EVALUATING LOW IMPACT DEVELOPMENT PERFORMANCE ON THE SITE IN GRAND RAPIDS, MICHIGAN

By

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ABSTRACT

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Urbanization has increased the adverse impact of society, environment and economy. An urgent issue is associated with stormwater as impervious surfaces area increased. Low Impact Development (LID) is an innovative sustainable practice that can decrease the influence of adverse stormwater. It has also been widely applied to many sites. However, the effectiveness of LID is still associated with uncertain results, depending on different site conditions, design strategies and assessment approaches. This study evaluates the LID performance by examining four different design scenarios including two designs with LID and two without LID, through eleven variables in Grand Rapids, Michigan. The Friedman analysis of comparison method has been applied to the treatments to determine whether the designs with LID elements are more effective. The result shows that designs with LID elements are significantly greater than the existing condition ($p \leq 0.05$).

Key words: Landscape Architecture, Landscape Urbanism, Urban Design, Ecological Planning, Impact Assessment.

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Along with the development of cities, counties, and towns, more impervious surfaces have been created. Stormwater runoff flows over impervious surfaces and contains contaminants including residual oil, bacteria, sediments and other chemicals that find their way into lakes and streams that provide people their daily drinking water (USEPA, 2012b). The United States Environment Protection Agency (USEPA) has reported that the most important sources of the pollution in the stream, rivers, and lakes are caused by stormwater (Lehner, Aponte Clark, Cameron, & Frank, 1999). Besides pollution, stormwater runoff also can cause flooding, erosion, habitat destruction, and sewer overflows (Jacoby, 2012). To reduce the excess water runoff, numerous innovative stormwater management techniques, especially LID are applied into neighborhoods, which create sustainable wildlife habitats, and recharge groundwater while also improving water quality and slowing the flow of runoff (Jacoby, 2012).

LID is a best-management practice (BMP) approach to managing stormwater, and is accomplished by minimizing impervious surfaces, and promoting more natural infiltration and evapotranspiration. (Darner & Dumouchelle, 2011). Also, as an alternate comprehensive approach to stormwater management, LID has been implemented into new developments, redevelopment, or as a retrofit to existing development (Kibert, 2012). As LID technology becomes more mature and the LID concept has been embraced by communities throughout the United States as well as many other parts of the world, the application of LID will become extensive. But the previously research and study of LID is limited and uncompleted, it is critical to provide more scientific evidences about the LID performance, especially in the area of benefits and shortcomings.

The purpose of this study is to evaluate the LID performance with eleven variables based on the four design scenarios. By comparing the results, the impact of LID will be clearly presented. The aim of this study includes: (1) presenting LID strategies and comparable strategies; (2) explaining the specific variables of each design; (3) calculating the results and identifying if the designs with LID are better than the other design scenarios; and (4) considering the limitation, providing recommendations and explaining why this study is important for designers, governments, and future researchers.

Chapter2. Literature Review

2.1 Low Impact Development Overview

2.1.1 LID Development

What is LID and why use LID? Freeman, H. (2010, p.1067) demonstrated that, "while conventional stormwater permitting is often simplified into a few primary performance goals – usually peak flow and nutrient removal – LID permitting is significantly more complicated." And Southeast Michigan Council of Governments (SEMCOG, 2008, p.1) said, "LID is the cornerstone of stormwater management."

Clean water is the key to keep the economic vitality, which requires a balanced hydrologic cycle (SEMCOG, 2008). In the water cycle, water percolates downward through the soil and reaches the water table, then provides baseflow for streams, rivers and lakes under the effect of gravity (SEMCOG, 2008). However, Victorian Stormwater Committee (1999) indicated that with massive urbanization, the densely developed inner urban area is an almost impervious surface, which reduces the water infiltration and completely transforms rainfall into runoff. The SEMCOG (2008, p. 6-7) reports that adverse impacts include: increased flooding and property damage, degradation of the stream channel, less groundwater recharge and dry weather flow, impaired water quality, increased water temperature, loss of habitat, and decreased recreational opportunities.

In the past, traditional stormwater management approaches were applied to control the adverse impact of urbanization, including storm sewers, deep tunnels, stormwater retention ponds, and other engineered strategies (Dane, 2012). These gray infrastructure approaches have been proven to be destructive to the environment, society and economy, leading to the deterioration of species biodiversity and the destruction of recreational landscape (Dane, 2012). In contrast, the green infrastructure – LID's main goal is to present the pre-development hydrology and reduce the impact to the soils, habitat and aquatic system on the site by minimizing the disturbance, rather than just mitigating the runoff (Dietz, 2007). LID becomes a recommended alternative way to the traditional stormwater management (Dietz, 2007).

From a stormwater management point of view, LID is the use of strategies that imitate the regular water cycle by using a basic standard: manage the runoff by utilizing procedures that infiltrate, filter, store, evaporate, and detain the runoff (SEMCOG, 2008). Moreover, the United States Environmental Protection Agency (USEPA) indicated LID as "an approach to land development (or re-development) that works with water to manage stormwater as close to its source as possible" (USEPA, n.d.). Summarizing the LID working techniques, LID emulates the water cycle by 1) minimizing the volume of runoff; 2) reducing the peak rate of runoff; 3) maximizing infiltration and groundwater recharge; 4) maintaining stream baseflow; 5) controlling evaporation; and 6) improving water quality (SEMCOG, 2008).

As an environmentally friendly approach, LID has cooperated with many sustainable programs, such as the Best Managements Practices (BMPs), Smart Growth, and the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED). The core concept of BMPs is reducing soil erosion, sediment and treating the diverse levels of the containments (Yu, J., Yu, H., & Xu, 2013). As the component of the BMPs, nonstructural BMPs have less structural form, but wider planning and design approaches, which are the factors of LID site in the pre-development stage (Clary et al., 2011; SEMCOG, 2008). From a stormwater management perspective, the nonstructural BMPs are the cluster development in purpose of minimizing soil compaction and disturbed area, protecting natural flow system, riparian buffer and sensitive area, and reducing impervious surface and stormwater disconnection (SEMCOG, 2008). In nonstructural BMPs, the basic characteristic of LID is keeping stormwater runoff from the site (SEMCOG, 2008). As post-development strategies, the structural BMPs require LID to mitigate the runoff through bioswale, bioretention, rain garden, green roof, and porous pavement (SEMCOG, 2008). The principles of smart growth and the requirements of the LEED program also meet the mission of LID (SEMCOG, 2008). For example, the smart growth guideline, include encouraging community and stakeholder collaboration and making development decisions predictable, fair and cost effective, is also suitable for the LID design concept. LEED has created a rating system with certification for various development scenarios in order to augment global adoption of sustainable green building practices (SEMCOG, 2008). Actually, LID is compatible with the LEED requirement, which optimize each design scenario into the LEED policy (SEMCOG, 2008).

There are several challenges existing during the LID application. When implementing LID, different organizations will confront various stormwater regulations and some regulations may contradict with LID techniques (SEMCOG, 2008). Lack of basic awareness, technical knowledge and financial support of LID will also exert negative impacts on LID development (SEMCOG, 2008). In addition, some existing site conditions could constrain the LID application, such as bad soil or geology (SEMCOG, 2008).

Even though there are lots of challenges, we have still witnessed significant progress in the LID development. Some institutions with jurisdiction over the stormwater and land use their purview to improve LID application (SEMCOG, 2008). For instance, according to the USEPA report (2012d), the City of Philadelphia has offered multiple incentives to move LID forward, including LID implementation fee credits, LID practice grants, compensation for installing LID as well as contests and awards for LID projects. Also the integrated regulation and monitor system is imperative for LID improvement. Public education and participation provide people an opportunity to embrace the concept of LID stormwater management, which also has the support of the public, elected officials, and some environmental organizations (SEMCOG, 2008; Davis, 2005).

2.1.2 LID Design Principle and Process

Without an integrated design principle and process manual, LID application cannot be successful. In order to achieve this, the Southeast Michigan Council of Governments (SEMCOG, 2008, p.9) and other organizations have summarized the combination of several principles, which includes:

- Plan first. When applying LID stormwater management practice, the process of combining with the community planning and zoning process can help minimize stormwater impact and maximize the benefits of LID (SEMCOG, 2008).
- Prevent firstly, then mitigate. The essential goal of LID is to prevent stormwater runoff by preserving natural features and minimizing impervious surfaces, which also requires the incorporation of LID into the nonstructural practice during the design process

(SEMCOG, 2008). Then, structural BMPs can be prepared for post-development to mitigate the runoff (SEMCOG, 2008).

- Minimize disturbance. During the LID design process, the limitation of disturbance can decrease the amount of stormwater runoff and maintain the natural hydrology (SEMCOG, 2008). Also, the cluster development enables the protection of existing open spaces and scenic views (Kibert, 2012).
- Manage stormwater as a resource – not a waste. Different than the conventional design understanding that stormwater is a problem, LID treats runoff as a resource for groundwater recharge, stream base flow, lake and wetland health, water supply, and recreation (SEMCOG, 2008).
- Imitate the natural water cycle. LID's working mechanism emulates the natural water cycle, including peak rate control, runoff volume reduction, groundwater recharge and water quality protection.
- Disconnect. Decentralize. Distribute. Instead of gray infrastructure, such as catch basins, piping, and stormwater ponds, LID manages stormwater as close to the source as possible. (Kibert, 2012). Also, depending on the location of the runoff point, the pattern of LID is decentralized across the site (SEMCOG).
- Integrate natural systems. As green infrastructure, LID not only protects the water system, but also preserves natural resources (SEMCOG). Moreover, LID utilizes natural resources to work for the project, such as biological drainage and retention (Kibert, 2012).

- Maximize the multiple benefits of LID. LID has provided numerous benefits to stormwater management, as well as the environment, society and economy (SEMCOG). When implementing LID, the communities should be aware of these other benefits, which can increase the extent of LID application (SEMCOG, 2008).
- Apply LID everywhere. LID techniques can be used in any development stage by integrating into early planning stages in undeveloped areas and incorporating with existing sites to solve problems in developed areas (USEPA, 2012b). The form of the LID performance is also variable, from rain gardens, bioswales, green roofs, to pervious pavements.
- Make maintenance a priority. Understanding the maintenance requirements and organizing a maintenance program are crucial components of the LID program (SEMCOG, 2008).
- Follow the monitor system. The monitoring programs of the LID design are important because they provide a science-based evaluation of stormwater management practices and present LID achievement of runoff management to the public (Shuster, Morrision, & Wedd, 2008).

Based on the explicit design principles, the LID design process is also essential to land development. SEMCOG (2008, p. 50-52) has offered nine sequential design steps to help integrate LID into the site successfully.

- Step 1: Property purchasing and land use analysis. Before purchasing property, the developer should learn about land use that belongs to residential, commercial or industrial use, which determines the price of the property.

- Step 2: Inventory and analysis of the site. In the LID pre-development phase, it is significant to assess the basic information of the site, especially the natural system, which may create challenges and/or opportunities of the stormwater management. The natural resource systems that need to be evaluated include floodplains, riparian areas, wetlands, all the drainage ways, soils and topography, geology, groundwater, and vegetation.
- Step 3: Blend municipal, county, state and federal requirements. In the design process, it is crucial to update the information of land development regulation, which varies between county, state, federal and all stakeholders.
- Step 4: Develop initial concept design with nonstructural BMPs. Based on the previous steps, the initial design concept can be integrated into nonstructural BMPs, such as cluster development, natural flow pathway, riparian buffer and sensitive area protection, disturbed area control, and impervious surface reduction.
- Step 5: Make a pre–proposal meeting and site visit with local decision makers. It is necessary to have a pre-meeting between municipal leaders and the developers, which offers a chance to incorporate everyone’s perceptions into the design concept.
- Step 6: Integrate corrections into the development concept. According to the previous information, an acceptable revision should be applied.
- Step 7: Decide the structural BMPs selection. In structural BMPs, different types of LID designs should be determined depending on the particular stormwater management

requirements of the site.

- Step 8: Apply calculation and methodology. Calculation and methodology should be applied in order to fulfill the LID design criteria encompassing groundwater recharge, runoff volume control, peak rate control, stream channel protection and water quality purification.
- Step 9: Finish the preliminary site plan. According to the completion of the previous steps, the preliminary site plan about stormwater management and existing natural resource practice can be merged and presented to the local government. It should be comprehensive and satisfying for both developers and the community.

2.1.3 Benefit of LID

The practices of LID have offered numerous benefits and the following paragraphs present the details of these benefits in the areas of society, economy and environment.

Society – The LID design elements have served as green infrastructure to social aesthetics, which create beautiful sustainable park-like elements to neighborhoods, increasing green streetscape and offering recreational opportunities (USEPA, 2013a). LID not only improves citizens' life quality, but also provides people environmental education opportunities (SEMCOG, 2008).

Economy – For communities, agencies and the public, LID has decreased municipal infrastructure and utility maintenance costs, and saved energy costs for heating, cooling and irrigation (SEMCOG, 2008). Also, LID has increased the properties' marketing values by improving the environmental quality and creating more green space (USEPA, 2012c). For developers, LID helps reduce land clearing and grading cost, as well as property damage costs caused by flooding (SEMCOG, 2008; USEPA, 2012b). Moreover, LID, as an alternative stormwater management practice, has contributed to conventional stormwater construction payment reduction (SEMCOG, 2008).

Environment –LID's benefits for environment is abundant. First of all, LID has improved water quality by impeding runoff pollutants and filtering the water through green construction (SEMCOG, 2008; USEPA, 2012b). Second, LID practices retain the rainfall on-site instead of channeling into ditches or drains, which ameliorates groundwater recharge (USEPA, 2012b). The third, LID has preserved ecological and biological system, especially the aquatic habitat, through retarding the runoff speed and controlling bank erosion (SEMCOG, 2008; USEPA, 2012b). Fourth, as the green infrastructure, LID has enhanced carbon sequestration and improved air quality (SEMCOG, 2008). Fifth, LID also diminishes the urban heat island effect and climate change (USEPA, 2012b).

2.2 Design Elements of LID

Different types of LID design have been applied based on the concern of the specific site conditions and stormwater management requirements. Bioretention, typically referred to as rain garden, is adequate in removing concentrations and storing the runoff (Dietz, 2007). Pervious pavement is also effective in penetrating the stormwater runoff (Dietz, 2007). Moreover, an average 63% of rainfall can be captured by green roof in different climates (Dietz, 2007). Thurs, the comprehensive understanding of different types of LID is significant and necessary to achieve the best result of stormwater management.

2.2.1 Rain Garden

Rain Gardens are the shallow low-lying land covered by specific native plants, which retain and infiltrate runoff from buildings, streets and potentially parking lots (SEMCOG, 2008). As the result of this process, the runoff volume and peak discharge rate will decrease, as well as sediment and pollutants can be separated from rainfall (SEMCOG, 2008). In addition to managing stormwater, rain gardens also strengthen site aesthetics, habitat suitability and air quality. However, there are inherent limitations that restrict the effectiveness of rain garden due to high maintenance cost and inflexible plant selection (SEMCOG, 2008).

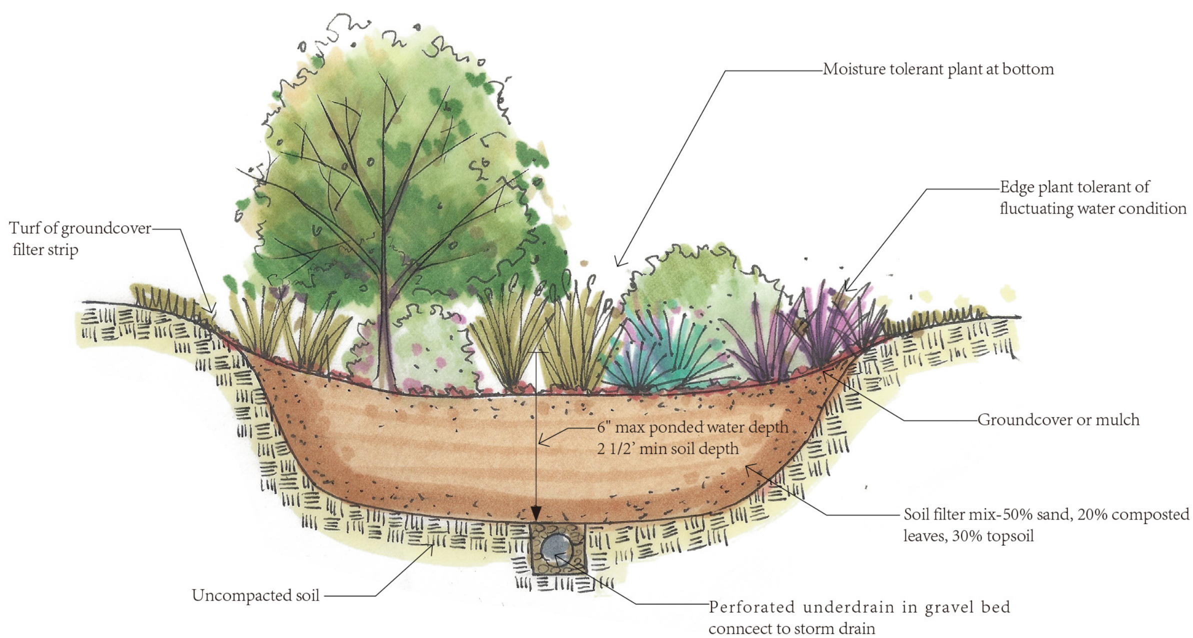

Figure 1. Schematic of rain garden (adapted from SEMCOG, 2008)

Figure 1 illustrates the fundamental construction of rain garden, which demands detailed design in pond depth, plant selection, soil type, infiltration bed, penetration of under-drainage and overflow structure depending on the stormwater management functional requirement

(SEMCOG, 2008).

In addition to the basic rain garden structure, several considerations should be involved into design process. To be suitable for the rain garden, the area must have at least a 0.25-inch per hour infiltration rate and the slope should not be deeper than 20% (SEMCOM, 2008; DES, 2007). The flow entrance and positive overflow system is created with erosion control and appropriate surplus runoff conveyance (SEMCOG, 2008). The total surface area and ponding area should be able to support runoff volume without exceeding the depression depth (SEMCOG, 2008). In order to keep vegetation health, planting soil should be mixed with a composted organics that can remain soil PH between 5.5 and 6.5 and designed between 18 to 48 inches deep (SEMCOG, 2008). Additionally, selecting plants should follow two guidelines – 1) runoff entrance area is not acceptable to woody plant material caused by soil erosion; 2) the depth of ponding is unequal, which requests pay attention to different plant saturation tolerances (DES, 2007). After deciding the plants species, vegetation will be placed from mid-April to early June or mid-September to mid-November (SEMCOG, 2008). Also, a 2-3 inches mulch cover can protect vegetation from erosion and pollutants (SEMCOG, 2008). A gravel-subsurface infiltration bed that requires no less than six inches deep should have plenty of space to store 40 percent runoff at the minimum, enfolded by geotextile fabric (SEMCOG, 2008). Finally, under the condition of more than 48 hours drainage period, underdrain system should be applied to the site (SEMCOG, 2008).

2.2.2 Bioswale

Bioswale, also referred to as “green engineered ditches”, offers effective routing for stormwater runoff with low cost, which can be applied in various locations including highways, farms, residential, industrial and commercial areas (Borst et al. 2008). As an enhancement of conventional stormwater piping, bioswale has many advantages, such as reducing volume of runoff and improving infiltration and groundwater recharge at the same time by utilizing soil, vegetation and microbes (Clark & Acomb, 2008). This versatile runoff conveyance can also improve landscape aesthetic and biodiversity (Clark & Acomb, 2008). The major limitation of bioswale is insufficiency in runoff peak rate and volume control (SEMCOG, 2008).

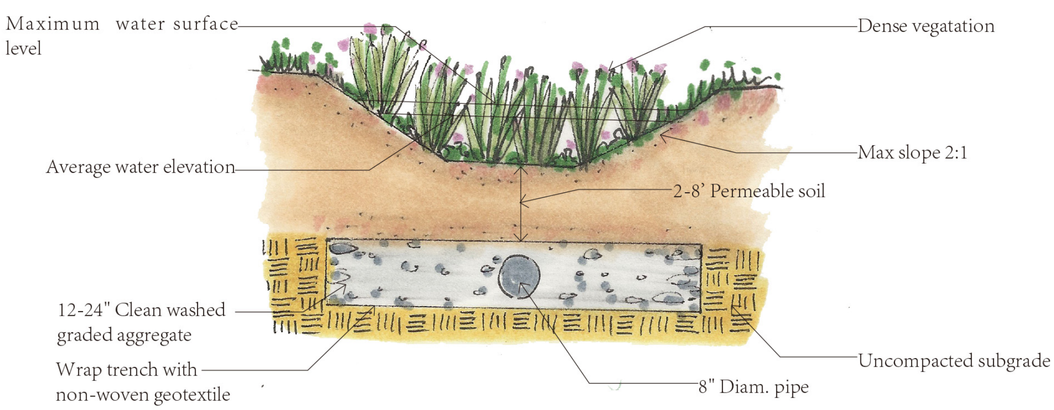

Figure 2. Schematic of bioswale (adapted from SEMCOG, 2008)

As figure 2 presents, bioswale surface is covered by grass, while subsurface incorporates with four vertical layers – an impervious liner located in bottom serves as segment isolator and over infiltrated water protector; sitting on the impermeable membrane, a clean washed gravel aggregate should be designed from 12 to 24 inches; an inserted pipe surrounded by gravel conveys all infiltrating water to a targeted point; the top layer is a 2 to 8 inches deep media separated by a porous fabric from the gravel (Borst et al., 2008; SEMCOG, 2008). According to bioswale design criteria, the size of bioswale is designed for 10-year storm event peak discharge and one-inch storm event storage requirement (SEMCOG, 2008). Also, slope ratio of bioswale should be arranged from 3:1 to 5:1 (SEMCOG, 2008). Finally, a critical consideration component is soil type, which should be compliant to plant growth, restrict infiltration rate and isolate the heavy metals and nutrient contaminants from runoff (Borst et al., 2008). SEMCOG (2008, p. 320) also recommends, “soil should be at least 12 inches of loamy or sand with an infiltration rate of at least 0.5 inches per hour.”

2.2.3 Constructed Wetland

As the multifunctional shallow water detention, constructed wetlands utilize the natural process to treat stormwater efficiently through storing, filtering and cleaning runoff in both temperate and tropical climates. (Moat, Simpson, Ghanem, Kandasamy, & Vignerswaran, 2008). Constructed wetland treats wastewater and stormwater as a resource by reducing the levels of nutrients, sediments, pathogens, heavy metals and hydrocarbons in the water, which also builds the wetland habitats and environmental aesthetics (Moat, Simpson, Ghanem, Kandasamy, & Vignerswaran, 2008). Although constructed wetland is effective in reserving runoff, the capability of volume reduction and peak rate control is limited (SEMCOG, 2008).

In order to receive a long-term success, there are several considerations should be noticed during the wetland installation (SEMCOG, 2008). The characteristics of the wetland plant species should fulfill the criteria that require a tolerance of the local climate, pollutant and water-saturated condition, as well as satisfy the surrounding ecosystem (Moat, Simpson, Ghanem, Kandasamy, & Vignerswaran, 2008). Also, topsoil that blends with medium textures silty to sandy loans is the essential component of a successful aquatic-plant establishment (Moat, Simpson, Ghanem, Kandasamy, & Vignerswaran, 2008). Moreover, the constructed wetland is flexible in boundary, shape, width and depth based on the local geography and stormwater treatment requirements (SEMCOG, 2008).

2.2.4 Green Roof

Green roof serves as a vegetated rooftop constructed by multiple layers that are displayed in figure 4 (SEMCOG, 2008). Considered as a stormwater best management practice (BMP), green roof can retain plenty amounts of rainfall and detain the infiltration rate to the drainage system (Sutton, 2015). Furthermore, green roof can absorb atmospheric pollutants and contaminants in precipitation (Sutton, 2015). Especially in a densely populated city where the tree planter area is limited, green roof is an effective air pollution control tool. (Yang, Yu, & Gong, 2008). Green roof also has effective microclimate function to mitigate the city heat island and climate change, while enhancing habitat quality and city aesthetics. (Sutton, 2015; SEMCOG, 2008). The restrictions of green roof include high installation and plant maintenance cost, as well as disconnection with ground, which means it can’t treat runoff from other place (SEMCOG, 2008).

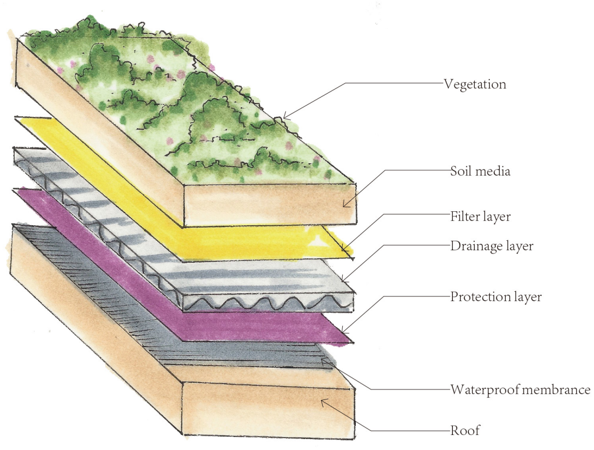

Figure 3. Schematic of green roof (adapted from SEMCOG, 2008)

A standard green roof design involves multilayers (figure 3) including vegetation, growth media, filter layer, drainage layer, protection layer and waterproof membrane (SEMCOG, 2008). The growth media criteria recommend a soil-like combination with organic content that should be less than 15 percent of entire media (SEMCOG, 2008). Also, the roof slope greater than 45 degree is inapplicable for green roof system (SEMCOG, 2008). Irrigation is only required in first two year to establish the drought tolerant vegetation and after that, the annual rainfall is adequate to maintain plants (SEMCOG, 2008).

2.2.5 Permeable Pavement

As an alternative to the conventional impermeable asphalt and concrete pavement, porous pavement allows runoff infiltrate into pavement and temporarily retain the water through several layers (Collins, Hunt, & Hathaway, 2008). Therefore, permeable pavement can mitigate runoff volume and peak rate and produce groundwater recharge (Collins, Hunt, & Hathaway, 2008; SEMCOG, 2008). The limitations are high maintenance budget and restricted site conditions.

Soil quality is the most significant consideration in pervious pavement design. The permeable pavement design doesn't accept compacted soil, while poorly draining soil should be designed with adjoining swale, wetland or rain garden in case of overflow (SEMCOG, 2008). The bottom elevation of infiltration bed must be flat (SEMCOG, 2008). Moreover, the infiltration bed requires a two-year storm event storage capability and also incorporates with perforated pipe based on the storage requirement (SEMCOG, 2008). Finally, appropriate winter maintenance can keep the snow removal and deicing working effectively (SEMCOG, 2008).

2.3 Previous Studies about LID

As the new technology, the studies and researches of LID are still not complete and comprehensive. Base on the numerous literature reviews, the current articles about LID can be separated into three categories: 1) Basic concept and information of LID's characterization, application, benefit, and limitation; 2) Evaluating the LID performance in a single area, such as stormwater management, pollutant remove, sediment control, or air quality improvement with few variables; 3) Monitoring method and calculation method applied into evaluation.

The first category has been well described in the previous sections. For the second category, there are many studies cases about LID performance. In Michigan, several developments that have intergraded LID BMPs into their designs has been presents in SEMCOG. The Pokagonek Edawat Housign Development located in Dowagiac has applied different type of LID in order to maximize stormwater infiltration and recharge of groundwater (SEMCOG, 2008). LID BMPs have been utilized into Mid Towne Village redevelopment in Grand Rapids, Michigan, which helps reduce the impervious surface and reuse the rainwater through cisterns (SEMCOG, 2008). In other state, the applications of LID are diverse, which not only provide the benefits of stormwater management, but also bring advantages to both air and water quality. In Chicago, the 19.8 ha of green roofs have removed a total of 1675kg air pollutants that constituted of O_3(52%), NO_2(27%), PM_{10}(14%), and SO_2(7%) in one year (Yang, Yu, & Gong, 2008). The LID study cases have also been found in other counties. A calibrated hydrodynamic model and water quality model have been applied to Sazlidere Watershed, in Istanbul, Turley, which predicate the both peak flow rate and total suspended solid will decrease after implementing different types of

LID (Gulbaz & Kazezyilmaz-Alhan, 2015). Jia, Lu, Yu and Chen indicate that, comparing with the existing site, the recommended LID BMPs could reduce, respectively, 27% and 21% of total runoff volume and the peak flow rate in Beijing Olympic Village (2012).

The methodologies applied for existing LID study cases are mainly based on the database from different monitoring system. The evaluation of designed scenarios is generally predicted by the specific equations or models. The EPA Storm Water Management Model (SWMM) has been utilized widely in numerous study cases. As a computer software, \SWMM can calculate the dynamic hydrologic situation including the change of rainfall intensity, flow rate and pollutant concentration for a site based on the design strategy (Gulbaz & Kazezyilmaz-Alhan, 2015).

2.4 Conclusion

In conclusion, based on the previous reviewed material, the application of LID performs widely and effectively with multiple benefits, but the limitations cannot be neglected depend on different cases. Thus, to achieve the full range of possible, it is significant to have further studies about how LID can be integrated into urban stormwater facilities successfully.

Chapter 3. Methodology (including pre-results calculations)

The experimental design of this study is to develop four design scenarios. Then apply eleven LID related variables to the four scenarios. Finally, after calculating the variables, compare the four scenarios across the eleven variables, with the Friedman One-way Analysis of Variance Test.

3.1 Design Scenarios Description

The methodology of this thesis is developed based on four design scenarios – Existing Site, Traditional Design, LID Design and LID with Cloud Design. These designs are based on the United States Environmental Protection Agency (USEPA) campus RainWork competition that our team has participated in and produced in 2015. The challenge requires student teams to design a green infrastructure project for their campus with the purpose of effectively managing stormwater runoff, improving the campus community and environment, and involving the climate change concept (USEPA, 2015). Our team members, including Na Li, HaoxuanXu, Yanzhi Xu and myself, designed a master plan and several details for Michigan State University's (MSU) new medical campus area and its neighborhoods in Grand Rapids, Michigan, which integrates numerous innovative LID design elements into the selected site. The LID with Cloud Design scenario is the final submission we provided to the USEPA completion and the rest of the design scenarios are created based on this project. Therefore, after introducing the existing site, the LID with Cloud Design will be described.

3.1.1 Existing Site

The site (figure 4) is located besides the Grand River in the city of Grand Rapids, Michigan, and occupies 98.5 acres. The selected area contains the MSU Grand Rapids Research Center (GRRC), the MSU College of Human Medicine (CHM) – Secchia center, Butterworth Hospital: North Office Building Radiology that besides the Secchia center and partially the North Monroe business district.

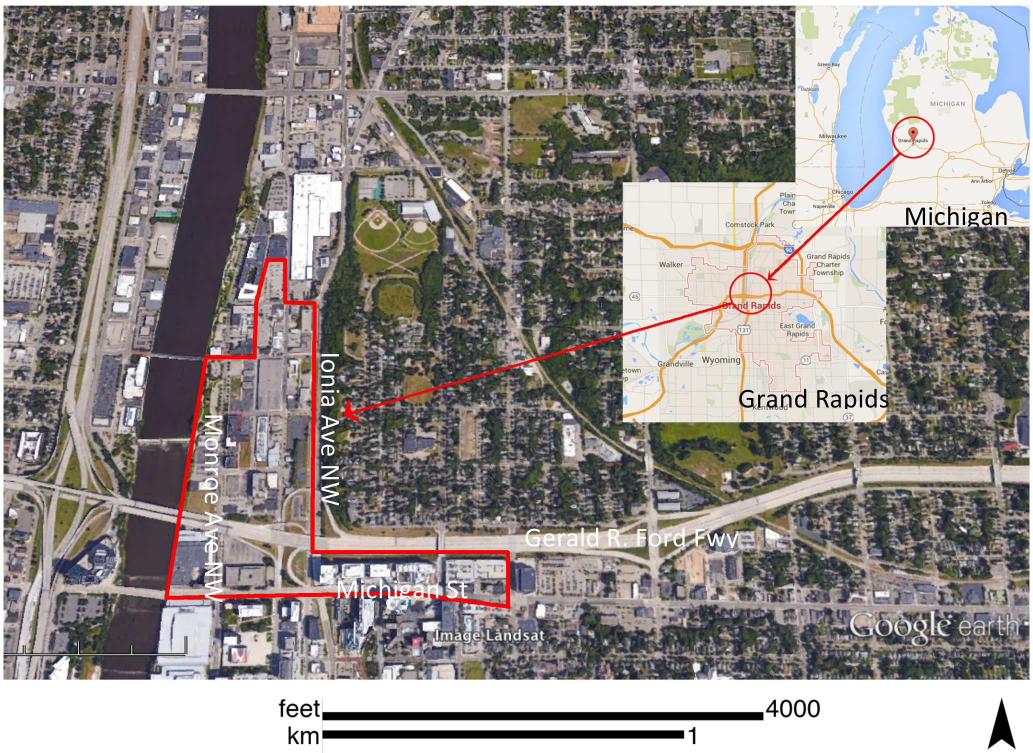

Figure 4. Location and aerial view of existing site (adapted from Google earth ©2016)

The Secchia center is located between Gerald R. Ford Freeway and Michigan and encompassed by several eminent hospitals and therapies. As the headquarters for the Michigan State University College of Human Medicine, the Secchia Center serves as a privately funded medical education building, which cost 90 million dollars and opened on September 2010 (MSU, n.d.). The mission of the Center Secchia is to addresses the sustainability at both social and environmental level. From the community perspective, the Secchia Center is designed for objectives that provide community multiple opportunities to interact, as well as functions a social center for students, faculty, staff and visitors (MSU, n.d.). At the environmental level, the Center Secchia is honored with the Gold LEED certification and also integrates the stormwater best management practices into the site (MSU, n.d.).

GRRC is located at the intersection of Michigan Street and Monroe Avenue besides the highway ramp, which becomes the new entrance of campus and help mitigate the existing traffic flow. This new laboratory building incorporates with CHM to advance the trajectory of NIH-funded research growth (MSU, n.d.)

The North Monroe business district can be found in the north of the freeway and lies along the Grand River, which is underdeveloped and isolated from other districts by traffic line and elevation change.

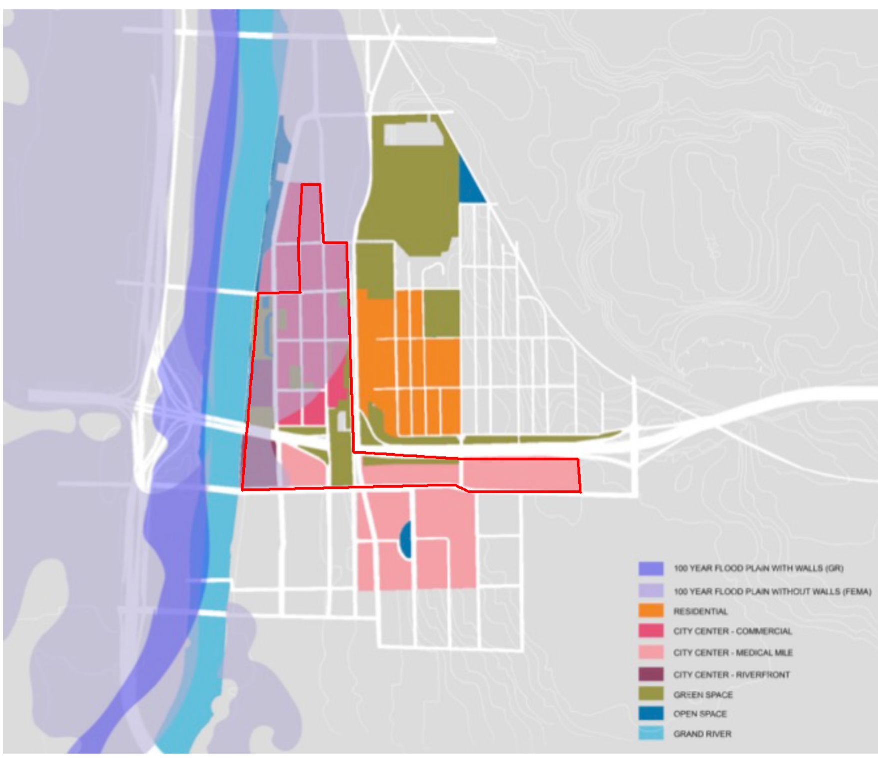

Figure 5. Functional diagram of site context

From Figure 5, the land use in the site is primarily for industrial occupation, where the impervious surface that includes the building area, parking lots and road takes nearly 84% of the entire area and the largest part of the site is located on the 100-year floodplain. Moreover, the 100 feet elevation change on Michigan Street has intensified the runoff impact that stormwater flows rapidly into the Grand River with sediments, pollutants and contaminants. The only concentrated green space is located by the riverside, which is unsuitable to retain the stormwater runoff. West Michigan Environmental Action Council (WMEAC, 2012) has illustrated that hundreds of millions of dollars have been spent to isolate sewage from stormwater systems though eliminating the sewage overflows, but the water quality of the Grand River is still treated as impaired waterway according to the Clean Water Act. Moreover, because of the climate change, Federal Emergency Management Agency (FEMA) has recalculated the 100-year 24-hour storm event and added 3 more feet to the current flooding walls, which demands an immediately effective approach to control and manage the stormwater (Bunte, 2013).

3.1.2 LID with Cloud Design

The city of Grand Rapids aims to build a diverse-populated downtown area that contains various job opportunities and balances the relationship between economy, society and environment. Thus, this project is designed toward creating a multifunctional community that provides green infrastructure, economic value, walkability, and livability; and involves the perceptions of sustainable stormwater management and climate change adaption (Burley, Li, Ying, Tian, Troost, 2016).

Based on the previous existing site inventory and analysis, our team has listed the following challenges that will be treated during the design process (Burley, Li, Ying, Tian, Troost, 2016):

- Stormwater problems combining with the Grand River, especially after Federal Emergency Management Agency (FEMA) recalculates the 100-year 24-hour storm event and adds 3 more feet to the current flooding walls.
- The 100 feet elevation change of Michigan Street NE.
- Disconnection between different districts
- Lack of crossings
- Narrow sidewalks
- Poor streetscape
- Highway ramps breaking the connections between the commercial and residential districts
- Climate change effects: Warm and wet winter and spring, but dry summer; precipitation and temperature increase; frequent storm events

In order to solve the above challenges, our team develop the fundamental strategies that integrates LID best management practices into the site, replaces the hardscape by green infrastructure, and utilizes the microclimate to mitigate the climate change (Burley, Li, Ying, Tian, Troost, 2016). To fulfill these plans, the team collected data and information through the following steps (Burley, Li, Ying, Tian, Troost, 2016):

- Literary information research
- Site visit
- Interviewing with campus stakeholders

- Geographic information system (GIS) data analysis
- Grand Rapids governmental document study
- Interviewing with MSU transportation engineers, the directors of Planning Department and Office of Energy and Sustainability in Grand Rapids, SmithGroup JJR that participates in GRRC project.
- During the each interview, the team presented and updated the design information and revised the project based on the feedbacks from advisors and administrators.

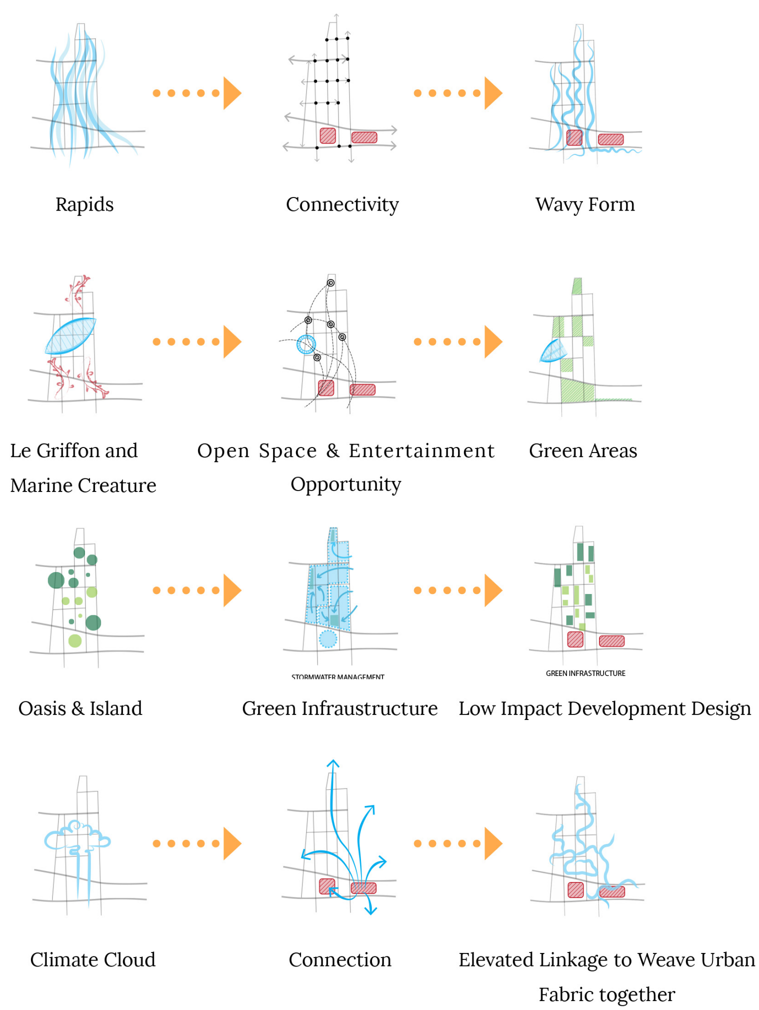

Figure 6. Design process (LID with Cloud Design)

The preliminary concept is developed as the “Vault of Heaven”, where rainfall lands on the earth. There are four elements applied through the design process (figure. 6) – Rapids, Le Griffon and Marine creature, Oasis and Island, and Climate Cloud. Each element responds to different functional objectives. Rapids, as refer to by the name of the city – Grand Rapids, represents the vertical connectivity with wavy form. According to the historical content, Le Griffon was the first commercial sailing ship on the Great Lakes of North America and vanished in northern Lake Michigan during a storm (Ashcroft, 2014). The redevelopment of the riverside park is inspired by the story of “Le Griffon”. Starting with the ship-shape riverside park, and several consequential green open spaces that are created on the site. The Oasis and Island concept is relative to the green infrastructure, especially the LID design, which symbolizes the stormwater management strategy. An elevated walkway is developed from the shape of a cloud, which breaks the disconnection between different districts and services as an aerial pedestrian crossing the freeway. Therefore, this cloud-shape elevated walkway is named as “Cloud”.

The master plan (figure 7) is designed from four procedural elements (figure 6), which mainly integrates LID design into the site, and resolves the current problems as well as offers extensive benefits. Different types of LID features include green roof, rain garden, bioswale, constructed wetland and porous pavement. These LID elements are applied to the site according to the local stormwater conditions. Moreover, the ineffective facilities and useless parking lots are replaced by green open space with numerous canopies and several creative mixed-use buildings, which improves both commercial and environmental value. A farm garden has been adopted in the middle of the site (figure 7), where the residents can communicate, enjoy the festivals and get the agricultural education. For the campus and the health center area that are well developed, the design scenario only focuses on recreating the streetscape and redesigning the crossing section at the campus entrance. The details are displayed in figure 7 with details. The Cloud, where 2/3rds of the area are covered by vegetation, provides people with the convenience to cross the freeway and streets, and also brings them the opportunities to learn about green infrastructure.

Figure 7. Master plan and details (LID with Cloud Design)

In the LID with Cloud Design (figure 8), the impervious area has been reduced and the total green space becomes 29.55% of the entire space. Also, the LID design has incorporated with other green elements.

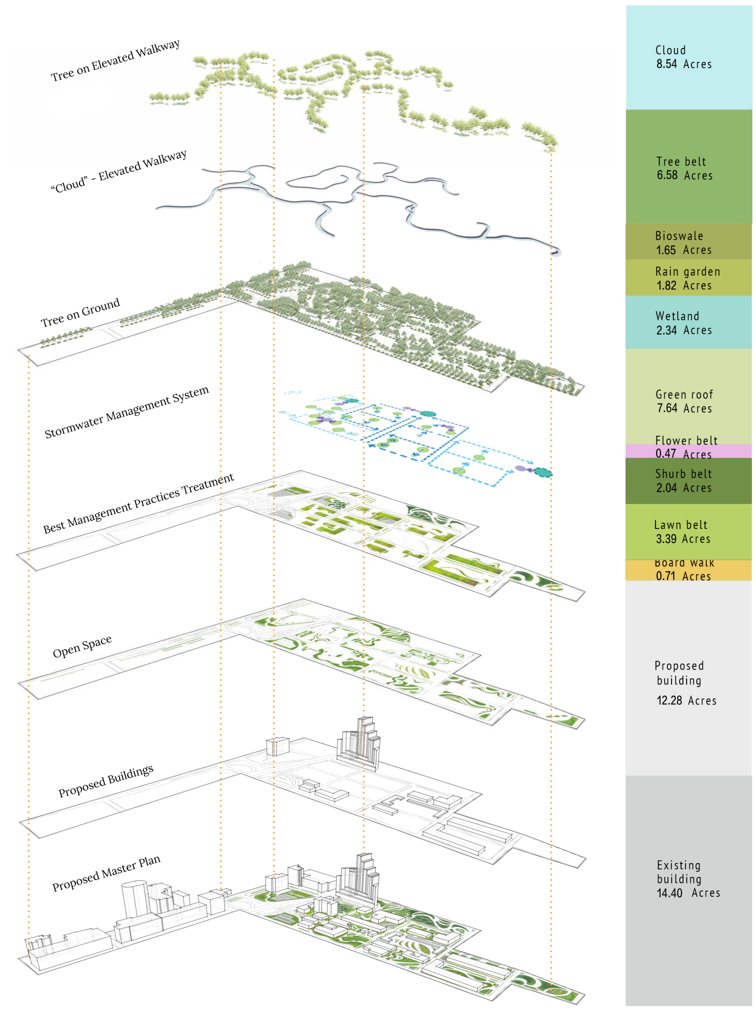

Figure 8. Layer analysis (LID with Cloud Design)

Figure 9 illustrates the complete LID stormwater management strategy. The green roof has been applied to the proposed buildings and several existing buildings based on the roof conditions. The building area is mainly surrounded by the rain garden in order to collect extra runoff from the green roof. All the pathways and parking lots have been redeveloped with permeable material. Bioswale has been arranged with all traffic line in the commercial district, which also offers beautiful streetscape. Three wetlands have been constructed in the north, middle and south of the site and several cisterns are placed depending on the local stormwater conditions. Based on these essential layouts, the site has been divided into three LID systems. Each system has a particular stormwater management scope, which is illustrated by dotted line and circles with different color in figure 9. In each system, the runoff is collected and filtered through the green roof, permeable pavement and rain garden; then, bioswale will convey the excess runoff into wetland or cistern.

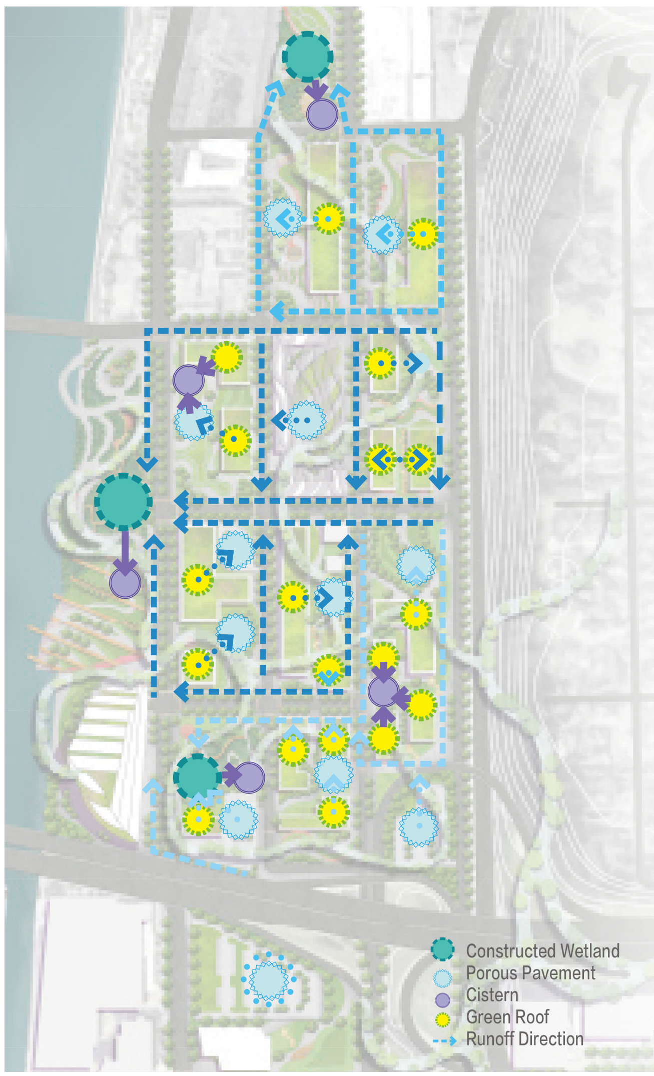

Figure 9. LID system analysis (LID with Cloud Design)

The implementation process of the project has been developed into four phases (figure 10): Phase I is GRRC that serves as campus gateway. The Michigan Department of Environmental Quality announced a $1 million grant of disposal of contaminated soil and old building demolition. MSU has planed to invest $88 million to build the new research center (MSU, n.d.).

Phase II is Medical Mile along Michigan Street, which is besides the Secchia Center. The city of Grand Rapids will receive the $6,171,966 Transportation Economic Development Fund (TEDF) grant from the Michigan Department of Transportation (MDOT) to improve the freeway ramp configurations and modify the traffic flow issues (MSU, n.d.)

Phase III is along Grand River. The national Fish and Wildlife Foundation has funded a $1.5 million grant to remove Grand River dams and restore of rapid in downtown area (Bunte, 2015). Moreover, Grand Rapids is looking for $10 million from state grant to buy the land along riverfront, which is located at the west side of Monroe Avenue NW, north of I-196 (Bunte, 2015).

Phase IV is the Monroe business district, which will involve many local business stakeholders. The redevelopment and recreation of commercial district with green infrastructure and mix-use building improve both environmental and economic value. But there are several challenges, such as the process of private ownership transfer (Burley, Li, Ying, Tian, Troost, 2016).

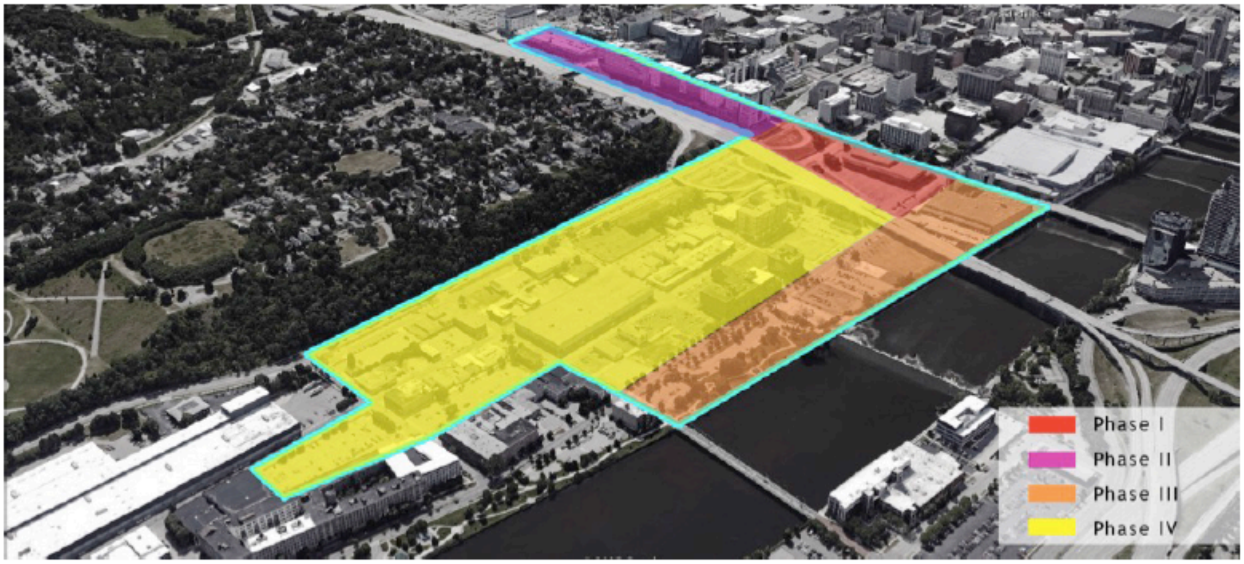

Figure 10. Implementing Phase Illustration (Copyright ©2016 Na Li with permission)

3.1.3 LID Design

In figure 10, the only difference between the LID Design and the LID with Cloud Design is the elevated walkway. Without the “Cloud”, the LID Design has less green space and shadow area, as well as less connectivity between different districts. However, in this scenario, the stormwater management is still effective and the project budgets will shrink significantly without the “Cloud”.

Figure 11. Master plan and details (LID Design)

3.1.4 Traditional Design

The Traditional Design is the scenario without any LID application, which only considers generated green space development, building retrofit and streetscape recreation. In order to have comparability with other scenarios, the Traditional Design is converted from the LID Design by changing the LID Design's rain garden into a shrub belt, switching the bioswale and wetland into lawn area, and removing the entire green roof. Also, in the Traditional Design, all the pavements and parking lots are impermeable. Therefore, the stormwater management in this design is a more conventional approach. The master plan and layer analysis in figure 11 has explained these differences comprehensively.

Figure 12. Master plan and details (Traditional Design)

3.2 Comparable Elements Calculations

In order to evaluate different design scenarios, eleven comparable variables has been selected in the area of energy use, climate change, stormwater management and ecosystem. These variables are impervious surface, permeable pavement, green space, average tree water consumption, total shadow area, the number of trees, runoff, soil infiltration, evaporation, Field Sparrow habitat suitability index and Fox Squirrel habitat suitability index. Impervious surface, permeable pavement, green space, runoff, soil infiltration, and evaporation are relative to stormwater impact and management. The average tree water consumption represents the energy use. Total shadow area and the number of trees can influence the effect of climate change. The habitat suitability index of Field Sparrow and Fox Squirrel are selected in the area of ecosystem evaluation. The four design scenarios have been ranked according to the analysis of each variable.

3.2.1 Area Calculation

Table 1 lists the specific area of the every element including the existing building, proposed building, pathway, parking space, road, different types of vegetation, various LID components and other elements in each design scenario. The total areas of the four design scenarios are equal except for the LID with Cloud Design that has included the "Cloud" into the total area. The total green space comprises of a shrub belt, flower belt, tree planter and lawn area in the Existing Site and the Traditional Design. The rest of the scenarios have also included the LID elements in the total green space, such as green roof, bioswale, rain garden and constructed wetland. The total impervious area is equal to the total site area minus green space and permeable pavement.

Table 1. List of different design elements area

	Elements	Feet Square	Acres	Percentage
Existing Site	Existing building	915616.9589	21.02	21.34%
	Road	1241481.995	28.5	28.93%
	Impervious pathway	815597.227	18.72	19.01%
	Impervious parking space	645287.0779	14.81	15.04%
	Open green space	615329.0754	14.13	14.34%
	Trees area	57362.9385	1.32	1.34%
	Total site area	4290675.273	98.5	100%
	Total green space	672692.0139	15.44	15.68%
	Total permeable pavement	0	0	0.00%
	Total impervious area	3617983.259	83.06	84.32%
Traditional Design	Existing building	627099.58	14.4	14.62%
	Proposed building	534891.19	12.28	12.47%
	Impervious pathway	790820.54	18.15	18.43%
	Impervious parking space	213758.68	4.91	4.98%
	Road	1296401	29.76	30.21%
	Shrub belt	168268.29	3.86	3.92%
	Flower belt	20261.46	0.47	0.47%
	Lawn area	321588.67	7.38	7.50%
	Tree planter	286775.31	6.58	6.68%
	Other elements	30810.56	0.71	0.72%
	Total site area	4290675.28	98.5	100.00%
	Total green space	796893.73	18.29	18.57%
	Total permeable pavement	0	0	0.00%
	Total impervious area	3493781.55	80.21	81.43%
LID Design	Existing building	627099.58	14.4	14.62%
	Proposed building	534891.19	12.28	12.47%
	Permeable pathway	790820.54	18.15	18.43%
	Permeable parking space	213758.68	4.91	4.98%
	Road	1296401	29.76	30.21%
	Green roof	332888.46	7.64	7.76%
	Bioswale	71985.73	1.65	1.68%
	Constructed wetland	101978.77	2.34	2.38%
	Rain garden	79352.72	1.82	1.85%
	Shrub belt	88915.57	2.04	2.07%
	Flower belt	20261.46	0.47	0.47%
	Lawn area	147624.17	3.39	3.44%
	Tree planter	286775.31	6.58	6.68%

Table 1 (cont'd)

LID Design	Other elements	30810.56	0.71	0.72%
	Total site area	4290675.28	98.5	100.00%
	Total green space	1129782.19	25.94	26.33%
	Total permeable pavement	1004579.22	23.06	23.41%
	Total impervious area	2156313.87	49.5	50.26%
LID with Cloud Design	Existing building	627099.58	14.4	13.45%
	Proposed building	534891.19	12.28	11.47%
	Permeable pathway	790820.54	18.15	16.96%
	Permeable parking space	213758.68	4.91	4.58%
	Road	1296401	29.76	27.80%
	"Cloud"	372004.32	8.54	7.98%
	Green roof	332888.46	7.64	7.14%
	Bioswale	71985.73	1.65	1.54%
	Constructed wetland	101978.77	2.34	2.19%
	Rain garden	79352.72	1.82	1.70%
	Shrub belt	88915.57	2.04	1.91%
	Flower belt	20261.46	0.47	0.43%
	Lawn area	147624.17	3.39	3.17%
	Tree planter	286775.31	6.58	6.15%
	Other elements	30810.56	0.71	0.66%
	Total site area	4662679.6	107.04	100.00%
	Tree planter (cloud)	248002.88	5.69	5.32%
	Impervious area (cloud)	124001.44	2.85	2.66%
	Total green space	1377785.07	31.63	29.55%
	Total permeable pavement	1004579.22	23.06	21.55%
	Total impervious area	2280315.31	52.35	48.91%

The increase of the impervious surface is one of the most crucial reasons for stormwater adverse impact. The large size impervious surface that mainly includes road, pathway and parking lots not only intensifies the peak runoff rate, but also impedes the infiltration. Thus, the total impervious area, permeable pavement area and green space has been chosen as stormwater impact criteria. Table 2 indicates the rank of the four design scenarios by comparing the data in Table 1. Also, the rank 1 means the impact on the stormwater increase is slight, while 4 means a severe influence to runoff growth. In permeable pavement, the results of the LID Design is same with the LID with Cloud Design, so we decide the ranks of these two scenarios are equal to 1.5, which is the average of one adding two. In a similar way, the ranks of the Existing Site and the Traditional Design are 3.5, which is the average of three adding four, in the area of permeable pavement. According to the rank results, it is obvious that the LID with Cloud Design has fewer impermeable areas with less impact of the stormwater growth comparing to the Existing Site.

Table 2. Ranks of stormwater impact criteria

	Impervious Surface	**Permeable Pavement**	**Green space**
Existing Site	4	3.5	4
Traditional Design	3	3.5	3
LID Design	2	1.5	2
LID with Cloud Design	1	1.5	1

3.2.2 Energy Use – Average tree water consumption

Urban tree canopies have high perceptible value in environmental functions. For instance, urban forestry can provide a city with shade and cooling, as well as improved air quality (Bartens, Day, Harris, Wynn, & Dove, 2009). Society is increasingly dependent on trees cause they not only simply fulfill environmental protection, but also effectively reduce stormwater runoff (Bartens, Day, Harris, Wynn, & Dove, 2009). Urban trees retain and infiltrate runoff by hydraulic redistribution whose working mechanism is known as conveyance of water from upper to lower soil layers through root system (Nichols & Lucke, 2015). Thus, the application of urban trees is one of the most crucial components in the city development.

The Grand Rapids City Commission (2012) has indicated that currently, the canopy coverage in the city is 34.6%, but this is less than the target of 40% based on American Forests recommendation. According to Google Earth aerial and street-view photography, the existing canopy coverage is 4.95% of the site and the quantity of the trees is 590, which is much less than the average. Therefore, in the following design scenarios, the team adopts plenty of canopies with a goal that increases trees number to at least 1030 and canopy coverage to 8.64%, which meets the government's objective of 7% tree cover for the city center in Grand Rapids (Burley, Li, Ying, Tian, Troost, 2016). Also, the plant species is selected depending on the local site condition, especially the LID application area. The details of tree species are listed in Table 3 and the most of them are native water tolerance canopies.

To estimate irrigation requirement, the average water consumption per tree has been calculated by using the Simplified Landscape Irrigation Demand Estimation (SLIDE). SLIDE is an approach to estimate the water demand for irrigated landscapes based on studies of "landscape plant water requirements" and "plant water-use physiology" (SLIDE, 2015).

SLIDE (2015) has framed four rules:

> **SLIDE Rule #1.** Reference evapotranspiration (ETo) accurately estimates water demand of lawns and other uniform turf areas, but it marginally represents water demand of non-turf, non-uniform, physically and biologically diverse landscapes.
>
> **SLIDE Rule #2**. Plant Factors (PFs) alone accurately adjust ETo to estimate landscape water demand, and they are assigned by general plant type categories, not by individual species.
>
> **SLIDE Rule #3**. A landscape area or zone controlled by one irrigation valve (hydrozone) is the smallest water management unit in a landscape; when plant types are mixed in a

hydrozone, the water demand is governed by the plant type with the highest PF.

SLIDE Rule #4. Water demand of dense plant cover (canopy covers ≥80%of the ground surface) comprised of mixed plant types is that of a single 'big leaf' governed by the plant type category in the mix with the highest PF; demand of sparse plant cover (canopy covers <80% of the ground surface) is that of individual plants and is governed by their leaf area and the PF of their plant type category. (SLIDE, 2015)

The basic SLIDE equation is:

$$\text{Landscape Water Demand (gal.)} = ETo \times PF \times LA \times 0.623 \qquad \text{(Equation 1)}$$

Where (SLIDE, 2015),

- ETo is inches if historical average or real-time evapotranspiration for the period.
- PF is the Plant Factor.
- LA is the landscape area, in square feet.
- 0.623 is the factor to convert inches of water to gallons.

In some specific cases, the water demand is complex and incorporates with a larger scale landscape. Equation 2 and 3 can be applied (SLIDE, 2015)

$$\text{Landscape Water Demand (gal.)} = \sum\{(ETo \times PF) \times LA\}1\text{-}x \times 0.623 \qquad \text{(Equation 2)}$$

Where (SLIDE, 2015),

- ETo is historical average or real-time evapotranspiration data in inches for the period of interest.
- PF is the Plant Factor for the plant category represented in a hydrozone or a landscape area, 1 through x; when plant categories are mixed in a landscape or

a hydrozone it is the highest PF among the plant categories represented.

- LA is the landscape area or hydrozone planted with the respective PF, in square feet.
- 0.623 is the factor to convert depth of water to volume (gal. ÷ [in. x sq. ft.]); omit this factor if the estimated water demand is desired in inches.

$$\text{Irrigation Demand (gal.)} = \sum\{([ETo \times PF] - P)J\text{-}D \times LA \times (1 \div DU)\}1\text{-}x \times 0.623 \quad \text{(Equation 3)}$$

Where (SLIDE, 2015),

- ETo is historic or real-time annual or monthly average evapotranspiration data in inches for months January through December, or other period of interest.
- PF is the Plant Factor for the plant category represented in a hydrozone or occupying a portion of landscape area, 1 through x; when plant categories are mixed in a landscape or a hydrozone it is the highest PF among the plant categories represented.
- P is optional; it is the historical average or real-time effective precipitation in inches for months January-December, or other period of interest; usually 50% or similar percentage of P is considered effective and is the amount used in the equation.
- LA is the landscape area or hydrozone, in square feet, devoted to the respective PF.
- 0.623 is the factor to convert depth of water to volume (gal. ÷ [in. x sq. ft.]); omit this factor if the estimated water demand is desired in inches.
- DU is the distribution uniformity of irrigation in the landscape area or hydrozone 1 through x (often mandated to be ≥0.7).

In this case, we used Equation 1 because the plant factors and water conservation suggestions are clear and accurate without any large database (Burley, Li, Ying, Tian, Troost, 2016). The assessment period we chose is the intensive irrigation time that is from May to October. The estimated evapotranspiration in Grand Rapids is 31.48 inches from May to October based on the real-time and historical evapotranspiration data collection in Sparta, MI (Enviro-weather, 2015). The plant factor of woody plants including trees, shrubs, vines and groundcover is 0.5 and 0.3 for deserted adapted plants (SLIDE, 2015). Based on the plant selection in Table 3, the team estimated the plant factor of several trees could be 0.4 except for Spruce and Basswood trees. The average tree coverage is 360 square feet according to Grand Valley State University tree canopy analysis (GRPC, 2012, p. 79).

Table 3. Plant species and average water consumption

	Plants	**Area/ea. tree**	**Quantity**	**ETo (in./ May-Oct.)**	**PF**	**LA (ft^2)**	**To Gallons**	**Result (gallon/ May-Oct.)**
Existing site	Ailanthus	360	15	22.66	0.5	5400	0.623	38116.39
	Green Ash	360	63	22.66	0.5	22680	0.623	160088.82
	Aspen	360	9	22.66	0.5	3240	0.623	22869.83
	Callery pear	360	28	22.66	0.5	10080	0.623	71150.59
	Cottonwood	360	8	22.66	0.5	2880	0.623	20328.74
	Crabapple	360	6	22.66	0.5	2160	0.623	15246.55
	Eastern redbud	360	22	22.66	0.4	7920	0.623	44723.23
	Elm	360	10	22.66	0.5	3600	0.623	25410.92
	Ginkgo	360	11	22.66	0.5	3960	0.623	27952.02
	Honey locust	360	141	22.66	0.5	50760	0.623	358294.03
	Linden	360	58	22.66	0.5	20880	0.623	147383.36
	Magnolia	360	3	22.66	0.5	1080	0.623	7623.28
	Norway maple	360	5	22.66	0.5	1800	0.623	12705.46
	Red maple	360	44	22.66	0.5	15840	0.623	111808.07
	Silver maple	360	50	22.66	0.5	18000	0.623	127054.62
	Sugar maple	360	36	22.66	0.5	12960	0.623	91479.33
	Red cedar	360	7	22.66	0.4	2520	0.623	14230.12

Table 3 (cont'd)

	Red oak	360	17	22.66	0.4	6120	0.623	34558.86
	Spruce	360	29	22.66	0.5	10440	0.623	73691.68
	Viburnum	360	1	22.66	0.5	360	0.623	2541.09
	Walnut	360	21	22.66	0.5	7560	0.623	53362.94
	White pine	360	6	22.66	0.4	2160	0.623	12197.24
	Total		590			212400	0.623	1472817.16
						4.88 acres	Average	2496.3 gal./tree
Traditional Design & LID Design	Swamp white oak	360	20	22.66	0.5	7200	0.623	50821.848
	Red maple	360	20	22.66	0.5	7200	0.623	50821.848
	Serviceberry	360	50	22.66	0.5	18000	0.623	127054.62
	Alternate leaved dogwood	360	80	22.66	0.4	28800	0.623	162629.9136
	Juneberry	360	80	22.66	0.5	28800	0.623	203287.392
	American hophornbeam	360	80	22.66	0.5	28800	0.623	203287.392
	Allegheny serviceberry	360	80	22.66	0.5	28800	0.623	203287.392
	White oak	360	60	22.66	0.5	21600	0.623	152465.544
	Bur oak	360	80	22.66	0.5	28800	0.623	203287.392
	Kentucky coffeetree	360	80	22.66	0.5	28800	0.623	203287.392
	Red oak	360	60	22.66	0.5	21600	0.623	152465.544
	Northern hackberry	360	50	22.66	0.5	18000	0.623	127054.62
	Blackcherry	360	50	22.66	0.5	18000	0.623	127054.62
	Basswood	360	20	22.66	0.4	7200	0.623	40657.4784
	Shagbark hickory	360	50	22.66	0.4	18000	0.623	101643.696
	Pignut hickory	360	50	22.66	0.5	18000	0.623	127054.62
	Black spruce	360	20	22.66	0.5	7200	0.623	50821.848
	Eastern red cedar	360	50	22.66	0.5	18000	0.623	127054.62
	Eastern white pine	360	50	22.66	0.4	18000	0.623	101643.696
	Total		1030			370800	0.623	2515681.476
						8.51acres	Average	2442.41 gal./tree

Table 3 (cont'd)

LID with Cloud Design	Pawpaw	360	20	22.66	0.5	7200	0.623	50821.848
	Yellow birch	360	30	22.66	0.5	10800	0.623	76232.772
	Swamp white oak	360	20	22.66	0.5	7200	0.623	50821.848
	Red maple	360	20	22.66	0.5	7200	0.623	50821.848
	Serviceberry	360	130	22.66	0.5	46800	0.623	330342.012
	Alternate leaved dogwood	360	130	22.66	0.4	46800	0.623	264273.6096
	Juneberry	360	130	22.66	0.5	46800	0.623	330342.012
	American hophornbeam	360	200	22.66	0.5	72000	0.623	508218.48
	Allegheny serviceberry	360	200	22.66	0.5	72000	0.623	508218.48
	White oak	360	60	22.66	0.5	21600	0.623	152465.544
	Bur oak	360	80	22.66	0.5	28800	0.623	203287.392
	Kentucky coffeetree	360	80	22.66	0.5	28800	0.623	203287.392
	Red oak	360	60	22.66	0.5	21600	0.623	152465.544
	Northern hackberry	360	50	22.66	0.5	18000	0.623	127054.62
	Blackcherry	360	50	22.66	0.5	18000	0.623	127054.62
	Basswood	360	20	22.66	0.4	7200	0.623	40657.4784
	Shagbark hickory	360	60	22.66	0.4	21600	0.623	121972.4352
	Pignut hickory	360	70	22.66	0.5	25200	0.623	177876.468
	Black spruce	360	70	22.66	0.5	25200	0.623	177876.468
	Eastern red cedar	360	70	22.66	0.5	25200	0.623	177876.468
	Eastern white pine	360	50	22.66	0.4	18000	0.623	101643.696
	Total		1600			576000		3933611.035
						13.22acres	Average	2458.50 gal./tree

In Table 3, the plant species and average water usage is the same for the Traditional Design and the LID Design, which is 2442.41 gallons for each tree between May to October. The LID with Cloud Design's average water consumption is 2458.5 gallons per tree and decreases 37.8 gallons comparing with the Existing Site's. Also, the LID with Cloud Design has the largest quantity of tree. Table 4 has ranked the 4 design scenarios for water consumption and total tree number, which is based on the results from Table 3. For water usage, 1 means the fewest irrigation requirements and for tree quantity, 1 represents the largest amount of tree.

Table 4. Ranks of the average water consumption per tree and tree quantity

	ga/tree/may-oct.	**Rank**	**Tree No.**	**Rank**
Existing Site	2496.3	4	590	4
Traditional Design	2442.41	1.5	1030	2.5
LID Design	2442.41	1.5	1030	2.5
LID with Cloud Design	2458.5	3	1600	1

3.2.3 Climate Change – Shadow area

Urban area is the key point of the greenhouse gases generation, which increases the adverse impacts of climate change (Satterthwaite, Hu, Reid, Pellin, & Lankao, 2009). These impacts include more intense and frequent storms, heat waves and other indirect influences in the area of society, environment and economy. (Satterthwaite, Hu, Reid, Pellin, & Lankao, 2009).

West Michigan Environmental Action Council (WMEAC, 2013) has reported the climate change variables of temperature and precipitation that were projected through the years 2022 to 2042 in Grand Rapids. The report forecasts the average temperature will increase 2.6% with 1.1 degree centigrade rise by 2022, and will increase 8.5% with 2.2 degree centigrade rise by 2042. WMEAC (2013) also indicates the primary goal and process that allows Grand Rapids to become climate-resilient city, respectively, in the area of economy, environment and society.

In our project, we receive the mission of climate change adaption by mitigating the stormwater runoff, saving energy cost and increasing the shadow area. LID application can effectively reduce and control runoff. Also, instead of gray infrastructure, canopies and green space absorb the exceeding heat, provide shadow area for cooling, and minimize the greenhouse gases.

In this section, the total shadow area of canopy and building facilities has been estimated through 4 design scenarios. The canopy shadow area is calculated in Table 3. The equation of the building shadow area is:

$$A = L \times W \qquad \text{(Equation 4)}$$

Where,

- A is total area.
- L is shadow's length, which is decided by angle between Sun and horizon.
- W is shadow's width, which is equal to half of the building's perimeter.

The equation of shadow's length is:

$$L = h/\tan(\alpha) \qquad \text{(Equation 5)}$$

Where,

- L is shadow's length.
- h is building's height.
- α is angle between Sun and horizon, which effected by time, date, and location.

We estimate the existing building's height by using Google earth's elevation function. The proposed building's height is designed based on the site condition and economic purpose. The measure date that has been picked is the summer solstice, which represents the beginning of summer in the Northern Hemisphere. In 2016, the date of the summer solstice is June 20, and we choose noon as the measure time. As the multiple factor, 1/tan (α) equals to 0.40 (figure 13) on this specific time and date in Grand Rapids (Find My Shadow, n. d.).

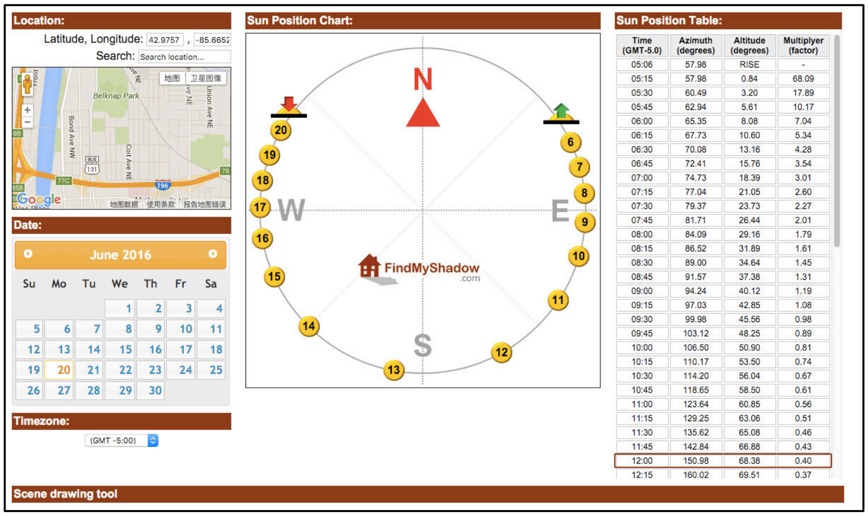

Figure 13. Sun position information (adapted from Find My Shadow, n. d.)

The Figure 14 is the building location key of the Existing Site, while the Figure 15 is the location key of other three design scenarios. Table 5 illustrates the detailed information and calculation process.

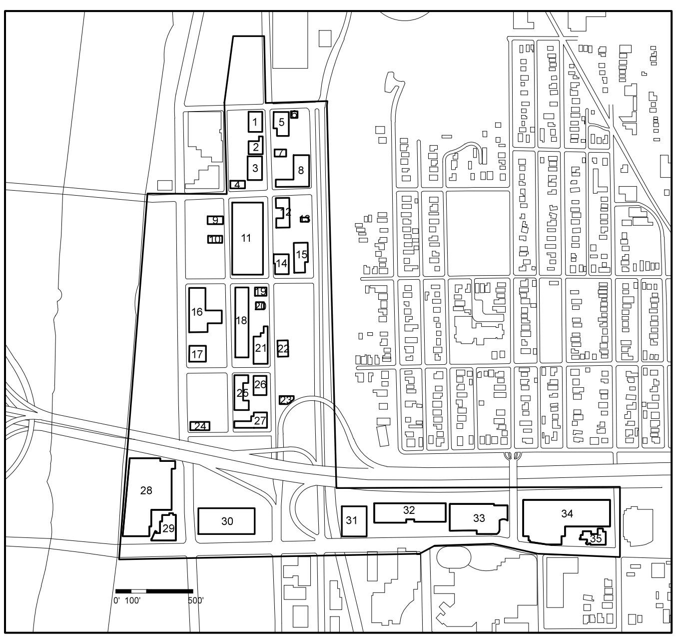

Figure 14. Location key (Existing Site)

Figure 15. Location key (Traditional Design, LID Design, & LID with Could Design)

Table 5. Building shadow area calculations

	Building NO.	Building height (ft.)	Shadow width (ft.)	Shadow length (ft.)	Total area (ft^2)	1/tan (α)
Existing Site	**1**	31	12.4	219.26	2718.824	0.4
	2	12	4.8	207.56	996.288	0.4
	3	22	8.8	246.94	2173.072	0.4
	4	26	10.4	144.33	1501.032	0.4
	5	17	6.8	251.42	1709.656	0.4
	6	10	4	84.86	339.44	0.4
	7	19	7.6	119.88	911.088	0.4
	8	33	13.2	418.17	5519.844	0.4
	9	21	8.4	150.93	1267.812	0.4
	10	30	12	137.72	1652.64	0.4
	11	37	14.8	663	9812.4	0.4
	12	16	6.4	324.5	2076.8	0.4
	13	14	5.6	228.25	1278.2	0.4
	14	15	6	78.29	469.74	0.4
	15	16	6.4	282.41	1807.424	0.4
	16	54	21.6	496.08	10715.328	0.4
	17	62	24.8	209.99	5207.752	0.4
	18	25	10	536.58	5365.8	0.4
	19	12	4.8	128.79	618.192	0.4

Table 5 (cont'd)

Existing Site	**20**	12	4.8	98.42	472.416	0.4
	21	20	8	334.16	2673.28	0.4
	22	22	8.8	171.33	1507.704	0.4
	23	20	8	142.6	1140.8	0.4
	24	18	7.2	179.5	1292.4	0.4
	25	108	43.2	313.7	13551.84	0.4
	26	38	15.2	207.78	3158.256	0.4
	27	24	9.6	309.63	2972.448	0.4
	28	52	20.8	799.81	16636.048	0.4
	29	97	38.8	291.35	11304.38	0.4
	30	54	21.6	531.17	11473.272	0.4
	31	102.1	40.84	355.01	14498.6084	0.4
	32	89.4	35.76	581.26	20785.8576	0.4
	33	76.6	30.64	546.52	16745.3728	0.4
	34	76.6	30.64	850.82	26069.1248	0.4
	35	24	9.6	277.89	2667.744	0.4
	Total				203090.8836	4.66
Tradition Design, LID Design, & LID with Cloud Design	**1**	24	9.6	541.38	5197.248	0.4
	2	24	9.6	631.74	6064.704	0.4
	3	36	14.4	339.23	4884.912	0.4
	4	36	14.4	280.25	4035.6	0.4
	5	12	4.8	513.88	2466.624	0.4
	6	12	4.8	332.42	1595.616	0.4
	7	16	6.4	324.5	2076.8	0.4
	8	24	9.6	269.69	2589.024	0.4
	9	16	6.4	282.41	1807.424	0.4
	10	54	21.6	496.08	10715.328	0.4
	11	62	24.8	209.99	5207.752	0.4
	12	25	10	536.58	5365.8	0.4
	13	12	4.8	128.79	618.192	0.4
	14	12	4.8	98.42	472.416	0.4
	15	20	8	334.16	2673.28	0.4
	16	24	9.6	412.09	3956.064	0.4
	17	22	8.8	171.33	1507.704	0.4
	18	24	9.6	745.25	7154.4	0.4
	19	18	7.2	179.5	1292.4	0.4
	20	108	43.2	313.7	13551.84	0.4
	21	38	15.2	207.78	3158.256	0.4
	22	24	9.6	309.63	2972.448	0.4

Table 5 (cont'd)

	23	24	9.6	204.13	1959.648	0.4
	24	48	19.2	215.08	4129.536	0.4
	25	52	20.8	799.81	16636.048	0.4
	26	97	38.8	291.35	11304.38	0.4
	27	76.6	30.64	346.45	10615.228	0.4
	28	102.1	40.84	355.01	14498.6084	0.4
	29	89.4	35.76	581.26	20785.8576	0.4
	30	76.6	30.64	546.52	16745.3728	0.4
	31	76.6	30.64	850.82	26069.1248	0.4
	32	24	9.6	277.89	2667.744	0.4
	Total				214775.3796	4.93

Table 6 displays the final total shadow area including both the building shadows and canopies shadows. The Traditional Design, LID design and LID with Cloud Design have the same building shadow, which adds 0.27-acres area compared to the pre-development site, but the LID with Cloud Design has also included the 8.54-acres "Cloud" shadow. In the post-development site, the increases of tree shadows are significant, respectively, which are 3.63 acres and 8.34 acres. Additionally, the LID with Cloud Design has the largest shadow area, while the Existing Site has the smallest shadow area.

Table 6. Rank of total shadow area

	Building shadow (acre)	**Tree shadow (acre)**	**Others (acre)**	**Total**	**Rank**
Existing Site	4.69	4.88	0	9.57	4
Traditional	4.93	8.51	0	13.44	2.5
LID	4.93	8.51	0	13.44	2.5
LID with Cloud	4.93	13.22	8.54	26.69	1

3.2.4 Stormwater Management – Runoff, infiltration & evaporation

To estimate the stormwater management results, the National Stormwater Calculator (SWC) has been applied into four design scenarios. The SWC is a simple software tool to evaluate the hydrological situation for any location within the US, especially for the small-scale site (USEPA, 2014). It can calculate the amount, infiltration and evaporation of stormwater runoff generated from a site under different design scenarios over a long term period based on the local historical rainfall, soil conditions, slope, land cover and meteorology (USEPA, 2014). Both LID application and future climate change has been employed into the calculation process (USEPA, 2014). The SWC's computational engine is run by the EPA Stormwater Water Management Model (SWMM), which is a well-established model for hydrology component analysis (USEPA, 2014).

The primary purpose of the SWC is providing site developers and property owners with information about how well can the designed stormwater management strategy perform, and answering the following questions that are listed in the SWC User's Guide (USEPA, 2014):

- What is the Largest daily rainfall amount that can be captured by a site in either its pre-development, current, or post-development condition?
- To what degree will storms of different magnitudes be captured on site?
- What mix of LID controls can be developed to meet a given stormwater retention target?
- How well will LID controls perform under future meteorological projections made by global climate change models?

The procedure information of the SWC that should be provided includes: 1) site location, 2) the site's soil type identification, 3) the site's soil drainage rate, 4) the site's surface topography characteristics, 5) hourly rainfall data by a nearby rain gage, 6) evaporation rate data by a nearby weather station, 7) climate change scenario selection, 8) the site's land cover for the scenario being analyzed, 9) LID control strategies within the site, and a long term hydrologic results will be analyzed and displayed in the end (USEPA, 2014).

The study site is 98.5 acres and only the LID with Cloud Design has added an elevated walkway area to the total site area. The site's soil type is B Hydrologic Soil Group, which also represents a moderately low soil type (NRCS, 2015). The hydraulic conductivity of the soil is 0.3 inches per hour, which means the soil has a moderate infiltration rate. The site topography is approximately 5% slope. The site precipitation and evaporation data are collected by the Grand Rapids Gerald R. Ford International Airport weather station. The climate change scenario is under warm and wet far term. The site's land cover and LID application data are based on the specific design scenarios. The wet day threshold is 0.10 inches on the site (MDEQ, 2006). Also, the statistics of the hydrological situation for this site is designed by 25-year 24-hour storm events. Table 7 shows all the parameters used in the SWC tool for each scenario.

Table 7. The National Stormwater Calculator (SWC) parameters

Parameter	**Existing Site**	**Traditional Design**	**LID Design**	**LID with Cloud Design**
Site Area (acres)	98.5	98.5	98.5	107.04
Hydrologic Soil Group	B	B	B	B
Hydraulic Conductivity (in/hr)	0.3	0.3	0.3	0.3
Surface Slope (%)	5	5	5	5
Precipitation Data Source	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport
Evap. Data Source	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport	Grand Rapids Intl. Airport
Climate Change Scenario	Warm/Wet/Far term	Warm/Wet/Far term	Warm/Wet/Far term	Warm/Wet/Fa r term

Table 7 (cont'd)

% Forest	1.34	6.68	6.68	11.47
% Meadow	0	4.39	8.45	7.77
% Lawn	14.34	7.5	11.2	10.31
% Desert	0	0	23.41	21.54
% Impervious	84.32	81.43	50.26	48.91
Years Analyzed	25	25	25	25
Ignore Consecutive Wet Days	False	False	False	False
Wet Day Threshold (in.)	0.1	0.1	0.1	0.1
Disconnection	33.39/47	40/47	25.3/85	25.3/85
Rain Harvesting	0	0	20/4	20/4
Rain Gardens	0	0	22.23/50	22.23/50
Green Roofs	0	0	7.62/100	7.62/100
Street Planters	1.34/6	8.96/6	8.96/6	8.96/6
Infiltration Basins	0	0	0	0
Porous Pavement	0	0	17.14/100	17.14/100

According to Table 8's statistic results, the average annual runoff of the four design scenarios are, respectively, 20.8, 16.84, 5.59 and 5.43 inches, while the maximum rainfall retained on the site are, respectively, 1.13, 1.41, 2.68 and 2.71 inches. The calculations also indicate that the green space and LID controls can effectively reduce runoff volume, increase humidity and mitigate peak rate by retaining the rainfall on the site.

Table 8. SWC statistic results

Statistic	**Existing Site**	**Traditional Design**	**LID Design**	**LID with Cloud Design**
Average Annual Rainfall (in.)	38.91	38.91	38.91	38.91
Average Annual Runoff (in.)	20.8	16.84	5.59	5.43
Days per Year With Rainfall	75.11	75.11	75.11	75.11
Days per Year with Runoff	46.93	39.29	12.43	12.03
Percent of Wet Days Retained	37.52	47.68	83.45	83.98
Smallest Rainfall w/ Runoff (in.)	0.15	0.15	0.15	0.15
Largest Rainfall w/o Runoff (in.)	0.3	0.39	0.94	1.06
Max. Rainfall Retained (in.)	1.13	1.41	2.68	2.71

Figure 16 schematically presents how effective the design with LID strategies contribute to stormwater management, which obviously reduces both runoff depth and intensity, controls the evaporation, and increases the infiltration.

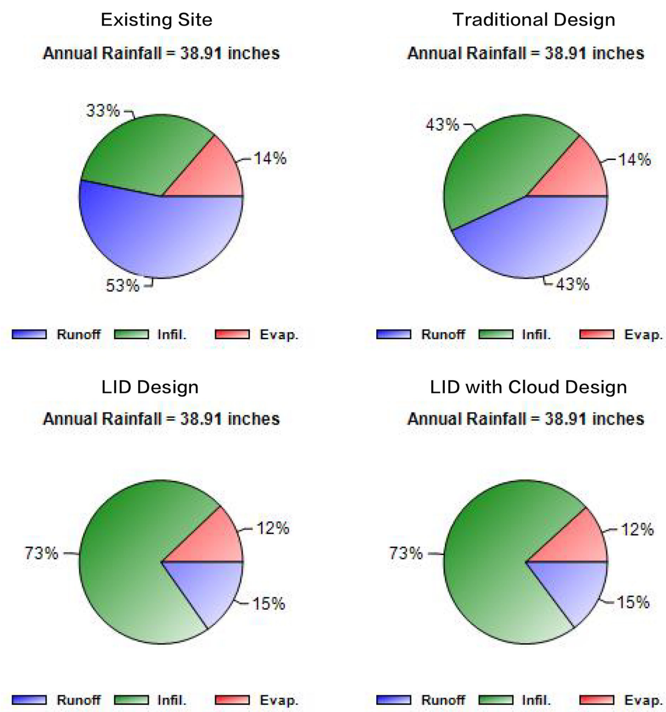

Figure 16. SWC runoff analysis results (adapted from SWC)

Based on the SWC runoff analysis, the LID Design and the LID with Cloud have same percentage in runoff, infiltration and evaporation, but dramatically different with the Existing Site and the Traditional Design. The runoff has reduced, respectively, 38% and 28% comparing with the Existing Site and the Traditional Design, while infiltration has increased 40% and 30%, respectively. Table 9 has ranked their effects on stormwater control in the area of runoff, infiltration and evaporation, where the number 1 means the most effective stormwater management design in specific area.

Table 9. Ranks of stormwater management results

	Runoff	**Soil infiltration**	**Evaporation**
Existing Site	4	4	3.5
Traditional Design	3	3	3.5
LID Design	1.5	1.5	1.5
LID with Cloud Design	1.5	1.5	1.5

3.2.5 Ecosystem – Sparrow & squirrel habitat index

In order to evaluate the ecosystem quality of each design, I picked up two common species – field sparrow (Spizella pusilla) and fox squirrel (Sciurus niger), and calculated their habitat suitability in different design scenarios. The Habitat Suitability Index (HSI) Model Series has been employed into evaluation process, which provides useful information for impact assessment and habitat management (Sousa, 1983).

Field sparrows live in the middle and east of the United States, and prefer old-field with scattered woody vegetation or brushy fencerows (Sousa, 1983). Their requirements of food are flexible from seeds to insects (Sousa, 1983). Additionally, field sparrow prefer to nest on the ground and in low shrubs or herbaceous vegetation area, especially during the breeding season (Sousa, 1983).

In order to evaluate the cover or reproduction value for the field sparrow habitat, HSI model has provided an equation to combine the suitability index values for the appropriate variables (Sousa, 1983). The equations is:

$$[\mathrm{MIN}(V1, V2) \times \mathrm{MIN}(V3, V4)]^{1/2} \qquad \text{(Equation 6)}$$

Where (Sousa, 1983),

- MIN(V1,V2) and MIN(V3,V4) mean to pick up the lowest of the suitability indices for variable 1 and variable 2, as well as the lowest value between variable 3 and variable 4.

- V1 is the suitability index for percent shrub crown cover.
- V2 is the suitability index about percent for total shrubs less than1.5m tall.
- V3 is the suitability index for percent canopy cover of grasses.
- V4 is the suitability index for average height of herbaceous canopy.

Figure 17 has schematically displayed the suitability index values for the variables of each design scenario. The field sparrow's habitat with more than 75% shrub cover is too dense to live and, also, if 50 to 75% of the shrub is higher than 1.5 meter, the habitat is considered to be inappropriate for nesting (Sousa, 1983). Grass is the main food source for field sparrow, which is recommended to be 50% to 90% canopy cover as optimal grass density (Sousa, 1983). Both shrub and herbaceous canopy are the important components of field sparrow reproductive suitability during the breeding season; therefore, the height of the herbaceous canopy is also under specific requirements (Sousa, 1983).

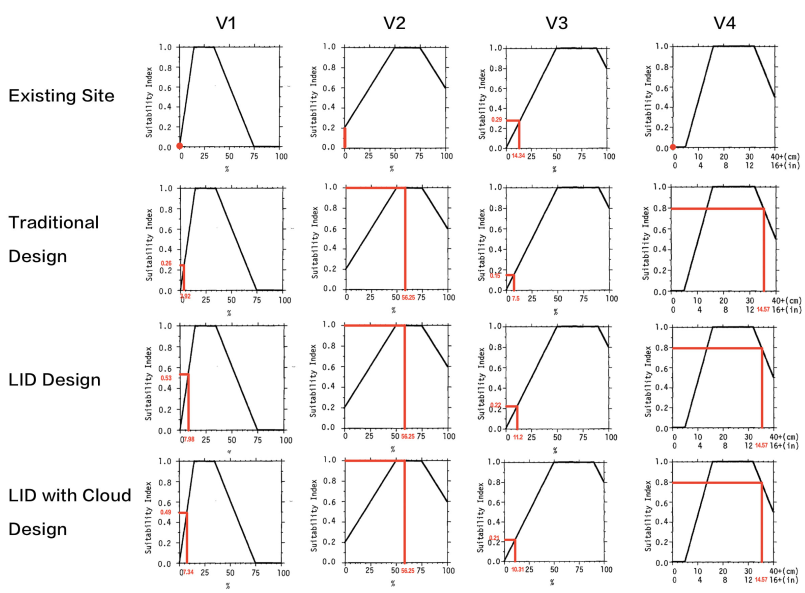

Figure 17. Field sparrow suitability indices for the variables (adapted from Sousa, 1983)

Table 10 shows the calculations based on Equation 6 and data analysis from Figure 17, and ranks these calculations, where 1 means this design scenario provides the most suitable habitat for field sparrow. The HSI value of the LID Design is 0.1166, which has the best habitat for field sparrow in the four design scenarios.

Table 10. Field sparrow HSI results and rank

	V1	**V2**	**V3**	**V4**	**HSI**	**Rank**
Existing Site	0	0.2	0.29	0	0	4
Transitional Design	0.26	1	0.15	0.8	0.039	3
LID Design	0.53	1	0.22	0.8	0.1166	1
LID with Cloud Design	0.49	1	0.21	0.8	0.1029	2

As the largest tree squirrel of North America, the fox squirrel has a wide arrange of the food requirements including mast, tree buds, insects, tubers, bulbs, roots, bird eggs, and the seeds of spring fruiting trees (Allen, 1982). Fox squirrels also live in various habitats depending upon the forest types and prefer the open forest with little understory vegetation (Allen, 1982).

HSI model has provided two equations to evaluate the sustainability values of winter food and cover/reproduction for the fox squirrel habitat (Allen, 1982). The equation about winter food is:

$$(3V1+V2)/3 \qquad \text{(Equation 7)}$$

Where (Allen, 1982),

- V1 is the suitability index for percent canopy closure of trees that produce hard mast.
- V2 is the suitability index for distance to available grain.

And the equation of cover/reproduction values is:

$$(V3\times V4\times V5)^{1/3} \qquad \text{(Equation 8)}$$

Where (Allen, 1982),

- V3 is the suitability index for average diameter at breast height (dbh) of overstory trees that are higher than 80% of the total trees.
- V4 is the suitability index for percent tree canopy closure.
- V5 is the suitability index for percent shrub crown cover.

Figure 18 has schematically showed the suitability indices for the variables of fox squirrel habitat bases on different design scenarios. The winter food functions as the most crucial component for the food requirements of fox squirrel, and is mostly produced by hard mast and grain (Allen, 1982). The trees with hard mast are optimal from 40% to 65% coverage, and the distance to available grain should be less than 200 meters (Allen, 1982). The overstory trees with an average dbh larger than 15 inches can provide the suitable cover and reproduction habitat (Allen, 1982). The proper tree canopy coverage is assumed to be from 20% to 60%, while the optimum shrub crown coverage should be less than 30% (Allen, 1982).

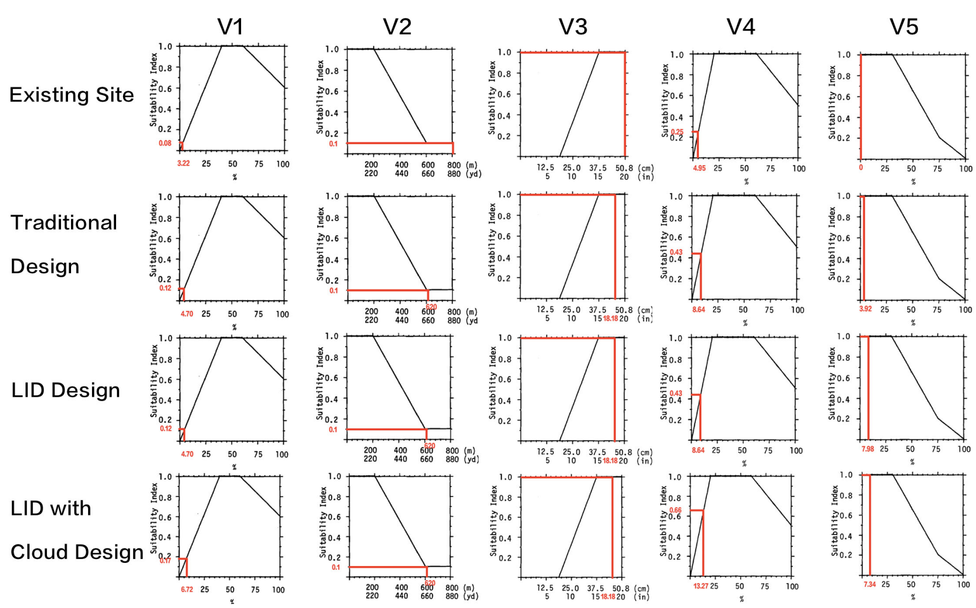

Figure 18. Fox squirrel suitability indices for the variables (adapted from Allen, 1982)

Table 11 displays the calculation results based on the Equation 7, Equation 8 and suitability indices from Figure 18. Table 11 also ranks these results, where 1 means this design scenario provides the optimum habitat for fox squirrel. The food HSI value of the LID with Cloud Design is 0.203 and the reproduction HSI value is 0.871, which is the optimum habitat for fox squirrel in the four design scenarios.

Table 11. Fox squirrel HSI results and rank

	V1	V2	V3	V4	V5	Food HSI	Reproduction HSI	Rank
Existing Site	0.08	0.1	1	0.25	1	0.113	0.630	4
Traditional Design	0.12	0.1	1	0.43	1	0.153	0.755	2.5
LID Design	0.12	0.1	1	0.43	1	0.153	0.755	2.5
LID with Cloud Design	0.17	0.1	1	0.66	1	0.203	0.871	1

3.3 Friedman Statistical Test

The selected site has been designed into four treatments – Existing Site, Traditional Design, LID Design and LID with Cloud Design. For each treatment, eleven variables have been selected for analysis based on the design impact criteria in the area of society, economy and environment.

The calculations for these design impact criteria can be ranked between four design scenarios. Stormwater impact criteria are ranked in Table 2, while the ranks of stormwater management results are displayed in Table 9. Table 4 shows the ranks of the average water consumption of each tree and quantities of tree. Table 6 indicates the total shadow area rank between four treatments. The ranks of the sustainability index results for field sparrow and fox squirrel appears in Table 10 and Table 11.

Friedman test is a nonparametric statistical test used to adjust and evaluate the treatments' values based on the rank results (Daniel, 1978). The Friedman two-way analysis of variance by ranks and multiple-comparison procedure will be utilized to determine whether the four design scenarios have statistically significant differences and whether the designs with LID elements are better than the other strategies (Daniel, 1978). The calculation process and results are explained in the next “Result” chapter.

Chapter 4. Result (including Friedman methodology)

The first step of Friedman statistical test is listing all the treatments' ranks under each block (Daniel, 1978). Blocks mean the selected variables that are treated as the design impact elements. Based on the previous tables, the overall rank results have been displayed in Table 12. These ranks have been valued from 1 to 4.

Table 12. Ranks of variable values for treatments

	Existing Site	**Traditional Design**	**LID Design**	**LID with Cloud Design**
Impervious Surface	4	3	2	1
Permeable Pavement	3.5	3.5	1.5	1.5
Green space	4	3	2	1
Tree avr. water use	4	1.5	1.5	3
Total shadow area	4	2.5	2.5	1
Tree number	4	2.5	2.5	1
Runoff	4	3	1.5	1.5
Soil infiltration	4	3	1.5	1.5
Evaporation	3.5	3.5	1.5	1.5
Field sparrow HSI	4	3	1	2
Fox squirrel HSI	4	2.5	2.5	1

The second step is to state the null and research hypotheses (Corder & Foreman, 2014). In this case, the null hypotheses Ho is all the design scenarios have identical effects, while the research hypotheses H1 is at least one design tends to have larger value than at least one other design strategy (Daniel, 1978, Corder & Foreman, 2014).

The next step is setting the level of risk called as alpha (α), which is associated with the Null Hypothesis (Corder & Foreman, 2014). In this case, the α equals to 0.05, which also can be described as - there is a 95% chance if H1 becomes real (Corder & Foreman, 2014).

The forth step is calculating the test statistic based on the sums of the ranks. The equation has been applied is (Daniel, 1978):

$$x_r^2 = \left(\frac{12}{bk(k+1)}\sum_{j=1}^{k} R_J^2\right) - 3b(k+1) \qquad \text{(Equation 9)}$$

Where,

- b is the number of block.
- k is the number of treatment.
- R is the sum for ranks of each treatment.

In this case, depending on Table 12, the block number is 11 with 4 treatments. The sums for the ranks of the Existing Site, Traditional Design, LID Design, and LID with Cloud Design are, respectively, 43, 31, 20 and 16. Therefore:

$$x_r^2 = \left(\frac{12}{4\times11\times5}\times(43^2+31^2+20^2+16^2)\right) - (3\times11\times5) = 24.05$$

Cause there are ties for ranks between the treatments in some blocks, we need to adjust the result of the previous test statistic (Daniel, 1978). The final result will equal to x_r^2 divide the adjustment number. The equation of adjustment number is (Daniel, 1978):

$$1 - \sum_{i=1}^{b} T_i\,/bk(k^2-1) \qquad \text{(Equation 10)}$$

Where (Daniel 1978),

- $T_i = \sum t_i^3 - \sum t_i$
- t_i is the number of ranks tied by a specific number in *i*th block.

In this case, there are six blocks with two ties and two blocks with four ties. Therefore:

$$\text{Adjusted test statistic} = 24.05/(1 - \frac{\big((2^3-2)\times6 + (4^3-4)\times2\big)}{11\times4\times15}) = 31.5$$

Then, we need to determine the required value for rejection of the Ho by utilizing the appropriate table that contains critical values for the particular statistics (Corder & Foreman, 2014). Daniel has provided a table (Daniel, 1978, p.452) containing chi-square values of $x^2_{(1-\alpha)}$ with k-1 degrees of freedom (Daniel, 1978). If the x^2_r is greater than or equal to the tabulated value of $x^2_{(1-\alpha)}$ with k-1 degrees of freedom, the Ho will be rejected (Daniel, 1978). In this study, the α equals to 0.05 and the k is 4. The value of $x^2_{0.95}$ with 3 degrees of freedom is 7.815, which is smaller than the 31.5. Therefore, in this thesis, at least one design is statistically better than at least one other design strategy.

In order to decide whether the designs with LID elements are better than the other scenarios, the multiple-comparison procedure for use with Friedman test has been applied (Daniel, 1978). The equation is (Daniel 1978):

$$|R_j - R_{j'}| \geq z\sqrt{\frac{bk(k+1)}{6}} \qquad \text{(Equation 11)}$$

Where (Daniel 1978),

- R_j and $R_{j'}$ are two sums of the different treatments' ranks.
- z is a tabulated value provided by a specific table in Daniel's book (Daniel, 1978, p. 452) and corresponding to α/k(k-1) (Daniel, 1978).

In this equation, if the difference between R_j and $R_{j'}$ is larger than or equal to the other side, we can assume that the treatment j is statistically absolutely better than the treatment j'. In this study, the α equals to 0.05 and the k is 4. According to this basic information, the z equals to 2.64 from the table in Daniel's book (Daniel, 1978, p. 452). Therefore:

$$2.64\sqrt{\frac{11\times4\times5}{6}} = 15.99$$

Table 13. Design Scenarios Differences

Design Scenarios Combinations	**Difference**
Existing Site & Traditional Design	12
Existing Site & LID Design	23
Existing Site & LID with Cloud Design	27
Traditional Design & LID Design	11
Traditional Design & LID with Cloud Design	15
LID Design & LID with Cloud Design	4

Table 13 has listed the differences between the four design scenarios. According to the previous statements and calculations, we can find only the differences between the Existing Site and LID Design, as well as the Existing Site and LID with Cloud Design, are bigger than the 15.99, which means the LID Design and LID with Cloud design are statistically significantly better than the Existing Site. However the other differences are smaller than the multiple-comparison procedure result, therefore, we cannot identify whether the designs with LID elements are significantly better than the Traditional Design.

As the result, in this four design scenarios test, we cannot determine between the designs with LID elements and a traditional design, which are better. But we can confirm the designs with LID elements are statistically better the current site situation.

Chapter 5. Discussion

5.1 LID Evaluation Between Theory and Reality

When I learn the previous LID study cases, I think the performance of LID is obviously more advantageous than the conventional stormwater management, which not only reduce the volume of runoff, but also integrate the entire natural hydrological cycle and ecosystem. Also, based on the most ranks of variables, the value of designs with LID elements is better than the Traditional Design and Existing Site. The results of Friedman Test support that the LID with Cloud Design and LID Design is statistically more appropriate than the Existing Site, but do not confirm that the designs with LID are better than the Traditional Design. The result is slightly different than what I expected, but still can validate the advantages of the LID.

In this research, the LID evaluation model constitutes four design scenarios with eleven variables, and the Friedman statistic test. A data model is used to represent information by setting the symbols and text (Kent, 1978). These information systems are just the limited subset of the real world and can be utilized to help scope projects (Kent, 1978). In order to estimate the feasibility of this LID evaluation model to other locations, I chose the Beijing, China as the test city.

With the extremely rapid urbanization, the traditional urban hydrological methods are destructive in China (Xu, Chen, Zhao, Zhang, & Cai, 2016). As the result, the runoff volume has exceeded the drainage system designed capacity (Yang, You, Ji, & Nima, 2013). During a heavy rain event, the drainage system congestion will lead to a flood hazard with overflow into the streets and parking spaces, resulting in economical and social adverse impacts. (Yang, You, Ji, &

Nima, 2013). Also, the urban stormwater problems increase the level of non-point pollution, which becomes a significant reason for water system containment and ecological system degradation in many cities, especially in big cities (Yang, You, Ji, & Nima, 2013).

As the capital of China, Beijing becomes the main center of social and economic development. The intensive urbanization in Beijing causes the serious stormwater problems. Also, the poorly monitored system in Beijing has impeded the developers and government in effectively applying the best management practices to control the runoff (Ren et al., 2008). But stormwater management is being modified and improved in some cases in Beijing. For instance, the Beijing Olympic Village (BOV) has converted to a residential complex after the 2008 Olympics and LID application are being planned on the site as a demonstration of the "green community" concept (Jia, Lu, Yu, & Chen, 2012). According to the report's SWMM evaluation results, the design scenarios contain green roof, bioretention, infiltration trench and rain barrel, which could maximize reduce 27% of the runoff volume and 21% of the peak low rate (Jia, Lu, Yu, & Chen, 2012). We can consider the BOV as the test site in Beijing.

Therefore, the background of the Monroe business district in Grand Rapids and the BOV in Beijing are similar, which both contain gray infrastructure and stormwater problems. The BOV occupies 36 ha and consists of residential, apartments and auxiliary facilities, which is well developed (Jia, Lu, Yu, & Chen, 2012). Also, the function and connection is complete and prominent in the village. Therefore, the design concept of proposed building and elevated walkway is not suitable to the BOV. The four-design scenarios models are not applicable to this test site, where the LID Design with Cloud is unnecessary. Besides the LID application, I think the BOV redevelopment scenarios can enhance the residents' and visitor's experience, provide information about the system and education about the Olympics. Also, the available area that can be modified is limited in the BOV. The large-size green infrastructure, such as constructed wetland, is inappropriate to the BOV. The Green roof, rain garden, pervious pavement and cistern can be the major elements in the LID application for the BOV.

The native plant species between Grand Rapids and Beijing are totally different, which will cause that the parameters in the Simplified Landscape Irrigation Demand Estimation not to be equal. In the BOV design scenarios, the building shadow area can be the same because the existing buildings fit perfectly to the site. Thus, the rank of shadow area for different design scenarios could be slightly different or mostly same with each other. I think the BOV redesign can focus on the canopy quantity and distribution based on the functional purpose and basic site condition.

The runoff evaluated by the National Stormwater Calculator (SWC) is explicit and comprehensive in Grand Rapids study case. But, the data and information about soil, precipitation, evaporation and climate change are deficient and less known in China. The runoff methodology in the model possibly cannot support the study case in Beijing. Otherwise, the Storm Water Management Model (SWMM) is utilized widely in China and can be applied instead of SWC.

For the species habitat part, the field sparrow is common for Beijing, but the fox squirrel is rarely found in Beijing. Also, the Habitat Suitability Index Model is developed based on the research and data collection in the United Sates, which is indeterminate to other countries.

Beijing is highly urbanized, which is unsuitable for the majority of wild mammals. Therefore, the species habitat study can associate with field birds.

From the previous analysis, the feasibility of the LID evaluation model is restricted in usefulness for the BOV, Beijing. The significant reasons include the different existing site conditions, data requirements and regional characteristics. The procedure of this LID evaluation model is not appropriate to every study case.

5.2 Limitation

The site selected in this study is unique, which contains a mass of gray infrastructures and stormwater problems. Cause of these existing conditions, the site provides plenty of space for redevelopment and recreation. From the previous research, we can notice that both stormwater control and habitat quality are improved significantly in the post-development. Also, almost all the ranks for LID Design and LID with Cloud Design are better than the Existing Site's, which directly influences the results of the Friedman test. Therefore, if the selected site is well development with lots of green spaces and less stormwater problems, it is hard to predicate whether the design with LID elements is the best strategies.

The only data collected by the reality is in the Existing Site. Even though, the partial data can be inaccurate during the research from governmental documents or other technological tools. The rest of the data are all depending on the design scenarios, which are flexible and subjective. The design team decided the specific characteristics of each element, such as green elements, LID types, tree quantity and species, proposed buildings or the "Cloud". Also, every element in the designs can influence the final result of the test, which means if we change any parts of the design scenarios, the result could be different. Moreover, the most crucial component in the Friedman test – "treatment" is the number of the design scenarios. In this study, we have four treatments. If we add or deleted treatment, the result could be totally different.

The variables in this research are selected in the area of energy use, climate change, stormwater management and ecosystem. Actually, the impacts of the each area are complex and numerous. The variables we picked up absolutely cannot decide the comprehensive situation of the each area. Also, the variables immediately affect the statistic test. The ranks are calculated based on the standard of the variables, and the value of the block in the Friedman test is decided by the quantity of the variables. Therefore, we only can state that the designs with LID elements are better than the Existing Site with the support of these variables in the Friedman test analysis.

During the Friedman test, the error rate α we selected is 0.05, which means the veracity of the result is 95%. If we select other error rate, the final statement will be different.

The hypothesis and result in this study is based on the specific preconditions, which cannot symbolize all the situations. But the process and method in this study can be the useful considerations in further research.

5.3 Recommendation

For all the developers, communities and designers, it is important to awarded the functions and benefits of LID design. In order to achieve the best result, the relationships between LID and BMPs including structural BMPs and nonstructural BMPs should be clarified during the pre-development phase, as well as the post-development phase. The LID elements have various characteristics and considerations, which requests the developers and designers to inventory the local situations and select the most suitable LID control. During the installation, all the requirements for different LID types should be noticed.

The calculation of stormwater management results is significant, which provide a preview of the design strategy. According to the results, the developers, designers, and government can adjust the design scenarios based on the final objective. Not only the stormwater management results, other impacts that have been considered importantly can also be calculated. People can utilize the Friedman test to evaluate the best strategy according to the specific considered impacts. This thesis can illustrate or be a guideline for LID application and design scenario evaluation.

5.4 Conclusion

The LID BMPs are applied widely throughout the United States as well as many other parts of the world, where the stormwater issues are frequent and intensified. LID provides numerous benefits by reducing, retaining and reusing the runoff. These benefits not only include the stormwater control, but also contribute to the environmental and economic value. However, there are many limitations and considerations that impede the LID development. These limitations include site conditions, local regulations, ambiguity of establish considerations and other elements.

In order to evaluate the effect of the design with LID elements in the area of environment, society and economy, the four design scenarios has been applied to the selected site in Grand Rapids. Also, several variables have been utilized and calculated by the Friedman test. The final results cannot support the initial hypotheses, because the differences between the Traditional

Design, LID design and LID with Cloud Design did not provide a significant value, but the improvement of the designs with LID elements is significant comparing with the current condition. Also, according to the previous discussion, the evaluation model applied in this paper may be not suitable to every site, and the designed model should be flexible based on the particular situations and requirements.

According to the literature review and other LID case study articles, the most studies about LID performance only forces on the impact of the stormwater, and the variables applied in the studies are plain and uncomplicated. In my study, the performance of LID is not only evaluated by the influence of stormwater, but also assessed by many other variables in the area of the impact of ecosystem, climate change and energy use, which appraises LID with a more comprehensive approach. Although there are many limitations, I think my thesis still can provide useful scientific information and procedure for future research and study.

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