (Werthmann, 2007).

Figure 3. ASLA Headquarters Green Roof Components Layer (source: ASLA)



4.3.2. Sustainable Stormwater Management

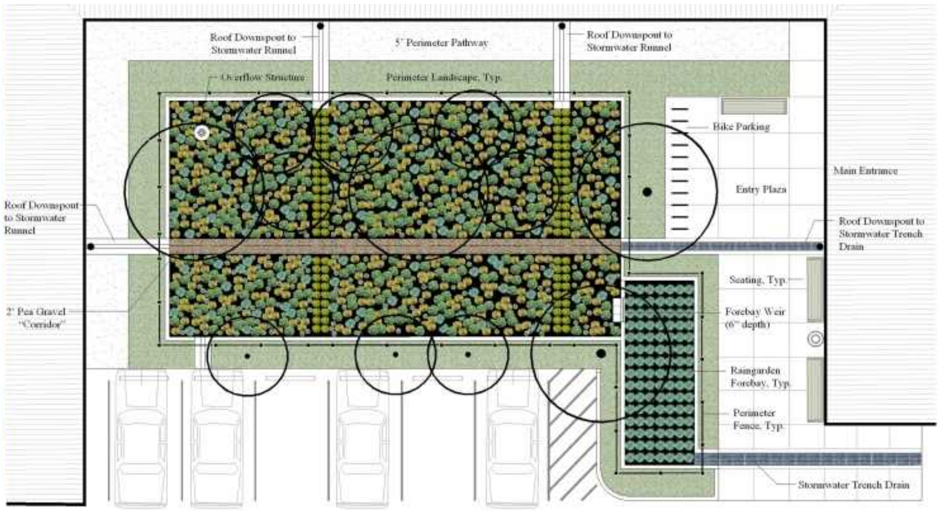
ASLA green roof prevented 27,500 gallons (104,098 L) of stormwater – 77% of all precipitation hitting the roof – from flowing into Washington, D.C.'s overburdened sewer system during the initial monitoring period, from July 2006 to May 2007. Flow meters and rain gauges are in place on the ASLA green roof to collect data on stormwater retention. Data collection for one began on July 6, 2006 and ran through May 27, 2007. During this period, a total of 11.83 inches of rain fell on the green roof. Total roof runoff during this period was over 27,500 gallons, meaning that 77% of rain was retained by the green roof. ASLA green roof also reduces the amount of nitrogen entering the watershed, according to results from water quality testing. ETEC, LCC monitored water quality and quantity on the green roof for five rain events in the fall of 2006 and the spring of 2007. The sampling and monitoring were performed in accordance with the standard operations for collection and measurement promulgated by the EPA. pH, temperature, total suspended solids (TTS), total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), and nutrients (ammonia, nitrite, nitrate, phosphate, and total phosphorus) were measured on rain water collected on the roof and runoff collected from the downspout form the green roof. Nitrogen concentrations measured in the ASLA green roof runoff were similar to the values measured in the rainwater indicating that, when combined with the measured volume reduction, a significant overall reduction of nitrogen in stormwater runoff from a green roof can be expected (Werthmann, 2007).

4.4. Mount Tabor Middle School Rain Garden

4.4.1. Design Overview

The Mount Tabor Middle School Rain Garden project is unique to Portland and the United States in the way this schoolyard has been transformed to sustainably manage stormwater runoff. The project demonstrates the City of Portland's commitment to promote a more natural approach to stormwater management, and many regard this "urban rain garden" project as one of Portland's most successful stormwater management retrofit projects. In a collaborative effort between the City of Portland and Portland Public Schools, the Mount Tabor Middle School Rain Garden project converts what was previously 4,000 square feet (371 m^2) of underutilized asphalt parking area abutting the school's courtyard entrance into an innovative rain garden designed to capture, slow, cleanse, and infiltrate nearly an acre of the school's runoff. After a careful site analysis, the design team recognized several inefficiencies in the layout of the parking lot. By reorganizing the courtyard space, the design team was able to provide sufficient room for a 2,000 square foot (185m^2) rain garden and an entry plaza with bike parking and student seating, while maintaining adequate parking for school staff. What is particularly unique about this rain garden project is that it is first of several stormwater retrofit projects specifically designed at Mount Tabor Middle School to help solve a chronic neighborhood problem of local basement flooding. It is important to understand this context in order to help gauge the success of the rain garden project (ASLA, 2007).

Figure 4. Mount Tabor Middle School Rain Garden Plan (source: Kevin Robert Perry)



4.4.2. Sustainable Stormwater Management

The Mount Tabor Middle School Rain Garden project essentially disconnects a portion of the school's stormwater runoff from the neighborhood's combined sewer system and manages it on-site using a landscape approach. Approximately 30,000 square feet (2,787m2) of impervious area runoff generated by the school's asphalt play area, parking lot, and rooftops, is elegantly captured and conveyed into the rain garden via a series of trench drains and concrete runnels. Once inside the landscape space, the water is allowed to interact with both plants and soil while soaking into the ground. Depending on how intense a particular storm event is, runoff will rise within the rain garden until it has reached the 8inch design depth. Once exceeding capacity, the water exits the landscape system and enters the combined sewer system. The rain garden's infiltration rate varies from 2-4 inches per hour, meaning that any runoff that is retained in the rain garden is completely gone within a couple of hours. Since its completion in September 2006, the Mount Tabor Middle School Rain Garden's performance has been very impressive. All of the rainfall captured within the rain garden has infiltrated without ever overflowing into the combined sewer system. As a result, approximately 500,000 gallons (1,892,705 L) of stormwater runoff has been infiltrated on-site. For illustration purposes, the amount of runoff infiltrated equates to a volume of water that would stand 36 feet tall within the footprint of the rain garden. It is also estimated that the successful performance of the rain garden, along with the other stormwater improvements planned for the school, will ultimately save $100,000 in future sewer infrastructure replacement costs within the neighborhood (ASLA, 2007).

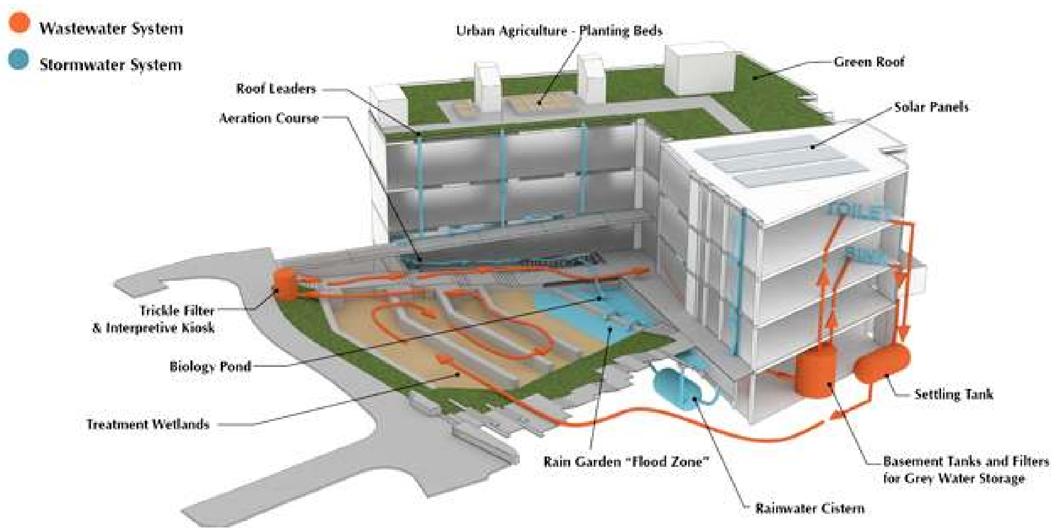
4.5. Sidwell Friends School Courtyard

4.5.1. Design Overview

The Sidwell Middle School addition treats sewage on-site with a series of biological processes. The

Multiple Mechanism are integrated into both the landscape and architecture, and leveraged into a system that enhances the character and operation of both. Additionally, the system is visible to the students, serving as a sustainable education tool. Biological processes are highly-efficient as they rely strictly on natural biodegradation and do not require extensive electrical input. Many conventional systems use significantly greater electrical inputs and produce greater quantities of sludge that must be removed off-site. Biological systems produce little sludge by comparison, but are generally slower and require a larger footprint. At Sidwell, the terraced wetland needed for biological processes is also used as a courtyard, outdoor classroom, and habitat with a diversity of plant species. Compared to centralized systems that involve extensive collection infrastructure, on-site waste treatment systems require relatively little infrastructure investment. Additionally effluent is readily available for on-site uses, such as irrigation and toilet flushing. In contrast, it is rarely cost-effective for a centralized system to recirculate effluent, and instead, its nutrient-rich effluent is discharged into nearby water bodies, often leading to increased eutrophication (Margolis et al., 2010).

Figure 5. Sidwell Friends School Courtyard Water Circulation Diagram (source: Andropogon Associates)



4.5.2. Sustainable Stormwater Management

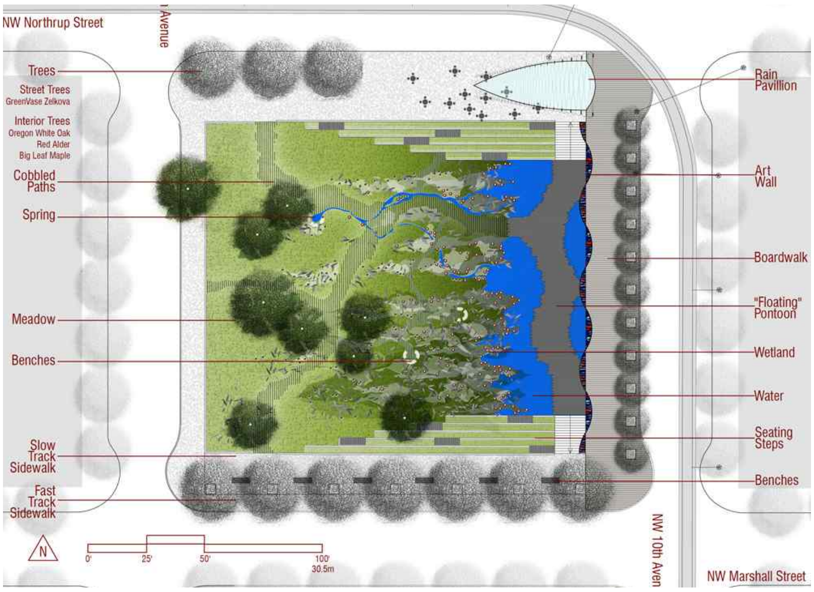
At Sidwell, the on-site waste and effluent flows tie biological operations of landscape and architecture into a circular, mutually beneficial relationship. Sewage from the building is given primary treatment in an underground tank and then circulated through a series of terraced reed beds in the courtyard (sewage water is not accessible at the surface). Within the wetlands, microorganisms attached to the gravel planting media and plant roots provide an efficient breakdown of water contaminants. A trickle filter and sand filter provide further treatment. The system receives up to 3,000 gallons (11,356 L) per day and has a residence time between four and six days. The high-quality outflow from the system is intended for reuse in the building to supply 100% of the water required for toilet flushing. During the wintertime, warm wastewater from the building will ensure that the wetlands never freeze, though their biology will slow down. Stormwater runoff is directed to a rain garden and pond. Runoff from the roof is collected in an underground cistern, which is designed to maintain the water levels of the pond during dry weather. Water fills the rain garden during a storm and then slowly seeps into the ground, where it is naturally filtered by the soil. Excess rainwater in the cistern wells up from a millstone springand flows to the pond. During a heavy rain, the pond will also overflow through a slotted weir into the rain garden. The dynamics of the changing water levels are a visible reflection of the local rainfall, cycling from wet to dry throughout the season (Margolis et al., 2010).

4.6. Tanner Springs Park

4.6.1. Design Overview

Tanner Springs is an urban water park that provides green space in a previously industrial area and reconnects visitors with nature. The project seeks to capitalize on the sensory characteristics of a wetland while embracing the urbanity of the surrounding mixed-use neighborhood. More than three hundred citizens were involved in there public events at which art, brainstorming, and planning workshops informed and inspired the design process. The purpose of the park is not to restore a native wetland but to use natural processes similar to those found in a wetland to cleanse and manage on-site stormwater. Combined sewer overflows during wet weather occur in the Williamette River, which runs through Portland, an average of one hundred days per year. In response to this environmental and human health issue, Atelier Dreiseitl created a living water system that reduces inputs to existing storm drain systems(Venhaus, 2012).

Figure 6. Tanner Springs Park Plan (source: Atelier Dreiseitl)



4.6.2. Sustainable Stormwater Management

All stormwater runoff from the 1.2-acre (0.5-hectare) site flows to the cleansing biotope and lower pond at the eastern end of the property. The biotope, comprised primarily of coarse sand and plant media, functions as a wetland and supports native vegetation that begins the cleansing process. After moving through the soil and vegetation, water is treated with ultraviolet light via an underground utility vault, then pumped to the man-made springs at the top of the slope. The water then forms streams that are accessible to park visitors and slowly meanders through the site back to the biotope. Five-year storm events are managed on-site; additional storm-flow is sent to the public storm drain. Native vegetation covers the majority of the site and includes trees obtained by an Oregon tree salvage company. Similar to a natural ecosystem, the vegetation in the biotope is intended to be self-selecting based on growing conditions. Symbolic of the old city fabric, historic railroad tracks form a wave-wall along the edge of the lower pond. The “Art Wall” acts as a visual backdrop and barrier to the noise and commotion of the surrounding city. It is 197 feet (60 m) long and composed of 368 rails, with 99 pieces of fused glass inset with images of nature hand-painted by artist Herbert Dreiseitl. Bleacherlike lawn terraces provide a place for leisure and a connection to the water’s edge (Venhaus, 2012).

5. Conclusions

This paper was originally purposed to investigate green infrastructure as water sensitive urban design strategy to prevent and mitigate urban flood, water pollution, and water shortage in urban area caused by extreme droughts, heavy rain, and heat waves. To do this, firstly, this paper reviews the original concept and current trends of green infrastructure. Green infrastructure was originally defined as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” by Benedict and McMahon. However, recently green infrastructure is being applied as a sustainable stormwater management strategy in urban areas to evaporate, capture, cleanse, reuse, and infiltrate stormwater within on-site. Through several case studies of green infrastructure for sustainable stormwater management, this paper investigates sustainable design methods, environmental performance, and benefits of green infrastructure.

First, green infrastructure is being realized by sustainable urban landscape design such as green roofs, rain gardens, constructed wetlands, bioswales, stormwater planters, permeable paving and cisterns on buildings, streets, or small-scale sites in urban areas. These landscape types should connect each other to maximize environmental performances. For example, all of landscape types of Sidwell Friends School such as green roofs, cisterns, constructed wetlands, biopondss, and rain gardens are networked each other. Sewage from the building is given primary treatment in an underground tank and then circulated through a series of terraced reed beds in the courtyard. The high-quality outflow from the system is intended for reuse in the building to supply 100% of the water required for toilet flushing. Runoff from the roof also is collected in an underground cistern, which is designed to maintain the water levels of the pond during dry weather. Second, sustainable landscape design need to integrate landscapes and buildings to enhance environmental performances. For example, Taylor 28 streetscape integrates street landscape and building facilities. Stormwater is managed with a 16,000 gallon rainwater cistern that provides water reuse for nonresidential toilet flushing and is also the sole water source for all on-site and right-of-way landscape irrigation. Third, Green infrastructure could be applied existing buildings and sites, streetsas well as new ones. SW 12th Avenue’s street project converts the previously underutilized landscape area between the sidewalk and street curb into a series of landscaped stormwater planters designed to capture, slow, cleanse, and infiltrate street runoff. ASLA headquarters green roof was installed on 12-year-old, 3-story headquarters building in

Washington, D.C. The building's original rubberized membrane roof had already begun to develop pinhole leaks, and a structural engineering study showed that the roof had additional load capacity to accommodate an extensive green roof. Mount Tabor Middle School Rain Garden project converts what was previously 4,000 square feet of underutilized asphalt parking area abutting the school's courtyard entrance into an innovative rain garden designed to capture, slow, cleanse, and infiltrate nearly an acre of the school's runoff. Fourth, Green infrastructure supplies various environmental benefits such as stromwater runoff reduction, stormwater cleansing and reuse, wastewater treatment, and native and wildlife habitats supply. For example, SW 12th Avenue's street planters are designed to handle 60% of its street runoff, a total of 180,000 gallons annually, for the three-lane street with parking. At Taylor 28 street, rainwater reuse strategy saves up to 122,000 gallons of potable water per year. ASLA green roof prevented 27,500 gallons of stormwater–77% of all precipitation hitting the roof – from flowing into Washington, D.C.'s overburdened sewer system during the initial monitoring period, from July 2006 to May 2007.ASLA green roof also reduces the amount of nitrogen entering the watershed, according to results from water quality testing. At Tanner Springs Park, all stormwater runoff from the 1.2-acre site flows to the cleansing biotope and lower pond at the eastern end of the property. Fifth, Green infrastructure supplies social and economic benefits as well as environmental benefits such as energy saving, renewable energy production, social interaction and environmental education. ASLA green roof reduces building energy use by 10% over the winter months. At Sidwell, the terraced wetland needed for biological processes is also used as a courtyard, outdoor classroom, and habitat with a diversity of plant species. The roof also houses a photovoltaic array that generates 5% of the building's electrical load. At Tanner Springs Park, more than three hundred citizens were involved in there public events at which art, brainstorming, and planning workshops informed and inspired the design process.

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Conflict of Interest

The authors declare no conflict of interest.

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