FROM FLAT ROOF TO ROOF GARDEN: COMPARING FIVE DIFFERENT APPROACHES ON ROOFTOP DESIGN

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ABSTRACT

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This study addresses categories of design treatments for a rooftop at The Sylvester Broome Empower Village, located in Flint, Michigan. Five design treatments: flat roof, self-design roof, extensive green roof, semi-intensive green roof, and intensive green roof, were evaluated by 36 variables chosen by the investigator. The Friedman test was applied to examine significant differences between the five treatments ($\alpha \leq 0.05$). The Friedman's multiple comparison test revealed the treatment of the flat roof performed the poorest. There was no significant difference to demonstrate that the other four design treatments perform better than the other, but the treatment of intensive green roof performs better than self-design rooftop.

Keywords: landscape architecture, green roof, roof garden, flat roof, rooftop design, rooftop, self-design rooftop, extensive green roof, semi-intensive green roof, intensive green roof.

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CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

Prior studies have shown the benefits of urban green space. One part of a building that is scarcely used is the rooftop; however, utilizing the rooftop is often a method of creating an inner-city alternative social space (Pomeroy, 2012), and tools in response to climate change (Peck, 2008). This is especially true in developed, highly populated, dense cities. However, this practice of building on rooftops in cities like Hong Kong must first receive government authorization.

First, people are more likely to visit an urban green space than a native green area (Peters, Elands, & Buijs, 2010). Secondly, people have a better sense of the neighborhood and better relationship with their neighbors if there are green spaces nearby (Kuo, Sullivan, Coley, & Brunson, 1998). Research also shows that having more trees and plants in an area is a better place-making strategy for social connection purposes than leaving the place abandoned because it encourages people to spend times outdoor (Kuo et al., 1998). Moreover, green roofs can boost worker creativity and help provide different perspectives for work by breaking the hard edge, order, and control of modern cities' architectures, which people found fatiguing (Loder, 2014). Thus, distance to green space is a positive factor for people to observe; but the designer should still design urban green space for people who are lacking in mobility (Schipperjin et al., 2010). Nevertheless, studies had found that vegetated rooftops are helpful on reducing urban heat island effect (Sanchez & Reames, 2019; Sutton, 2015), promote urban ecosystem (Sutton, 2015), reduce stormwater runoff (Peck, 2008), and increase water and air quality (Peck, 2008).

With numerous ecological and social benefits of green roofs and urban green space, research on the specific on rooftop design approach is lacking. The proposed study will address the different categories (convention rooftop, self-design rooftop, extensive green roof, semi-intensive green roof, and intensive green roof) of rooftop design approaches effects on their values to determine if one category of roof top design approach is better than the other.

Green spaces and green infrastructures play important roles in social activities and environment events. Urban cities' architectures promote orders, hard edges and control, which green roofs soften them (Loder, 2014). A green space itself encourage people to be outdoor (Perter et al., 2010). While they promote social cohesion, it is also important to look into social interaction and place attachment (Peters et al., 2010). Instead of leaving rooftops abandoned, the idea of having a social space within a community would make the rooftop accessible to the local neighborhood and could become a functional park in densely built areas. This idea provides restoration opportunities to the neighborhood and improves residents' sense of well-being (Mesimaki, Hauru, Kotze, & Lehvavirta). Research suggests that green common space is beneficial to individuals and the community because it attracts people to be out in a social common space and increases opportunities for casual social contact (Kuo et al., 1998). Neighborhood Social Ties are positively affected by the amount of common space vegetation; there is a linear correlation for the growth of neighborhood ties near a common space as more vegetation takes place (Kuo et al., 1998). Compared to people living near a barren space, people living near green infrastructures are more willing to help and support their neighbors and have a stronger feeling of belongings (Kuo et al., 1998). These communities also have more social activities and visitors (Kuo et al., 1998). Also, as vegetated rooftops are one the best management practice for stormwater runoff (Weiler, & Scholz-Barth, 2009). Researchers found that its efficiency on lengthen the time of concentration, increase infiltration, resulting in reduce workloads for existing sewer systems and decreasing risk of watershed safety by decentralizing stormwater, which green roofs keep stormwater on site to reuse and recycle it (Weiler, & Scholz-

Barth, 2009). It was determined vegetation roofs, especially extensive green roof, could hold reduce around 85% to 90% annual rainfall addressing on one inch falling event (Weiler, & Scholz-Barth, 2009). These prior studies support the positive correlation between neighborhood connections to green spaces and rooftops; and positive attribute of vegetated roof toward the environment, this proposed study focuses specifically on comparing whether if one rooftop design approach provide more value exhaustively than others.

Understanding if one rooftop design approach is better concerning design, maintenance, social, and environmental issues, is important for landscape architects, urban planners, policymakers, architects, and building owner. It may be possible to convert flat-topped barren rooftops into something more beneficial. It is important to understand and compare conventional rooftops, self-use rooftops, extensive green roofs, semi-intensive green roofs, and intensive green roofs. This research focuses on accessing these different design approaches.

Rooftops are often referred as the forgotten "fifth façade" that are ugly, barren, where people refuse to visit, and dispose elements that are unpleasant to watch, such as heating and cooling equipment and telecommunications towers (Peck, 2008). There are approximately 40% of impervious paving is composed by rooftops (Shafique, Kim, & Kyung-Ho, 2018). There is an opportunity for building owners, developers, urban planners, and governments to develop and utilize them in order to create an inner-city, alternative social spaces (Pomeroy, 2012), tools to alleviate urban heat island effects (Sanchez & Reames, 2019), and to create and improve urban ecosystems (Sutton, 2015).

The description of the literature is divided into four parts: history of green roof, types of green roofs, construction of green roofs, and benefits of green roofs.

1.1 History of Green Roofs

Green roofs are not new phenomenon. They have been constructed for thousands of years to protect people from arduous weather (Peck, 2008). The history of green roofs could be trace back to the Neolithic Period, around 600 BC, green roofs were built for royalty, aristocracy, and religious purposes, which the first known historical reference of green roof was on a stone temple (Peck, 2008; Jim 2017). In 800-1000 AD Viking Age, a new form of green roof – sod roofs became widespread throughout Northern Europe, lined the walls and roofs to protect housing from extreme weather, including winds, cold, and rain (Peck, 2008).

Subsequently, the era of modern green roof started around 1960s Germany, Switzerland, Austria, and Norway, since there were growing concerns about rapidly grown cities and towns, and intensive urbanization that qualities of livings were degrading and chances of being involve in the nature were declining (Peck 2008; Jim 2017). Reinhard Bornkamm, a botanist, who conducted research at University of Berlin, helped in developed a green roof system which we now known as the extensive green roof system, which is a green roof system with 6 inches or less growing media (Peck, 2008), which composed by relatively thin and light growing media profile (FLL, 2002). Then, the system had been heavily studied by German institutions and found numbers of positive attributes in stormwater management, plant survivability, fire retardation, and energy conservation (Peck, 2008). Guideline for the Planning, Execution and Upkeep of Green-Roof Sites (FLL), was a non-profit research society aimed at conduct researches about green roofs and set standards and guidelines for German landscaping industry (Peck, 2008). German then continue to emerge as the world leader on green roofs technologies, legislations, and economics incentives (Snodgrass, & Snodgrass, 2006).

Green roofs are still an on-going movement. Currently, the potential of retrofitting flat-topped rooftop has gained public policy support in over 75 jurisdictions resulting in green roof explosion in Germany, Austria, Switzerland, and Europe (Peck, 2008). Canada and the United have begun to look up to the European model on green roofs, to encourage and reward practice green roofs in their lands (Snodgrass, & Snodgrass, 2006). For example, green roofs are installed on city halls of Chicago and Toronto (Snodgrass, & Snodgrass, 2006). The U.S. Green Building Council had developed Leadership in Energy and Environmental Design (LEED), which is a program certification program reward green building practice (Snodgrass, & Snodgrass, 2006). Indeed, a higher reward could be obtain if a project included green roof as one of the sustainable practice (Snodgrass, & Snodgrass, 2006). This study focusing on compare conventional rooftops and other rooftops design approaches to advocate the utilization of rooftops.

1.2 Extensive Green Roofs, Semi-Intensive Green Roofs, and Intensive Green Roofs

"Green roof" is a term used as an umbrella reference of numerous sustainable systems which build over roofs (Weiler, & Scholz-Barth, 2009). According to the Peck (2008) green roofs are green space built on roof despite on their elevations. People may also call green roofs in eco-roofs, living roofs, planted roofs, and vegetated roofs but they are the same thing (Snodgrass, & Mclntyre, 2010; & Mentens, Raes, & Hermy, 2006), or simply open spaces over structures, which either serve as roofs or "floor" on the roof (Weiler, &Scholz-Barth, 2009). Depending on their substrate depth, planned usage and plant selection (Green Roof Research Program, n.d.; Sutton, 2015, p. 6.), modern green roofs could be divided into three major large categories:

“intensive”, “semi-intensive (aka simple intensive)”, and “extensive”. Their differences, as describe in Table. 1.

Table 1: Differences between Green Roofs’ Categories (Peck, 2008, p.27)

	Intensive	Semi-intensive	Extensive
Growing Medium Depth	More than 6”	25% above or below 6”	6” or less
Accessibility	Usually accessible	Partially accessible	Often inaccessible
Fully Saturated Weight	High	Varies	Low
Plant Diversity	Greatest	Greater	Low
Cost	High	Varies	Low
Maintenance	Varies, is generally high	Varies	Minimal

Extensive green roofs are usually not accessible for public (Peck, 2008). The main characteristics of they are low weight due to swallow, 2-6” growing medium, typically composed with mineral-based mixture, including sand, gravel, crushed brick, lightweight expanded slate, clay, shale aggregate, volcanic rock, pumice stone, scoria, zeolite, diatomaceous earth, perlite, or rock wool (Peck, 2008). Around 12-35 pound per square foot would increase from slat roof to fully saturated extensive green roof (Peck, 2008; Pittaluga, Schenone, & Borelli, 2012). Due to the sallowness of their growing media, arduous arid microclimates are created on these rooftops and only hardy and low plants could be successfully grow on extensive green roofs. The advantage of this would be low to no maintenance requirement (Peck ,2008, Pittaluga et al., 2012). On the other hand, low plant diversity would be the downside of extensive green roofs (Peck, 2008, p26-27).

Intensive green roofs are roof gardens. They could also refer as parks on rooftops. Intensive green roofs are always accessible to public or certain groups of people such as building occupants depending on owners' wills (Rowe, 2010; & Peck, 2008). Diverse plant varieties could be select and plant on intensive green roofs including trees and shrubs, due to support from deep growing mediums (FLL, 2008; Peck, 2008; & Pittaluga et al., 2012). Growing medias are more than 6" with saturated weight increase by 50-300 pounds per spare foot (Peck, 2008; & Pittaluga et al., 2012). However, intensive green roofs require high maintenance especially irrigation (Peck, 2008). They also have higher capital costs than extensive green roofs (Peck, 2008).

Semi-intensive green roofs are combinations of extensive green roofs and intensive green roofs that they have characteristics of both (Peck, 2008; Pittaluga et al., 2012). They are always accessible (Peck, 2008). Their growing medias are 25% below or above 6" and saturated load vary (Peck, 2008).

Due to variations in construction depth, greening selections are different. According to FLL, there are three types of greening: intensive greening, simple intensive greening, and extensive greening (FLL, 2002). Intensive greening includes shrubs, coppices, grass, and trees. Intensive greening needs regular maintenance, especially irrigation and fertility. Simple intensive greening involves usage of grass, shrubs, and coppices. It is less costly than an intensive greening site. Extensive greening uses greening that require minimum maintenance or propagation. Plants that are enclosed and flat such as mosses, succulents, herbaceous, and grasses are typical extensive greening. (FLL, 2002, p.12)

1.3 How to build green roofs?

Similar to other built structures, the strengths green roofs are highly variable depending on their foundations. Reliable structural system foundations required calculation of loading, waterproofing, draining, etc. (Osmundson, 1999, p153) There are three rules of thumbs on designing, building, and maintaining green roofs: (1) stay within structural loading limit, (2) prevent leaking, and (3) keep plants alive (Sutton, 2015, p.7). Indeed, there are three methods of green roofs installation: (1) conventional roofing system, (2) pre-vegetated mats, and (3) modules (Rowe, 2018).

1.3.1 Components of green roofs

The roof flat, which design is usually determined by architects and structural engineers, is base of green roof structure. It could be made with different materials, but roof flat made with site cast and precast concrete are the most prevalent due to its needs to provide ultimate support to elements that would establish on top if it (Osmundson, 1999, p.154). A layer of waterproof membrane is immediate above the roof flat to prevent roof leakage (Weiler, & Schoz-Barth, 2009). There are three major recognized waterproofing for low-slope roofing, which are:

1. Layout membrane, which is consider as the most reliable and susceptible from leaking. Its life expectancy is often from 15 to 20 years. It is assembling in-place by pouring molten bitumen mixed with fibrous materials, such as fiber glass or polyester. However, it is not as commonly used as simple-ply membrane because it requires more labor and maintain.
2. Simple-ply membrane, which apply a layer of large thermoplastic sheet. Its life expectancy is often from 10 to 15 years. Since its nature of low cost, easy to apply, and required less labor, it is being widely employ since late 1970s. However, if is less susceptible for leaking, cracking, and seam failure due to its flexibility.
3. Fluid-applied membrane, which often used in complex shape roofing. (Weiler, & Schoz-Barth, 2009, p. 134-141)

After that, a protection board will be place directly on top of the waterproofing layer. Protection boards are typically 1/8 to ¼ inches pressure-laminated fiberglass or mineral-reinforced asphaltic core (Weiler, & Schoz-Barth, 2009, p148). Then 2 inches thick, rigid polystyrene foam board would place on top of the protection board as an insulation layer to prevent heat transfer. Finally, a 2½ to 4 inches thick concrete flat would be place as the finished surface. (Osmundson, 1999, p.154) On top of this finished surface, a root repellent layer or component, a drainage layer, a landscape or filter cloth, an engineered growing medium, then plants would be install from below to the top as listed (Peck, 2008, p.27).

1.3.2 Green roofs installation

As mentioned, there are three green roof installation methods: conventional roofing systems, pre-vegetated mats, and modules (Rowe, 2018). Choosing the best-fitted installation method will depends on the complexity of green roof design, budget, availability of resources and expertise, and how much maintenance and responsibility the owner is willing to take to the roof (Snodgrass, & Snodgrass, 2006).

a. Conventional

The convention roofing system includes seeds, cuttings, plugs, and nursery containers. Seeds is the least expensive installation method, or so call planting method among the other two (Snodgrass, & Snodgrass, 2006). However, it also takes to longest time for a seeded green roof to mature and it is challenging to have 100% plant coverage when matured (Snodgrass, &Snodgrass, 2006; Rowe, 2018). Depending on the climate, seeding is best to be sown in spring and fall using rapidly germinate seeds by hand or hydro-seeding technology (Snodgrass, & Snodgrass, 2006). *Sedum album, Petrorhagia,* and *Dianthus* are good plant choices for this planting method because they are hardy and easy to establish (Snodgrass, & Snodgrass, 2006). If sedum is used for this method, about 20 seeds per square foot are required to archive the even coverage and optimum appeal (Snodgrass, & Snodgrass, 2006). However, this method is hard to precisely deliver the landscape design look because species or weed use in the seed mixture may not be controllable (Snodgrass, & Snodgrass, 2006).

Cuttings is the most commonly use green roof installation method in Germany (Snodgrass, & Snodgrass, 2006). It is more expensive than seeding but cheaper than plugs (Snodgrass, & Snodgrass, 2006). It required 12 to 18 months to mature which is less time compared to seeding (Snodgrass, & Snodgrass, 2006). Cutting requires less labor than seeding, but more work to transport than plugs since it is more fragile and would require a refrigerated method to ensure the survival of plants (Snodgrass, & Snodgrass, 2006).

Plugs are plants that already established root system in plug trays, leading them to have more flexibility on the planting season lengthen from the last frost of spring to early fall depending on climates (Snodgrass, & Snodgrass, 2006). It is hardier then cutting since the rooted plugs already have sufficient energies transport, transplant, and establish (Snodgrass, & Snodgrass, 2006). It commonly takes around 12-16 months for plants to mature and the green roof achieves a full-coverage view (Snodgrass, & Snodgrass, 2016).

Nursery containers are usually used if green roof designs need more established plants in the beginning (Snodgrass, & Snodgrass, 2006). An established plant itself needed a deeper growing medium which is able to accommodate the additional mass from the root (Snodgrass, & Snodgrass, 2006). Other than the width of the growing medium, there are other factors needed to be considered when using this method. For example: system weight, where the total weight of root and soil that saturated around the root could lead to exceeding design specification (Snodgrass, & Snodgrass, 2006).

b. Vegetated mats

A vegetated mat is a thin layer of growing medium and pre-grown plants grown at ground level (Snodgrass, & Snodgrass, 2006; Rowe, 2018). The plants on vegetated mats are fully mature upon installation (Snodgrass, & Snodgrass, 2006). Vegetated mats are heavy, and it required to transport in refrigerated trucks if in hot weather (Snodgrass, & Snodgrass, 2006). They work well on sloped roofs (Snodgrass, & Snodgrass, 2006). Most company required to received orders of vegetated mats at least one year before installation (Snodgrass, & Snodgrass, 2006).

c. Modules

Modules are discrete vegetated systems that pre-grown at ground level typically consist in black plastic trays or biodegradable materials such as coconut coir (Snodgrass, & Snodgrass, 2006; Rowe, 2018). It is the most expensive installation method among the other two (Snodgrass, & Snodgrass, 2006). Modules give higher accuracy of prediction of plants, and it is easy to be replaced because each module is a self-contained unit (Snodgrass, & Snodgrass, 2006). However, if modules are made with biodegradation material, they may decompose and fall apart when move (Rowe, 2018). It is easy to install, which labors could have no horticulture knowledge and install it just like installing other hardscapes, such as pavers (Snodgrass, & Snodgrass, 2006; Rowe, 2018). The biggest advantage of modules is that the roof would immediately become a green roof once install (Rowe, 2018).

From the above literature review reviewing different types of green roofs and plantings and construction of green roofs, we can see that the rooftop design option may be limit due to loading capacity and growing medium thickness. Therefore, before constructing a green roof, it is important to set a category of green roof design approach regarding desire outcomes.

1.4 Benefits of Green Roofs

Green roofs are vegetated rooftop involved with technology, aim at reducing the amount of lost green space caused by building contruction (Whittinghill, Rowe, 2011). Green roofs are promoted as the pioneer of “sustainable building practice” responding to environmental stresses we are facing (Sutton, 2015, p.1). They are potential aids on the effect of global warming, effect of urbanization, etc. Green roofs are always adopted for its ability on energy saving and heat island reduction (Getter, Rowe, Robertson, Cregg, & Andresen, 2009). However, green roofs are more than these that they could affect people psychologically and socially.

1.4.1 Green roofs reduce stormwater runoff

Reduce stormwater runoff is considered as the best eco-service provide by green roofs (Getter, Rowe, Andersen, 2007). Green roofs are often built for best management practices (BMPs) for urban stormwater since there are difficulties in managing water flow off from impervious surface in the urban area (Weiler, & Scholz-Barth, 2009; Whittinghill, Rowe, Andresen, & Cregg, 2015). With the increasingly rapid growth process of urbanization, permeable surface had been replaced by impervious surface, such as driveways and buildings, which changed the permeable nature of land, leading to increasing risk of flooding and decrease groundwater recharge (Berndtsson, 2010; & Feitosa, & Wilkinson, 2016). Indeed, it is expected that 90% human will live in the urban by 2030 (Montgomery, 2003). Although urban sewer infrastructures were developed to handle stormwater runoff from impervious surface, limit of their handle exceeded in many cases especially in highly developed areas and cities (Weiler, & Scholz-Barth, 2009). Stormwater and sanitary sewers are separated in newer city, which stormwater would discharge into water stream directly, while sanitary would route to sewage treatment plants to clean and purify before releasing into water course (Weiler, & Scholz-Barth, 2009). However, stormwater and sanitary sewers are combined into one system, they route to water treatment plants, resulting in overload and flooding (Weiler, & Scholz-Barth, 2009). The idea of sustainable development did not gain much attention until 1990s (Berndtsson, 2010). Strategy used for traditional stormwater management is to move water off-site into underground infrastructures, where BMPs decentralize stormwater to keep it on site to reuse and recycle, which alleviate peak flow rate, lengthen the time of concentration, and increase infiltration, resulting in allaying existing sewer loads (Weiler, & Scholz-Barth, 2009, p.31-32). With the needs of redesigning the urban hydrological cycle, green roofs seems to be the practical alternative because many of the BMPs such as stormwater ponds, retention basins, infiltration facilities, open channels, and treatment wetlands require lots of lands; creation of large green area in urban region is challenging due to high land price (Menten et al., 2005; & Berndtsson, 2010).

Green roof reduce stormwater runoff in three ways: (1) to delay the initial time of runoff by absorbing precipitation in the system, (2) to reduce total runoff by retaining part of precipitation, and (3) distributing runoff through long period of time by temporary storing precipitation in the substrate and slowly release excess water (Menten et al., 2005). Literature found that the retention capability for green roofs on range from 75% for intensive green roofs to 45% for extensive green roofs annually (Menten et al, 2005). Other studies conducted in Washington D.C. and Maryland found that green roof systems could reduce annual rainfall runoff addressing on inch rain fall event effectively at average of 85 to 90 percent. Especially with flat green roof with dry soil media, which provide maximize water storage capacity, which is around 100 percent of rainfall. (Weiler, & Scholz-Barth, 2009, p.31-32). As the "90 percent rule" is also being referred for green roof systems for storm water management (Weiler, & Scholz-Barth, 2009). Differences in magnitude of the retention could depending on lots of factors, such as structure of the green roof, depth of substrate, climate, plants selection, slope and amount of precipitation (Menten et al., 2005; Getter et al., 2007; Whittinghill, 2012). Depth of substrate plays the key role on the annual rainfall-runoff relationship of green roof, where intensive rooftop performs the best that there is a linear proportionally relationship between soil depth and peak flow reduction rate, but it depends on moisture condition of soil previously (Menten et al, 2005; & Castiglia Feitosa, & Wilkinson, 2016). Also, flat green roofs perform better of water retention than sloped green roofs (Cronk, 2012). Researchers found that negative relationship between slope of green roofs and retention value that when slope increase, retention rate decrease (Getter etal., 2007). In addition, Whittinghill (2012) found that plant selection has effect on rainwater retention, where prairies mix perform better then vegetable and herb mix (Whittinghill, 2012).

Green roofs promote for their potentials on their environmental benefits (Berndtsson, 2010). First half inch of precipitation is the most important when counting on rainfall on water quality, which green roofs may be useful on improve water quality. First half inch of rain is referred as the first flush, which it is traditionally a form of stormwater quality control. The first flush in recognized to have lower water quality with concentrated and flushed off pollutants from fossil fuel combustion, byproducts of transportation, energy generation, industrial and manufacturing processes, leaves, and bird droppings (Berndtsson, 2010; & Weiler, & Scholz-Barth, 2009). However, little studies pay attention on the quality of water runoff since rainwater is generally consider as non-polluted and acidic (Berndtsson, 2010). There are still debates concerning whether green roofs have the evident first flush effect. In addition, there is a question concerning a green roof ability to improve runoff quality (Berndtsson, 2010; Bliss, Neufeld, & Ries, 2008). Indeed, Berndtsson (2010) summarized 9 potential influential factors on water qualify of green roof runoff: (1) materials usage on the roof; (2) depth of soil; (3) type of drainage; (4) usage of chemical for maintenance; (5) greening; (6) precipitation; (7) wind direction; (8) sources of pollutants; and (9) physical chemical properties of pollutants (Berndtsson, 2010). Since these are nonpoint source pollutant, watersheds are in great risk. Also, stormwater runoff is the main cause of eutrophication and degradation of water quality due to excessive nitrogen, and phosphorus sourcing from fertilizers from agricultural fields and lawns, lead to watershed's ecosystems collapse (Weiler, & Scholz-Barth, 2009, p.32-35). Green roofs improve water quality of urban rainwater runoff by absorbing pollutant, yet they could still release pollutant from soil and fertilizer usage (Teemusk, & Mander, 2007). As there are large difference between studies that some found green roofs reduce pollutant concentration, while other consider green roofs as contaminator for pollutant leading increase turbidity of runoff (Weiler, & Scholz-Barth, 2009; Berndtsson, 2010; Monterusso et al., 2002; Bliss et al., 2008; & Teemusk, & Mander, 2007; Krogulecki, 2014).

1.4.2 Green roofs as tools to alleviate global warming

Carbon dioxide is often referring as one of the primary greenhouse gasses leading to the effect of global warming. Green roofs could alleviate global warming by reducing carbon dioxide in the atmosphere by (1) photosynthesis (Rowe, 2010), and (2) heat insulation on individual buildings (Whittinghill, Rowe, Schutzki, & Cregg, 2014; Rowe, 2010).

Green roofs reduce carbon dioxide by using plants. Even though the ability of carbon sequester of green roofs could not compare to old forests, they are still better perform then flat-top rooftops (Getter, 2009). Plants naturally sequester carbon dioxide into biomass and soil subtracts by photosynthesis (Rowe, 2010). Besides, green roofs reduce heat island effects, leading to reduction of demands on the usage of heating and air-conditioning, resulting in less carbon dioxide release from generating power for HVACs (Getter et al., 2009; Rowe, 2010). The process of terrestrial carbon sequestration refers to the process photosynthesis remove carbon dioxide into biomasses of plants, making green roofs became man-made carbon sinks (Getter et al., 2009). However, this man-made ecosystem of the green roof will reach its carbon equilibrium at one point that carbon the system absorbs for plant growth would equal its release by plant decomposition (Rowe, 2010). Heat island effects in urban areas made green roofs becoming more critical on alleviating global warming because urban areas tend to have higher temperatures than rural areas, there are higher carbon dioxide concentrations in urban areas (Whittinghill et al., 2014).

Researchers have discovered the green roofs ability to capture carbon dioxide is dependent on plant species selection, the complexity of plant community, age of plants, and depth of subtracts (Getter et al., 2009; Whittinghill et al., 2014). Whittinghill et al. (2014) found that woody plants perform better to sequester carbon than sedums and prairies. Indeed, ornamental landscapes systems on rooftop perform as well as if they are in-ground, while sedum and prairies system does not appear to be as well-perform due to soil and substrate on green (Whittinghill et al., 2014). Also, shading by full plant canopy maximize the cooling effect, it is found that engineered soil made by crushed porcelain and foamed glass could maximize the effect (Matlock, 2015).

Although green roof capture carbon dioxide, it is essential to consider the carbon cost of having a green roof. The embodied energy is the energy used to construct a green roof. Carbon payback periods of green roofs are ranging from 15 years to less than 3 years, which the length of period decreases when there is a more complex plant community (Whittinghill et al., 2014). A research on green roof performance on building's energy-saving had studied on an individual building, implemented with EnergyPlus, which is a building energy simulation model supported by the US Department of Energy, found a reduction of 2% of electricity and 9-11% of natural gas usage (Sailor, 2008). Reduction of fossil fuel usage directly related to the reduction of carbon dioxide production since carbon dioxide is a by-product of fossil fuel combustion (Rowe, 2010).

1.4.3 Green roofs in noise reduction

Noise is directly related to humans' negative health effects. People are more susceptible to have depression if they are surrounded by noise (Öhrström, 1991). As urbanity is continue growing rapidly, traffic noise annoyance is one of the major issues we have nowadays (Renterghem, & Botteldooren, 2008; & Montgomery, 2003). Although things had been done toward to the issue, such as sound barriers near highways, new types of road surface layers to eliminate noise productions, and houses as sound barriers, the expectation of quiet still have not been met (Renterghem, & Botteldooren, 2009). Green roofs could be very useful when creating very quiet environment especially in the urban area (Renterghem, & Botteldooren, 2008; Renterghem, & Botteldooren, 2009). Multiple studies found the high sound absorption capability of green roofs, especially when compare with traditional conventional rooftops (Pittaluga, 2012; Renterghem, & Botteldooren, 2008; & Renterghem, & Botteldooren, 2009). Green roofs have their acoustic performance in two ways-in and out of the building: (1) to absorb outdoor noise, and (2) to insulate outdoor noise for indoor environments (Pittaluga, 2012). It is found that there is a linear relationship between the green roof effect on sound absorption and amount of green coverage on the rooftop (Renterghem, & Botteldooren, 2008). Nevertheless, the green roof effect performs the best at 6”, which is the maximum depth of the substrate of an extensive green roof, and the effect does not amplify once it excesses the thickness (Renterghem, & Booteldooren, 2008). Renterghem, & Booteldooren (2009) also found positive effect on green roof and noise absorption on increase on traffic speed on light vehicles when there is sufficient presence of green roofs.

1.4.4 Wildlife habitat and biodiversity enhancement

Human activities altered the composition of biological community and ecosystem property, causing increasing rate of species invasions, endangered, and extinctions globally (Hooper, Chapin, Ewel, Hector, Inchausti, Lavorel, & Sveriges, 2005). With range of ecosystem services provided by green roofs, including establishing an urban ecosystem and providing habitat for urban biodiversity, green roofs should be adapted to enhance these great services been provide to the urban communities (Cook-Patton, 2016; Rumble, Finch, & Gange, 2018; Eakin, 2012). When the one of the rule of thumbs of deploying a green roof is to keep plants alive, plant composition on green roof design is important since study found that plant diversity affect survivability, sustainability and functionality of green roofs (Sutton, 2015, p.7; Nagase, & Dunnett, 2010; & Lundholm, Macivor, Macdougall, & Ranalli, 2010).

Since planting on green roofs serve multiple purpose, such as aesthetics, extent rooftop longevity, provide and improve functions of green roofs, selecting the right mixture of planting trait get difficult (Maclvor, & Lundholm, 2011; & Cook-Patton, 2015). Plant selections on green roofs are different than if they are on ground-level, plants needs to be more vigorous, stress-tolerance, and less nutrient-reliant to be selected due to the stressful and harsh growing environment on rooftops with high exposure to wind and solar radiation, and maybe disturbing environment (Snodgrass, & Snodgrass, 2006; Nagase, & Dunnett, 2010). Succulents are commonly plant on green roofs because of its evergreen nature making green roof "look" green all year-round (Nagase, & Dunnett, 2010; Lundhlm, Heim, Tran, & Smith, 2014). While studies found that there is a position relationship between plant composition and degree of ecosystem functioning, there is a movement to employ other living-form of plants, such as grasses and forbs (Lundholm et al., 2010; Spehn, Joshi, Schmid, Diemer, & Korner, 2000; & Maclvor, & Lundholm, 2011). Indeed, growing condition of plants affect ecosystem services provided by green roofs, for example, roof surface has the highest temperature on conventional rooftops, average of 10°C temperature reduction occurs on rooftops with only growing medium, additional average of 2°C temperature reduction occurs on rooftops with monocultural plantings. Finally, an additional average of 1.5°C temperature reduction occurs on rooftops with multispecies plantings (Lundholm et al., 2010). At least 7cm of subtract is recommended for sedum community development (Getter, 2009). In is also found that a minimum 13cm of is required for survival of most green roof plant species (Vandegrift, 2018). Spehn et al. also found that multispecies-communities product a significant higher amount of biomass and canopy height than monoculture communities (Spehn et al., 2001). Plants grow better in multispecies ecosystem than monoculture ones because of complementary usage of resources since the “insurance” hypothesis says insurance ecosystems would against decline in bios functioning because species richness provide better chance if some of them fail to function due to bad germination, growth or survival, etc., other of them could still maintain the ecosystem (Spehn et al., 2000; Yachi, Loreau, 1999).

Other than plant species and traits, plant origin is another consideration for plant selection. Researchers found that native plants and exotic plants have different effect toward the ecosystem (Cook-Patton, & Agrawal, 2014; Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009; & Burghardt, Tallamy, Philips, & Shropshire, 2010). Even though diverse plant communities composed with either native or exotic plants produce higher biomass and seed production than if those are in monocultural plant communities, yielding behavior between exotic plants and native plants are different causing exotic plants suppress native plants on seed production if they grow together (Cook-Patton, & Agrawal, 2014; Wilsey et al., 2009). Indeed, exotic species replaced native species and dominated in many systems, but species diversities decline more in exotic monocultural greenings than native ones (Wilsey et al., 2009). Also, exotic plants attract fewer arthropod than native plants (Cook-Patton, & Agrawal, 2014). According to “more individual hypothesis,” a higher plant species richness increase the ability of the productive site the support more a larger pollution of each species, which, in this case, more arthropod species means the site is being more productive and higher chance on rare species observation (more individual hypothesis, Srivastava, & Lawton, 1998). Another research team found a similar result with lepidopteran communities that exotic plants communities supported significantly fewer caterpillars and less species richness than native plants communities even if those exotics were with close relatives with native plants (Burghardt et al., 2010).

Green roofs act as habitats by the plant communities supporting the cascade effect through food webs to support lives of urban animals (Cook-Patton, 2015; Haddad, Crutsinger, Gross, Haarstad, Knops, & Tilman, 2009) There is a strong effect between plant species richness, herbivore richness because when the biomass increase, there is more resources and habitat spaces for animals, then these resources will travel through trophic levels (Haddad et al., 2009; & Cook-Patton, 2015). Researchers found correlation between vegetation cover and arthropod richness on green roofs; no effect of roof height and distance to habitat on ground level, on the arthropod richness on green roofs (Schindler, Griffith, & Jones, 2011). Monsma (2011) also found similar result that spider abundance and richness is effected by proportion of vegetation cover of green roofs (Monsma, 2011).

Existence of invertebrate communities make green roofs more biological valuable than conventional rooftops (Partridge, & Clark, 2018). Invertebrates, including spiders, arthropods, and insects are commonly see on green roofs, which are key and foundational organism for terrestrial food wed on converting plants into protein in providing food higher trophic levels (MacIvor, & Ksiazek, 2015). A research found green roofs bring positive effect on increasing habitat connectivity for avian community by providing supplementary resources (Eakin, Campa, Linden, Roloff, Rowe, & Westphal, 2015). While green roofs are visited by bird because of abundance arthropod food supplies (Partridge, & Clark, 2018), avian usage of rooftop habitats primarily on the summer (Washburn, Swearingin, Pullins, & Rice, 2016). Indeed, majority of avian found on green roofs are insectivores during migration period, while are rarely found on conventional rooftops (Partridge, Clark, 2018).

1.4.5 Urban parks benefit in social connection

The nature of green roof – soothing and calming, are good resources for horticultural therapy (Peck, 2002, p.10). There are opportunities of converting green roofs to be social nodes. Indeed, researchers have found that neighborhood social ties (NSTs) depend on the amount of informal social interaction that takes place (Kuo, Sullivan, Coley, & Brunson, 1998). In addition, there is a direct relationship between the level of greenness of a common social space and NSTs (Kuo et al., 1998).

Green space and green infrastructure promote social cohesion that plays important roles in engaging people (Peters, Elands, & Buijs, 2010). The idea of the "common living room" increases opportunity of casual interaction among people and boosts the sense of well-being among people at the same time (Mesimaki, Hauru, Kotze, & Lehvavirta, 2017). Recognition is built on regular contact (Kazmierczak, 2013), which is an essential factor for developing neighborhood social ties. By being recognized, users of an urban open space can increase their familiarity and casual interaction opportunities with others in the city, creating tighter community and neighborhood bonds. These factors are why it is important to consider the effect of recognition on social interaction and place attachment.

Green infrastructure adds social benefits to a neighborhood. There is a positive relationship between public green space quality and community attachment (Arnberger, & Eder, 2012). Green space quality is also a factor for drawing people to a public space. The amount of greenness in a social space has direct impacts on NSTs (Kuo et al., 1998). NSTs depends on the amount of informal social interaction (Kuo et al., 1998). While an abandoned common space discourages people to be there, a successful placemaking strategy uses plants to attract people

(Kuo et al., 1998). A common social space in a neighborhood with more plants encourages people spending time outdoors to stay in the public space (Kuo et al., 1998). Their study found that residents living near a green common space boost the feeling of belonging and attachment for residents in a neighborhood (Kuo et al., 1998). There is a stronger relationship among neighborhood residents as well as increased willingness to help one another if the neighborhood has a green social common space (Kuo et al., 1998). Because greening the common space has such a positive effect on the neighborhood, rooftops that are usually abundant and forgotten are an alternative social common space in a highly populated and dense city.

With the literature reviewed, rooftops are having many potentials, transforming barren conventional rooftops to other kinds of roofscapes which could attribute to society and the environment.

CHAPTER TWO: METHODOLOGY

The experimental design of this study is to develop 5 design scenarios with different rooftop design approach using the rooftop on an existing infrastructure at The Sylvester Broome Empower Village, located in Flint, Michigan.

2.1 Design Scenario Description

The methodology is based on 5 design scenarios: conventional rooftop, which is also the existing rooftop; self-design rooftop, extensive rooftop, semi-intensive rooftop, and intensive rooftop. These 5 design scenarios are based on the existing rooftop, known green roof category: extensive, semi-intensive, and intensive (FLL, 2002); and imaginary rooftop design approach if not designed by a professional. The intensive design scenario was used for course LA817 Environmental Design Studio at Michigan State University. The following sections will introduce the five design treatments: existing site, self-design rooftop, extensive green roof, semi-intensive green roof, and intensive green roof accordingly.

2.1.1 Existing site

The site is located at 4119 Saginaw St., Flint, MI (43.052800, -83.694300). Flint has the 7-th highest population density in Michigan, laying on M-475, M-69, and M-75. The building itself is owned by The Sylvester Broome Empower Village. Its vision is to transform Flint into a just and equitable city by developing and investing in youth. The organization offer summer day camp, adult literacy program, SKY after-school program, and other educational program related to youth and adult.

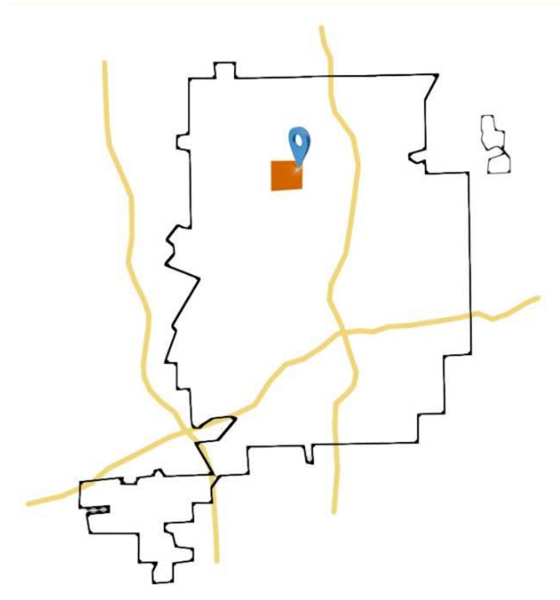

Figure 1: Location of the Sylvester Broome Empower Village in Flint, Michigan. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission)

This two-story structure is nearly a hundred years old. It is open to the public. The designated design area for this study has three level, with a total of 0.84 acres. Designated design area is indicated in figure 2.

Figure 2: Aerial view of designated existing design site. (Google, n.d., Retrieved October 15, 2019, from https://www.google.com/maps/@43.0524912,-83.6954075,17z.)

There are severe accessibily and safety challenges in the existing site, which indicated in figure 3 to figure 7. The rooftop could not be accessed excpet for climbing out from window in the computer lab, as describe in figure 3. Therefore, a proper entrance is requie. Also, there is about a 3 foot height differential between level one and level two rooftop without any ramp or stair giving visitors accessing to level two, as described in figure 4. There is a ladder for climbing up but it is not ADA accessible. Nevertheless, there is no railing on level three roofing. There is a possibily of falling. Accessibility and safty improvement is needed if the area is developed.

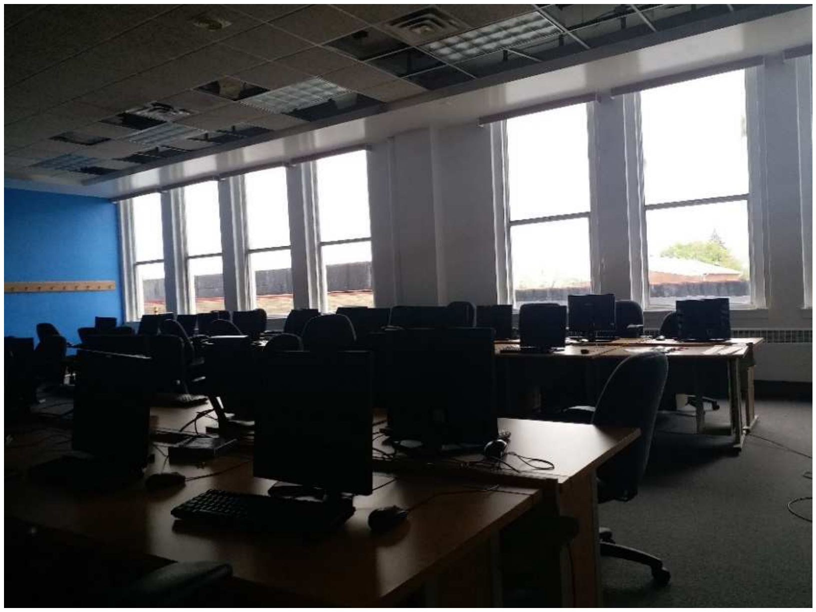

Figure 3: Accessibility challenge on accessing to the rooftop. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 4: Accessibility challenge on level two rooftop. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 5: A latter giving access from level two to level three roofing. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 6: No railing on level three rooftop. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 7 demonstrtate accessibility for exisiting conditions. The green shawdow indicates an area that is accesible for the user. The yellow shawdow indicates an area that is inaccessible to use, and requires some climbing to be there. The red shawdow indicates an area which is not accessible to users.

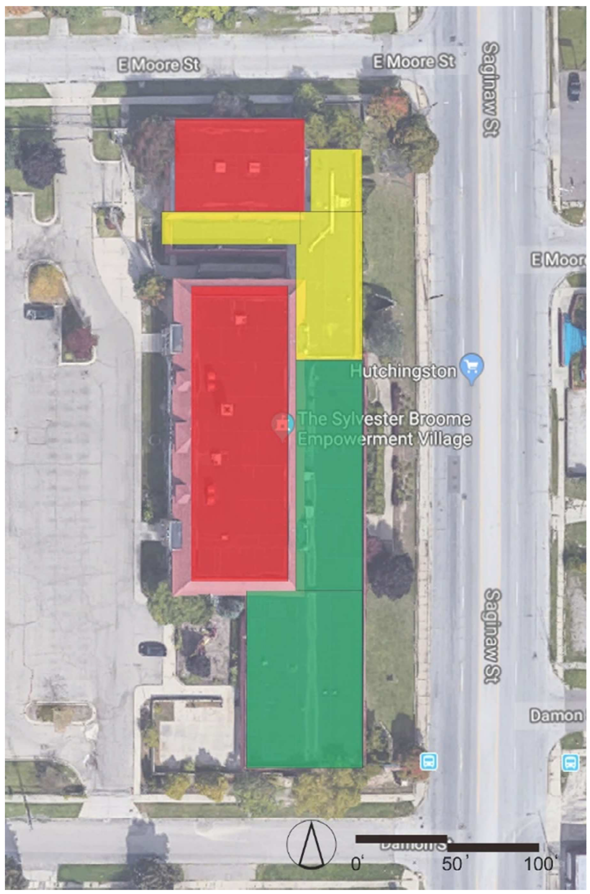

Figure 7: Accessibility indication on existing rooftop. (Google, n.d., Retrieved October 15, 2019, from https://www.google.com/maps/@43.0524912,-83.6954075,17z.)

Other than existing site challenges, renewable energy and outdoor classroom are design orientation lead to design programs of experiential design approaches present below.

2.2 Study scenario

2.2.1 Conventional rooftop

This design approach is based on existing site condition. Figure 8 is a birdseye view of the design treatment as there was no extra design work performed to the rooftop (Figure 8).

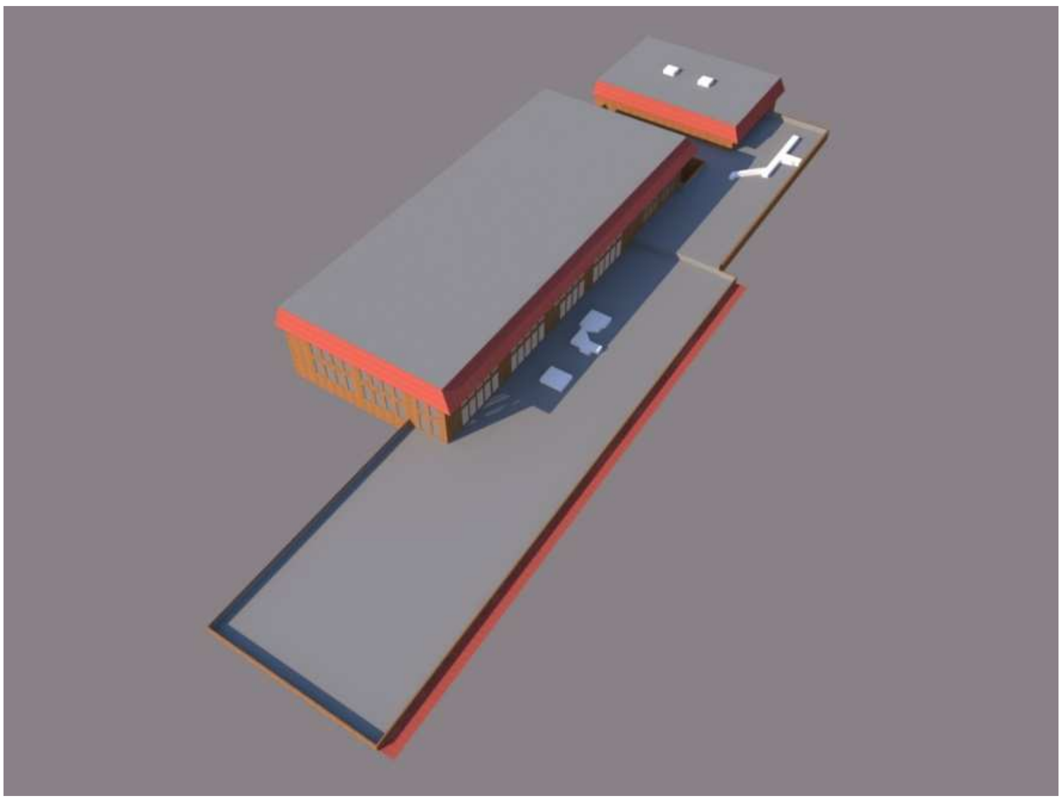

Figure 8: Birdseye view of a conventional rooftop. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

2.2.2 Self-design rooftop

As people may utilize the space that fit their needs without hiring landscape architects, green roof professionals, or urban planners, they place items to fill the space. This design (Figures 9-

12) approach imitates a utilized rooftop spatial response to the property by user. Design goals and objectives are:

- Enriching educational opportunity by creating outdoor classroom
- Encourage urban sustainability by establishing rainwater harvesting system
- Promote urban agriculture by building green house
- Create special relationship with proper planting layout
- Encourage social connection by creating gathering area
- Provide entertainment facilities
- Generate renewable energy by installing solar panels
- Improving accessibility by having an entrance accessing to the roof

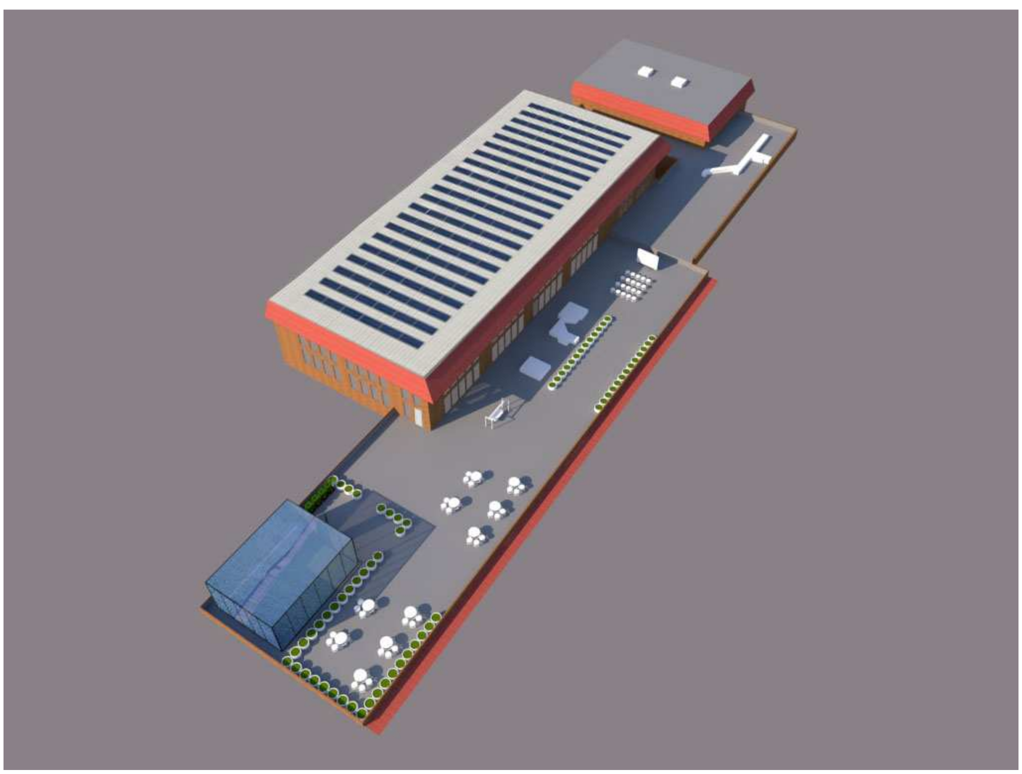

Figure 9: Birdseye view of a self-design rooftop. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 10: An outdoor teaching area for maximum 20 students. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 11: A corridor connecting active and quite area. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 12: The active area. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Other than, solar panels laying on top level of the roof, this self-design rooftop is divided into a quite area (figure 10) and an active area (figure 12), connecting by a corridor composed by planting pots (figure 11). The quite area has an outdoor classroom with maximum capacity of 20 students (figure 10). The active area has a greenhouse for urban agriculture, seats and tables for gathering, a swing for entertainment, a water harvesting system, and special planting pots layout to emphasize spatial relationship (figure 12).

2.2.3 Extensive green roof

Extensive green roofs are usually not open to public (Peck, 2008), so it would not have much design element but planting with extensive greening. Goals of this design (Figure 13) approach are:

- Reduce stormwater runoff, heat island effect, pollutant loading, carbon footprint, noise pollution
- Provide habitat for wildlife
- Improve surrounding human mental health by providing meadow view for people within the building; and
- Increase longevity of roofing membranes

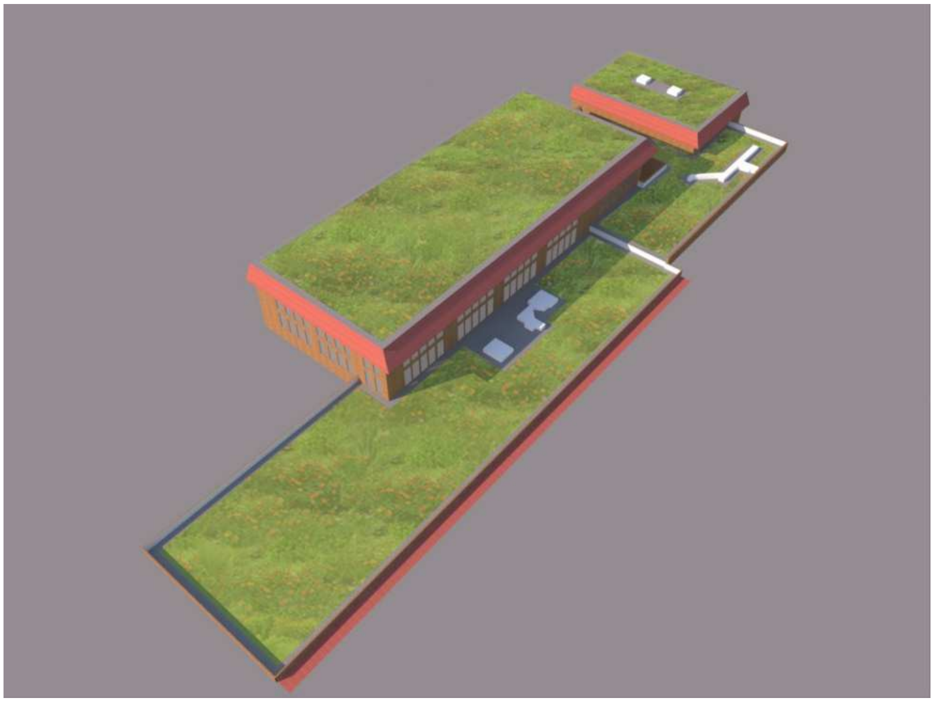

Figure 13: Birdseye view of an extensive green roof. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

2.2.4 Semi-intensive green roof

This design approach is aim at creating social space and encouraging builder user of that building to be outdoor since they could watch from windows that lots of facilities and activities could be done/ happening on rooftop. Below are goals and objectives of this design approach (Figures 14-23):

- Improving accessible challenge by designing ADA path from first level rooftop to second level rooftop
- Generate renewable energy by applying solar panels
- Addressing accessibility issue by having proper door entrance

- Encourage social interaction by having gathering space
- Allowing group activity or outdoor classroom by having plaza space
- Family friendly by having children entertaining facilities

Figure 14: Birdseye view of a semi-intensive green roof. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

This semi-intensive green roof is divided into two parts: quiet area, and active area. The reading area, as shown in figure 15, is the quiet area that is partly enclosed by walls and a foot-tall fence to create a quiet, and enclosed feeling. Flower plots in are employed to sit in the reading area to create an inclusive atmosphere and to emphasize on spatial relationship.

Figure 15: A reading area. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Active area includes interactive children entertaining equipment (figures 16 & 20), a viewing bar (figure 19), a multi-purpose area (figure 21), a flower bed, a dry garden (figure 22) and a fire pit with sofa (figure 23).

Figure 16: An interactive children entertaining facility / interactive chess area with seats aside for guardians to supervise their children alongside.(Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 17: Perspective overlooking from second level to first level rooftop along the end of a ramp. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

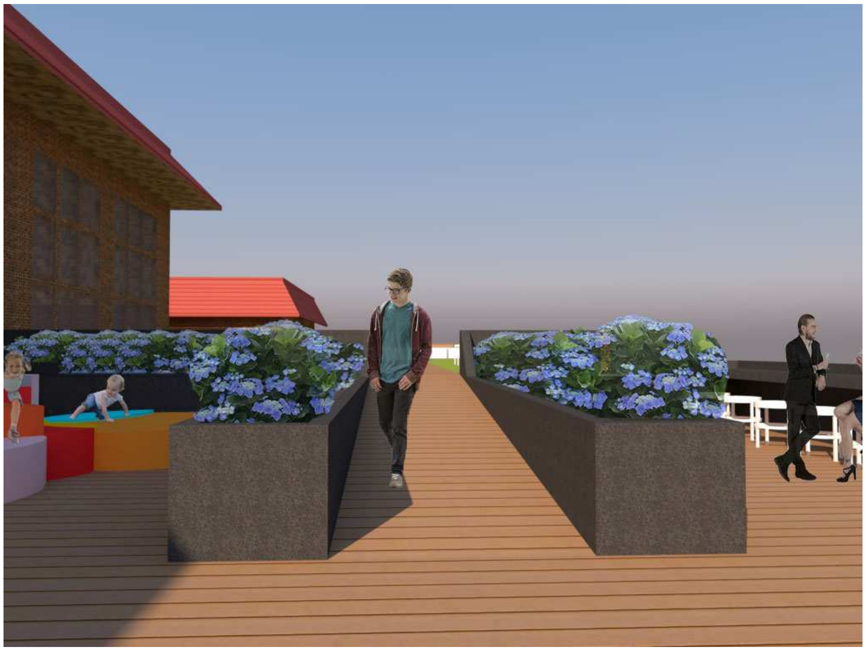

Figure 18: Perspective overlooking from first level to second level rooftop along the end of a ramp. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 19: A viewing bar with 7 seats. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

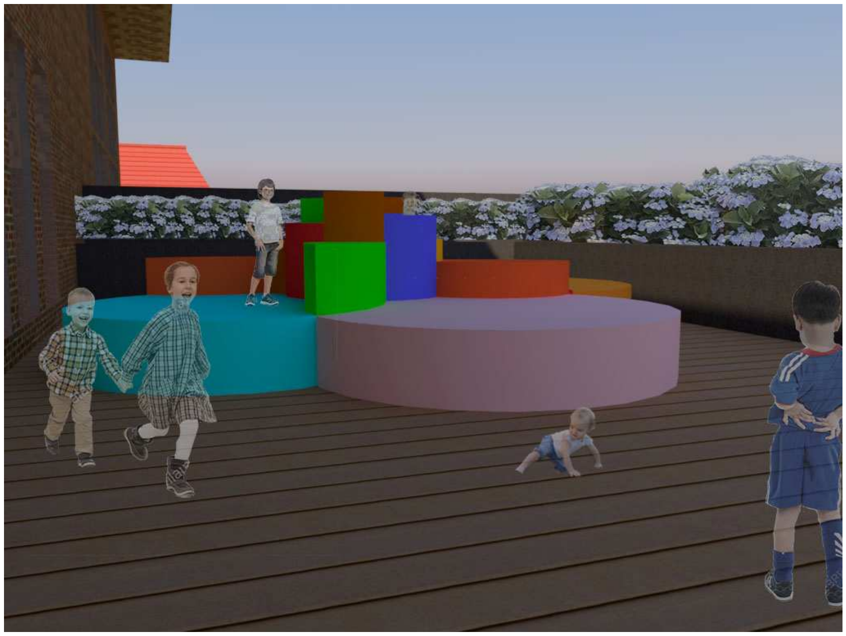

Figure 20: An Interactive child playing facility. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 21: A multi-purpose area. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 22: A dry garden. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 23: A fire pit with sofas. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

2.2.5 Intensive green roof

This design approach (Figures 24 - 29) is aim at creating an alternative of urban park, and a multi-functional space provides social, educational, and environmental value, which is also hoping to be influential to surrounding encouraging other building owners to utilize their rooftop and invest in green roof. The design criteria are:

- Generate renewable energy by applying solar panels;
- Reduce stormwater runoff by building it with special soil profile;
- Provide social opportunities by provide gathering space and seats;
- Provide educational opportunities by provide real time footage of butterfly garden with monitors and monitoring cameras;
- Encourage nature preservation by creating a man-made habitat for butterflies and provide educational programs about renewable energy and preservation of nature to visitors; and
- Improving accessible challenge by designing ADA path from first level rooftop to second level rooftop.

Figure 24: Top view of an intensive green roof. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Nature preservation, stormwater management, and energy efficiency are the three concepts that had been applied to the design. The site becomes not only a gathering site for youths and their families, but a biological spot for natural species (butterfly) and an educational spot for the community to have a better understanding about stormwater management, clean energy, and ecology.

The butterfly garden facilitates the site to become an educational and ecological spot. It is designated for nature preservation and educational purposes that there are two monitoring cameras, recording real time footage of the butterfly garden and providing it on monitors in the secret garden, as shown in figure 25.

Figure 25: A butterfly garden. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

The sectet garden (Figure 26) is a partlialy enclosed space prviding 4 sofa seats and two wall-mounted monitors provide real-time footage that is capture in the butterfly garden, allowing visitors to learn about the nearby butterfly garden, biodoversity, and urban ecosystem.

Figure 26: A secret garden. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 27: Ramp with railing alongside. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Figure 28: Plaza with a two-level creative seating element which encourage user to interact (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission).

Aluminum planting grates are employed to maximize walkable and planting area and to emphasize visual differences (Figure 29). An aluminum planting grate allow people to walk on it while having sedum to plant underneath it. The design was inspired by the green roof on ASLA headquarters in Washington, D.C.

Figure 29: Maximize walkable are and visual difference with use of two flooring materials: deck and aluminum planting grate. (Copyright © 2019 Wing Chi Vincy Tam all right reserved used by permission)

2.3 Data collection

This research will compare 5 rooftop design approach scenarios as listed and described in above sections: a conventional rooftop, a self-design rooftop, an extensive green roof, a semi-intensive green roof, and an intensive green roof. The conventional rooftop scenario is the existing rooftop; others four scenarios are designed by the investigator, Wing Chi Vincy Tam. In order to evaluate these scenarios, a list of 36 variables ranging in 7 aspects, including accessibility, plant, function, habitat value, active maintenance, water efficiency, and program are selected by the author, as describe in table 2.

Data will be treated with Friedman test to compare multiple variables, which had been used on many studies on landscape architecture (Burley, Li, & He, 2020; Feng, Burley, Machemer, Korkmaz, & Villanueva, 2018; Feng, Burley, Machemer, & Korkmaz, 2017; Lin, Burley, Nieratko, & Machemer, 2017, Burley, Li, Ying, Tian, & Troost, 2016; Wang, Burley, & Partin, 2013; Hallsaxton, Burley, 2011; Hallsaxton, Burley; 2010; Keefe, Burley, 1998; Burley, 1996; & Burley, Johnson, Larson, & Pecka, 1988). Data will treat in following steps:

1. All treatments across blocks are going to rank from smallest to largest by the author by observation (Daniel, 1978), which means the smaller score is a better score and the larger score is a poorer score. Treatments would receive same ranking if the author thinks they rank the same. For example, if the middle three treatments are all tied, they would all rank 3; while the best treatment rank 1 and the worst treatment rank 5;
2. Sum up within each treatment.
3. Apply $x_r{}^2 = (\frac{12}{bk(k+1)} \sum_{i=1}^{k} R_i{}^2) - 3b(k+1)$ (Equation 1), where,

   b equals blocks

   K equals numbers of treatments

   R equals sum for ranks in each treatment
4. Since there are ties, apply $1 - \sum_{i=1}^{b} R_i{}^2\, T_i \,/bk(k^2-1)$ (Equation 2) to justify $x_r{}^2$, where,

   $T_i = \sum t_i{}^3 - \sum t_i$

   t_i = the number of observations tied for a given rank in the ith block.

5. Apply $|R_i - R_{i'}| \geq z\sqrt{\frac{bk(k+1)}{6}}$ (Equation 3) to determine which scenarios is better than the other, where,

   R_i and $R_{i'}$ are the ith and i'th treatment rank totals

   z is the value from a table provided in Daniel's book, corresponding to $\propto/k(k-1)$ (Daniel, 1978);
6. Find z score from Daniel's book (Daniel, 1978)
7. Calculate differences between each scenario; and
8. Compare results from step 5 and step 7, if the result from step 7 is larger than result from step 5, there is enough different showing these two scenarios have nonidentical effects.

The p-value is set at 0.05. The null hypothesis of this study is all design approach scenarios have identical effect (Daniel, 1978); the research hypothesis is at least one scenario have larger value then at least one scenario ($p \leq 0.05$) (Daniel, 1978).

This is a preliminary study that will reach across different rooftop design approaches for purpose of understanding how each design approaches weight on design aspects.

Table 2: Variables

Aspect	No.	Variable
Accessibility	1	Accessible entrance to the roof
	2	ADA accessible
	3	Safety
Plant	4	Shading
	5	Diversity of plants

Table 2 (cont'd)

	6	Present of plant in number
Function	7	Reduce stormwater runoff
	8	Renewable energy production
	9	Conserve energy
	10	Reduce heat island effect
	11	Promote water infiltration
	12	Reduce pollutant loading
	13	Rainwater recycle
	14	Increase longevity of roofing membranes
	15	Reduce carbon footprint
	16	Reduce noise pollution
	17	Provide on-site education
	18	Provide on-site research value
Habitat value	19	Provide habitat for wildlife
	20	Promote biodiversity
Active maintenance	21	Minimal or no irrigation
	22	Do not require chemical inputs, such as fertilizers, pesticides, or herbicides
Water efficiency	23	No permanent irrigation
Program	24	Seating
	25	Table
	26	Gathering space
	27	Viewpoint/ observation deck
	28	Children playing equipment
	29	Encourage social interaction
	30	Improve public health

Table 2 (cont'd)

	31	Encourage volunteerism
	32	Promote neighborliness and social inclusion
	33	Provide views for people within the building
	34	Encourage for outdoor activities
	35	Improve surrounding human mental health
	36	Being influential and encouraging for having green infrastructure

2.4 Variable Rating Criteria

All treatments are going to process in ranking from smallest to largest (Daniel, 1978), which means the smaller number in the rank, better that treatment design on that variable. Below present ranking criteria of each variable respectively following their orders on above table (Table 2).

1. Accessible entrance to the roof

   If there is a proper accessible entrance from the building to the roof, such as a doorway, that treatment will rank the lowest; if there is no proper accessible entrance, that treatment will rank the highest.

2. ADA accessible

   There are two contents to compare across all treatments.

   a. Entrance. If there is no ADA accessible entrance from the building to the roof.
   b. Accessibility to the whole design area by wheelchairs. For example, if there is any ramp at where the elevation change.

If a treatment fails criteria (a), that treatment will immediately rank the highest because an entrance is the most immediate component for anyone who wants access to the roof. If a treatment success on both criteria (a) and (b), that treatment will rank the lowest. If a treatment only success on criteria (a), that treatment will rank in between the highest and the lowest.

3. Safety

   Prevention of people falling from the roof, such as at least 3-foot tall wall.

4. Shading

   Plants provide shades. The more shrubs and trees the treatments have on-site, the smaller it ranks.

5. Diversity of plant

   The higher diversity of plants a treatment has, the smaller it ranks.

6. Present of plant in number

   The more plant a treatment has, the smaller it ranks.

7. Reduce stormwater runoff

   Studies (Getter et al., 2007; Menten et al., 2005; Whittinghill, 2012) found that green roofs could reduce stormwater runoff. Ranking depends on plant coverage of treatment, the higher percentage of plant coverage, the smaller that treatment ranks.

8. Renewable energy production

   If that treatment produces any kind of renewable energy, such as solar energy, that treatment will rank the smallest. Otherwise, it will rank the highest.

9. Conserve energy

Studies (Getter et al., 2009; Rowe, 2010) found green roofs conserve energy by reducing the demand for HVACs. The more plant present on a treatment, the smaller that treatment ranks.

10. Reduce the heat island effect

    Studies (Rowe, 2010; Whittinghill, Rowe, Schutzki, & Cregg, 2014) shows that the presence of plant reduce heat island effect. This variable will evaluate by the percentage of plant cover of the roof. The higher percentage, the smaller number of rankings that treatment is.

11. Promote water infiltration

    By absorbing and retaining rainwater, green roofs promote water infiltration and increase the quality of stormwater (Berntsson, 2010; Teemusk, &Mander, 2007; Weiler, &Scholz-Barth, 2009). Therefore, the higher percentage of plant coverage on-site, the smaller that treatment will rank.

12. Reduce pollutant loading

    Green roofs could absorb pollutants (Teemusk, & Mander, 2007). Therefore, the higher percentage of plant coverage, the smaller that treatment ranks.

13. Rainwater recycles

    If a treatment has rainwater recycling facilities on-site, it will rank the smallest. If a treatment does not have any rainwater recycling facility on-site, but rainwater could use for irrigation, it will rank the next.

14. Increase longevity of roofing membranes

Green roofs can extend the life of rooftops (Snodgrass, & Snodgrass, 2016). Therefore, if a treatment is considered a green roof, it will rank the smallest. If not, it will rank the highest.

15. Reduce carbon footprint

    Implementation of green roofs could lead to less HVACs usage, resulting in carbon footprint reduction (Getter et al., 2009; Rowe, 2010). Also, plant natural sequesters carbon dioxide into its biomass by photosynthesis (Rowe, 2010). Therefore, the more plants a treatment has, the smaller it ranks.

16. Reduce noise pollution

    Studies (Pittaluga, 2012; Renterghem, & Botteldooren, 2009; Renterghem, & Botteldooren, 2008) found plants could reduce noise pollution. The more plant a treatment has, the smaller it ranks.

17. Provide on-site education

    The more educational facilities or opportunities installed or could be install, such as outdoor classrooms and research programs, the smaller that treatment rank.

18. Provide on-site research value

    The more research value a treatment has, the smaller it ranks.

19. Provide habitat for wildlife

    Studies (Schindler et al., 2011; Monsma, 2011) found a positive correlation between the proportion of vegetation cover of green roofs and spices richness. Therefore, the more plants a treatment has, the smaller it ranks.

20. Promote biodiversity

Plant communities have a cascade effect on promoting biodiversity by supporting urban animal lives through food webs. Therefore, the more plant a treatment has, the smaller it will rank.

21. Minimal or no irrigation

    The least irrigation that treatment needs, the smaller it ranks.

22. Do not require chemical inputs, such as fertilizers, pesticides, or herbicides

    If a treatment requires these chemical inputs, the more it needs, the higher it will rank.

23. No permanent irrigation

    If a treatment requires permanent irrigation, it will rank the highest. Otherwise, the treatment will rank the lowest. Usually, permanent irrigation related to plant presence and water requirement of plant selections.

24. Seating

    The more seats a treatment provides, the smaller it ranks.

25. Table

    The more tables a treatment provides, the smaller it ranks.

26. Gathering space

    If a treatment does not have an area for visitors to stay and gather, that treatment will rank the highest. If a treatment has a destinated and designed area that encourages gathering and social interaction, that treatment will rank the lowest. If a treatment has an area that people could stay or seat, but not encouraging people interaction, that treatment will rank in between.

27. Viewpoint/observation deck

If a treatment is accessible by visitors, the higher destined locations they are to be viewpoints/observation decks, the smaller that treatment ranks.

28. Children playing equipment

    If a treatment has any children playing equipment on site, the more it has, the smaller it ranks.

29. Encourage social interaction

    The more elements that would encourage social interaction, such as children playing equipment, gathering area, and seats a treatment has, the smaller it ranks.

30. Improve public health

    Green roofs provide numbers of services improve public health, including reduce stormwater runoff (Weiler, & Scholz-Barth, 2009), alleviate global warming (Rowe, 2010; Whittinghill et al., 2014), and reduce noise pollution (Renterghem, & Botteldooren, 2008; Renterghem, & Botteldooren, 2009). Therefore, if a treatment is considered as a green roof, it will rank the smallest. If it is not considered as a green roof but still provides opportunities for people to spend time outdoor, that treatment will rank the next. If a treatment provides neither of the functions nor opportunity, it will rank the largest.

31. Encourage volunteerism

    Volunteerism could use for site maintenance. The more maintenance treatment might require, the smaller it ranks.

32. Promote neighborliness and social inclusion

    Green roofs promote social inclusion and increase neighborhood social ties as green instructions (Peter et al., 2010; Kuo et al., 1998). A study (Kuo et al.,1998) found that the more greenness in a social space, the closer neighborhood social ties. Also, urban open spaces increase casual social opportunity which leads to tighter neighbor social bond (Kazmierczak, 2013; Mesimaki et al., 2017). Therefore, if a treatment is being accessible to visitors, the greener it is, the smaller it ranks. If a treatment is not being accessible but it is still green, that treatment will rank the next because having "quality green" nearby could encourage increase neighborhood social ties (Kuo et al., 1998). If a treatment is not being accessible and green, it will rank the highest.

33. Provide views for people within the building

    If a treatment could provide "green views" for people within the building, it will rank the smallest. If there is something that could look at, but not green, it will rank the next.

34. Encourage for outdoor activities

    If a treatment has elements that encourage people to go to the site and stay, such as interactive playing elements, reading area, fire pit, and observation deck, it will rank the smallest. If a treatment only allows people to access the area but it does not has any attractive element for leading visitors to be there for outdoor activity, it will rank the next. If a treatment is not accessible, it will rank the largest.

35. Improve surrounding human mental health

    If a treatment is considered as a green roof, it will rank the smallest. If a treatment is not considered as a green roof but still encourage neither outdoor activities nor social interactions, it will rank the next.

36. Being influential and encouraging for having green infrastructure

    If a treatment is utilizing the roof and it is considered as a green roof, it will rank the smallest. If a treatment is not utilizing the roof, it will rank the highest. If a treatment is utilizing the roof, but it is not designed as a green roof, it will rank in between.

CHAPTER THREE: RESULT

To process Friedman test, all treatments are going to rank from smallest to largest (Daniel, 1978), as shown (Table 3).

Table 3: Variables in rankings

Aspect	No.	Variable	Conventional	Self-Design	Extensive	Semi-intensive	Intensive
Accessibility	1	Accessible entrance to the roof	4.5	2	4.5	2	2
	2	ADA accessible	4.5	3	4.5	1.5	1.5
	3	Safety	3	3	3	3	3
Plant	4	Shading	4.5	4.5	3	2	1
	5	Diversity of plants	5	4	1	3	2
	6	Present of plant in number	5	4	1.5	3	1.5
Function	7	Reduce stormwater runoff	4.5	4.5	1	3	2
	8	Renewable energy production	4.5	2	4.5	2	2
	9	Conserve energy	4.5	4.5	1.5	3	1.5
	10	Reduce heat island effect	5	4	1.5	3	1.5
	11	Promote water infiltration	4.5	4.5	1	3	2

Table 3 (cont'd)

	12	Reduce pollutant loading	5	4	1.5	3	1.5
	13	Rainwater recycle	5	1	3	3	3
	14	Increase longevity of roofing membranes	4.5	4.5	2	2	2
	15	Reduce carbon footprint	5	4	1.5	3	1.5
	16	Reduce noise pollution	4.5	4.5	1.5	3	1.5
	17	Provide on-site education	5	2	4	3	1
	18	Provide on-site research value	5	3	2	4	1
Habitat value	19	Provide habitat for wildlife	5	4	1	3	2
	20	Promote biodiversity	5	4	1	3	2
Active maintenance	21	Minimal or no irrigation	2	2	2	4	5
	22	Do not require chemical inputs, such as fertilizers, pesticides, or herbicides	2	2	2	4	5
Water efficiency	23	No permanent irrigation	2	2	2	4.5	4.5
Program	24	Seating	4.5	3	4.5	1.5	1.5
	25	Table	4.5	1	4.5	2	3
	26	Gathering space	4.5	3	4.5	1.5	1.5

Table 3 (cont'd)

	27	Viewpoint/ observation deck	4.5	3	4.5	2	1
	28	Children playing equipment	4	2	4	1	4
	29	Encourage social interaction	5	3	4	1.5	1.5
	30	Improve public health	5	4	2	2	2
	31	Encourage volunteerism	5	4	3	1.5	1.5
	32	Promote neighborliness and social inclusion	5	3	4	1.5	1.5
	33	Provide views for people within the building	5	4	2	2	2
	34	Encourage for outdoor activities	5	3	4	1.5	1.5
	35	Improve surrounding human mental health	5	4	2	2	2
	36	Being influential and encouraging for having green infrastructure	5	4	2	2	2

Secondly, to determine if Ho is true or false by calculating the test statistic in summing ranking in each scenario, as shown on Table 4. If Ho is true, sums are close, and neither small nor large rank should show a tendency toward a scenario. However, if Ho is false, at least one scenario has sufficient differences in sum from the other.

Table 4: Sum in ranking of each scenario

	Conventional	Self-design	Extensive	Semi-intensive	Intensive
Sums	161.5	118	95.5	90	75

Thirdly, set the risk level alpha (α) in 0.05, which is associated with null hypothesis, meaning that there is 95% chance that the null hypothesis can be accepted.

Then, this equation has been applied (Daniel, 1978),

$$x_r{}^2 = \left(\frac{12}{bk(k+1)} \sum_{i=1}^{k} R_i{}^2\right) - 3b(k+1) \text{ (Equation1)}$$

Where,

- b equals blocks
- K equals numbers of treatments
- R equals sum for ranks in each treatment

Therefore, as describe in Table 4,

$x_r{}^2 = (\frac{12}{36\times5\times(5+1)} \times (161.5^2 + 118^2 + 95.5^2 + 90^2 + 75^2) - 3 \times 36 \times (5+1) = 50.35$

(Equation 1.2)

Since there are ties occurs, text statistic has been justified by dividing $x_r{}^2$, by

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

where,

- $T_i = \sum t_i{}^3 - \sum t_i$
- t_i = the number of observations tied for a given rank in the ith block.

There are 27 two-way ties, 12 three-way ties, and one five-way ties, therefore,

$$1 - \frac{(2^3-2)\times27+(3^3-3)\times12+(5^3-5)\times1}{36\times5\times(5^2-1)} = 0.868056 \text{ (Equation 2.2)}$$

Then, we calculate adjusted x^2 value by,

$$x^2 = 50.35 \div 0.868056 = 58.0032$$

Then, the $x_r{}^2$adjusted for ties is 58.0032.

Then, required value for rejecting the null hypothesis is needed to determine by using a table that contain chi-square value of $x^2{}_{(1-\alpha)}$ with k-1 degree of freedom, provided by Daniel (Daniel, 1978). If $x_r{}^2$is greater or equal than the determined value, the null hypothesis will be rejected (Daniel, 1978). In this study, the experimentwise error rate of α equal to 0.05 and k equal to 5. The value of $x^2{}_{0.99}$ with 35 degrees of freedom is 57.342. Since 58.0032 is greater than 57.342, at least one treatment is significantly different than another treatment.

In order to determine which scenario is better than the other, multiple-comparison procedure for use with Friedman test apply (Daniel, 1978). The equation is (Daniel, 1978);

$$|R_i - R_{i'}| \geq z\sqrt{\frac{bk(k+1)}{6}} \text{ (Equation 3)}$$

Where,

- R_i and $R_{i'}$ are the ith and i'th treatment rank totals
- z is the value from a table provided in Daniel's book, corresponding to $\propto/k(k-1)$ (Daniel, 1978).

In this study, experimentwise error rate of α equal to 0.05, which

$$z = \alpha \div k(k-1)$$

$$z = 0.05 \div 5(5-1) = 0.0025$$

z-score for 0.0025 is 2.81, found in a table in Daniel book.

Therefore, after applied multiple comparison procedure for use with Friedman test apply,

$$2.81\sqrt{\frac{36\times5\times(5+1)}{6}} = 37.7001 \text{ (Equation 3a)}$$

Differences between five design scenarios are listed in Table 5. According to previous statements and calculations, we can find differences between conventional rooftops and all of the other rooftop design approaches since their differences are larger than 37.7001 (Equation 3a). There are also differences between self-design rooftops and intensive green roofs, since their difference are larger than 37.7001 (Equation 3a).

Table 5: Design Scenarios Difference

Combinations of Design Scenarios	Difference

Table 5 (cont'd)

Conventional & Self-design	43.5
Conventional & Extensive	66
Conventional & Semi-intensive	71.5
Convention & Intensive	86.5
Self-design & extensive	22.5
Self-design & Semi-intensive	28
Self-design & Intensive	43
Extensive & Semi-intensive	5.5
Extensive & Intensive	20.5
Semi-intensive & Intensive	15

As a result, one can determine self-design rooftops, extensive green roofs, semi-intensive green roofs, and intensive green roofs are statistically significantly better than conventional rooftops. Nevertheless, intensive green roofs are statistically significantly better than self-design rooftops.

CHAPTER FOUR: DISCUSSION

4.1 Evaluation Between Theory and Reality

The performance of green roofs was predicted to do better than conventional rooftops and self-design rooftops when the researcher was reading the literature about the effects of rooftops on energy and water efficiency, environmental, psychological, and social interaction. Green roofs are obviously more advantageous than the other non-green-roof designs, not only on reducing stormwater runoffs and heat island effects, but also design programs, responses from the societies, plantings, and accessibilities. In addition, it was predicted that the intensive green roof scenario was the best rooftop design approach because there are lots of possibilities concerning designing the area. It has fewer regulations regarding to weight load than the other approaches. Also, this scenario addressed educational, environmental, nature preservation, and energy generation program elements. As a result, the assumption is partly correct.

The results for each individual scenario show my assumption is somewhat correct. Based on just the sum of the rankings, the intensive green roof scenario performs the best since it has the lowest sum of ranking. Then the semi-intensive green roof, the extensive green roof, and the self-design rooftop. Finally, the conventional rooftop scenario ranked the least. In contrast, the sum of ranking compared the performance of each scenarios. The Friedman test interpreted results statistically. The result of Friedman test supported the notion that the self-design rooftop, the extensive green roof, the semi-intensive green roof, and the intensive green roof scenarios are statistically better than the conventional rooftop scenario. However, Friedman test did not confirm that the self-design rooftop, the extensive green roofs, the semi-intensive green roofs, and the intensive green roofs are different on their performance. They had not shown remarkable statistical differences. Under this circumstance, the researcher could still confirm intensive green roofs are statistically better than self-design rooftops. This result has slightly differed from the assumption, but still validate that conventional rooftops should be converted into alternative social spaces or stormwater management tools. From the rankings, we can see that once a conventional rooftop is converted into a usable space, it would rank higher with most of the variables employed in the study.

In this research, rooftop design approaches had been evaluated to determine which is better comprehensively by comparing 5 rooftop design approach scenarios in 36 variables ranging from 7 aspects by Friedman test.

4.1.1 Green Roofs as social-inclusive areas

Greenspaces, including urban green space and native green areas, are places for people to spend their leisure time. Urban green space can serve as a place that it brings diverse communities together, often communities with varying socio-economic backgrounds (Krellenberg, Welz, Reyes-Packe, 2014). People are more likely to be in a "green" common social space in a neighborhood than in abandoned spaces (Kuo et al., 1998). A nationwide study of 11238 randomly selected adults in Denmark examined the influence on user motivations and distance to urban park on the park usage of urban parks, using a survey. The survey found that people are more willing to visit an urban park than a native park (Schipperjin et al., 2010). In addition, a research study on urban park concentrating on what it means to different ethnic group and their behaviors towards different types of parks, using surveying, observation, and interview methods in five selected urban parks in Netherland, found that urban parks are inclusive places that offer opportunities to all ethnic groups to spend their leisure time (Peter et al., 2010).

4.1.2 Green Roofs in the Biosphere Concept

Green roofs are being referred as the green lungs in urban and suburban areas since they provide lots of environmental, economic, climate, social, and technical advantages comparing to traditional conventional rooftop (Schrader, Böning, 2006). While rapid urbanization and expansion of urban sprawl caused habitat fragmentation, opportunities of green roofs to reserve urban biosphere and function as urban habitat networks should be explored (Kim, 2004). Indeed, green roofs had been adopted to a habitat network project in Seoul, South Korea, as steppingstones to connect fragment habitats and build biosphere networks (Kim, 2004). The project is divided into four categories: urban green belt biosphere reserve, urban green corridor biosphere reserve, urban green area cluster biosphere reserve, and urban region biosphere reserve; creating green space equivalent to 27.5% of Seoul administrative district (Kim, 2004). Since 42% of the city is covered with buildings, which is impossible to link fragment habitats without utilizing rooftops. As Seoul is facing a challenge in the storage of green space, converting these rooftops into green roofs would create green space equivalent to 30% of the area (Kim, 2004). The green belt project is designed to outskirt 15-25km from the center of Seoul. Green corridors: one circulates with the green belt, two divide the belt from north to south, and from east to west (Kim, 2004). Green roofs in inner Seoul play in for the area cluster that six sites, including Seoul form a large-scale green area cluster when various species inhabitant there (Kim, 2004). Finally, Seoul and its surrounding existing and implemented green areas lined to define the region as a biosphere reserve zone (Kim, 2004). Green roofs are being recognized on their excel of being providers of eco-services. They are employed to be elements of “building-integrate habitat” and biotopes in the case in Seoul. They are applications of the biosphere reserve concept.

Green roofs are no longer just build for humans to overcome arduous weather like our ancestors, they provide services to human, man-made environments, ecosystems, and nature. As this result of this study found that conventional rooftop performs the worst and many studies and cases found and prove advantageous of green roofs, these spare barren rooftops should have more attention from the public.

Innovation green roof constructions and designs in the future could regreen metropolis, like the habitat network project in Seoul. As green roofs are being increasingly popular to address challenges on urban sustainability development, supports from governments such as revising building codes and other beneficial policies would play a key role in pushing forward the movement of green roofs. With overseeing abilities from planners and landscape architects, a green roof would no longer be just an individual rooftop. Its effect would be bigger, to connect with other green roofs, nearby green areas, and over the globe.

4.2 Limitation

This study has a limited sampling size, in which a larger one could increase the accuracy of this study. Each rooftop design approach has only one design provided for comparison. Also, except the conventional rooftop scenario is adopted from the existing site, the other scenarios all depend on designed rooftops, which designed by the investigator, Wing Chi Tam. These designs may be subjective. Even though there are 65 variables selected from 7 aspects, which are chosen by the author, and it may be personal and not being comprehensive enough. In addition, the error rate is set at 5%, which if it is set at a different rate, the result might be different.

4.3 Recommendation

For all building owners, urban planners, developers, and government, it is beneficial to appreciate spaces that we have and maximize its use. Rooftops could be retrofit, design, and adjust scenarios base on the calculation of this study, which conventional rooftops could be more advantageous if they convert to social nodes or stormwater runoff alleviation tools.

Future study is recommended to have a larger sample size and to have more samples come from reality to let this study become more comprehensive.

4.4 Conclusion

There could be many possibilities toward rooftops, which could bring many attributes to the societies and natural environment. This study focusses on comparing five rooftop design approach scenarios: conventional rooftops, self-design rooftops, extensive green roofs, semi-intensive green roofs, and extensive green roofs, with the quantitative method. The result shows that conventional rooftops are the worst ones in these five scenarios. Intensive green roofs are better than self-design rooftops. However, there are insufficient statistical results to confirm if self-design rooftops, extensive green roofs, semi-intensive green roofs, and extensive green roofs are different from each other.

BIBLIOGRAPHY

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Arnberger, A., & Eder, R. (2012). The influence of green space on community attachment of urban and suburban residents. *Urban Forestry & Urban Greening, 11(1)*, 41-49.doi:10.1016/j.ufug.2011.11.003

Bliss, D. J., Neufeld, R. D., & Ries, R. J. (2009). Storm water runoff mitigation using a green roof. *Environmental Engineering Science, 26*(2), 407-418. doi:10.1089/ees.2007.0186

Burghardt, K. T., Tallamy, D. W., Philips, C., & Shropshire, K. J. (2010). Non□native plants reduce abundance, richness, and host specialization in lepidopteran communities. *Ecosphere, 1*(5), 1-22. doi:10.1890/ES10-00032.1

Burley, J.B. 1996. Designing to preserve wildlife. *Landscape Design 9(10)*:16-23.

Burley, J.B., S. Johnson, P. Larson and B. Pecka. 1988. Big Stone granite quarry habitat design: HSI reclamation application. ASSMR Conference Proceedings, PA., 161-169.

Burley, J.B., N. Li, J. Ying, H. Tian, and S. Troost. 2016. Chapter 3: Metrics in master planning low impact development for Grand Rapids, Michigan. Egren, M.(ed.) in: Sustainable Urbanization. *Intech Rijeka, Croatia*, 61- 86.

Burley, J. B., Li, X., & He, S. (2020). Metrics Evaluating Multivariate Design Alternatives: Application of the Friedman's Two-way Analysis of Variance by Ranks: A Personal Reflection. *Whitemud Academics: Perrinton, MI, USA*, 36.

Castiglia Feitosa, R., & Wilkinson, S. (2016). Modelling green roof stormwater response for different soil depths. *Landscape and Urban Planning, 153*, 170-179.doi:10.1016/j.landurbplan.2016.05.007

Cook-Patton, S. C. 2015. *"Plant Biodiversity on Green Roofs." P.193-210. In: R. Sutton (ed.). Green roof ecology.* Springer, NewYork, NY. (ISBN 978-3-319-14982-0)

Cook-Patton, S. C., & Agrawal, A. A. (2014). Exotic plants contribute positively to biodiversity functions but reduce native seed production and arthropod richness. *Ecology, 95*(6), 1642-1650. doi:10.1890/13-0782.1

Cronk, E. (2012). *Stormwater retention capabilities of steep sloped, extensive green roof systems*. Michigan State University. Environmental Design.

Czemiel Berndtsson, J., Lund University, Avdelningen för Teknisk vattenresurslära, Lunds universitet, & Division of Water Resources Engineering. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering, 36*(4), 351-360. doi:10.1016/j.ecoleng.2009.12.014

Daniel, W. W. (1978). *Applied nonparametric statistics*. Boston: Houghton Mifflin.

Eakin, C. J. (2012). *Assessing wildlife habitat contributions of green roofs in urban landscapes in Michigan and Illinois, USA: measuring avian community response to green roof factors*. Michigan State University. Fisheries and Wildlife..

Eakin, C. J., Campa, H., Linden, D. W., Roloff, G. J., Rowe, D. B., & Westphal, J. (2015). Avian response to green roofs in urban landscapes in the midwestern USA. *Wildlife Society Bulletin, 39*(3), 574-582. doi:10.1002/wsb.566

Feng, M., J.B. Burley, T. Machemer, A. Korkmaz, M.R. Villanueva. 2018. Earthquake spatial mitigation: Wenchuan China and Los Banos, Philippines Case Studies. *GSTF Journal of Engineering Technology (JET)5(2)*: p. 10.

Feng, Mengwen, J. B. Burley, T. Machemer, and Armagan Korkmaz. 2017. Spatial mitigation treatments: Wenchuan earthquake case study. 3rd Annual International Conference on Urban Planning and Property Development (UPPD 2017). *Global Science & Technology Forum (GSFT)*, 68-75.

Forschungsgesellschaft Landschaftsentwicklung--Landschaftsbau. (2004). *Guideline for the planning, execution and upkeep of green-roof sites: Roof-greening guidelines, January 2002 edition ; with Methods to be employed when investigating vegetation substrates and aggregate-type drainage materials used at roof-greening sites, 1995 edition with supplements dated January 2002 ; and, Procedure for investigating resistance to root penetration at green-roof sites, 1999 edition with editorial changes dated January 2002*. Bonn: Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.

Getter, K. L. (2009). *Extensive green roofs: carbon sequestration potential and species evaluations*. Michigan State University. Horticulture.

Getter, K. L., Rowe, D. B., & Andresen, J. A. (2007). Quantifying the effect of slope on extensive green roof stormwater retention. *Ecological Engineering, 31*(4), 225-231. doi:10.1016/j.ecoleng.2007.06.004

Getter, K. L., Rowe, D. B., Robertson, G. P., Cregg, B. M., & Andresen, J. A. (2009). Carbon sequestration potential of extensive green roofs. *Environmental Science & Technology, 43(19),* 7564-7570. doi:10.1021/es901539x

Google Maps. (n.d.). Retrieved October 15, 2019, from https://www.google.com/maps/@43.0524912,-83.6954075,17z.

Haddad, N. M., Crutsinger, G. M., Gross, K., Haarstad, J., Knops, J. M. H., & Tilman, D. (2009). Plant species loss decreases arthropod diversity and shifts trophic structure. *Ecology Letters, 12*(10), 1029-1039. doi:10.1111/j.1461-0248.2009.01356.x

Hallsaxton, M., and J.B. Burley. 2011. Residential interior occupant health criteria review and assessment in Holland, Michigan. *International Journal of Energy and Environment, 5(5):* 704-713.

Hallsaxton, M. and J.B. Burley. 2010. Residential interior occupant health criteria in West Michigan. Panagopoulos, T., T. Noronha, and J. Beltrao, (eds.) in: Advances In UrbanRehabilitation andSustainability 3rd WSEAS International Conference on UrbanRehabilitation And Sustainability (URES '10)University of Algarve, Faro, PortugalNovember 3-5, 2010, 2010:42-48.

Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., . . . Sveriges lantbruksuniversitet. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs, 75*(1), 3-35. doi:10.1890/04-0922

Jim, C.Y. (2017). An archaeological and historical exploration of the origins of green roofs. *Urban Forestry & Urban Greening, 28,* 32-42. doi:10 1016/j.ufug.2017.06.014

Kazmierczak, A. (2013). The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning, 109(1)*, 31-44. doi:10.1016/j.landurbplan.2012.05.0076

Keefe, P.S. and J.B. Burley. 1998. Post-mining predictive visual quality assessment: a methodology. Throgmorton, D., J. Nawrot, J. Mead, J. Galetovic, and W. Joseph (eds.) In: Proceedings Fifteenth Annual Meeting American Society for Surface Mining and Reclamation: Mining--Gateway to the Future! May 17-21, 1998, St. Louis, Missouri, *The American Society for Surface Mining and Reclamation* :752-760.

Kim, K. (2004). The application of the biosphere reserve concept to urban areas: The case of green rooftops for habitat network in seoul. *Annals of the New York Academy of Sciences, 1023*(1), 187-214. doi:10.1196/annals.1319.010

Krellenberg, K., Welz, J., & Reyes-Päcke, S. (2014). Urban green areas and their potential for social interaction – A case study of a socio-economically mixed neighbourhood in Santiago de Chile. *Habitat International, 44*, 11-21. doi:10.1016/j.habitatint.2014.04.004

Krogulecki, K. S. (2014). *Effects of Green Roof Plant Selection on Enhancing Stormwater Quality Under Steep Sloped Roof Conditions*. Michigan State University. Environmental Design-Master of Arts.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. *American Journal of Community Psychology, 26(6)*, 823-851. doi:10.1023/A:1022294028903

Lin, Wan-Chu, J. B. Burley, P. Nieratko, T. Machemer. 2017. Railroad station arrival cognition: way-finding at the East Lansing train station. 3rd Annual International Conference on Urban Planning and Property Development (UPPD 2017). *Global Science & Technology Forum (GSFT)*, 91-97.

Loder, A. (2014). ‘There's a meadow outside my workplace’: A phenomenological exploration of aesthetics and green roofs in Chicago and Toronto. *Landscape and Urban Planning, 126*, 94-106. doi:10.1016/j.landurbplan.2014.01.008

Lundholm, J., Heim, A., Tran, S., & Smith, T. (2014). Leaf and life history traits predict plant growth in a green roof ecosystem. *PloS One, 9*(6), e101395. doi:10.1371/journal.pone.0101395

Lundholm, J., Macivor, J. S., Macdougall, Z., & Ranalli, M. (2010). Plant species and functional group combinations affect green roof ecosystem functions. *PloS One, 5*(3), e9677. doi:10.1371/journal.pone.0009677

Matlock, J. M. (2015). *A critical evaluation of green roof substrate components*. Michigan State University.

MacIvor, J. S., & Lundholm, J. (2011). Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate. *Ecological Engineering, 37*(3), 407-417. doi:10.1016/j.ecoleng.2010.10.004

Mentens, J., Raes, D., & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and Urban Planning, 77*(3), 217-226. doi:10.1016/j.landurbplan.2005.02.010

Mesimäki, M., Hauru, K., Kotze, D. J., & Lehvävirta, S. (2017). Neo-spaces for urban livability? urbanites’ versatile mental images of green roofs in the Helsinki metropolitan area, Finland. *Land use Policy, 61*, 587-600. doi:10.1016/j.landusepol.2016.11.021

Monsma, J. L. (2011). *A Comparison of Insect and Spider Species Presence and Composition Across Multiple Vegetated Roof Systems*. Michigan State University. Environmental Design.

Monterusso, M. A., Rowe, D. B., Rugh, C. L., & Russell, D. K. (2002, August). Runoff water quantity and quality from green roof systems. In *XXVI International Horticultural Congress: Expanding Roles for Horticulture in Improving Human Well-Being and Life Quality 639* (pp. 369-376)

Montgomery, M. (2003). United nations world urbanization prospects: The 2001 revision. *Population and Development Review, 29*(3), 530

Nagase, A., & Dunnett, N. (2010). Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity. *Landscape and Urban Planning, 97*(4), 318-327. doi:10.1016/j.landurbplan.2010.07.005

Öhrström, E. (1991). Psycho-social effects of traffic noise exposure. *Journal of Sound and Vibration, 151*(3), 513-517. doi:10.1016/0022-460X(91)90551-T

Osmundson, T. (1999). *Roof gardens: history, design, and construction*. WW Norton & Company.

Ouldboukhitine, S., Belarbi, R., & Djedjig, R. (2012). Characterization of green roof components: Measurements of thermal and hydrological properties. *Building and Environment, 56*, 78-85. doi:10.1016/j.buildenv.2012.02.024

Partridge, D. R., & Clark, J. A. (2018). Urban green roofs provide habitat for migrating and breeding birds and their arthropod prey. *PloS One, 13*(8), e0202298. doi:10.1371/journal.pone.0202298

Peck, S. W. (2008). *Award-winning green roof designs: Green roofs for healthy cities*. Atglen, PA: Schiffer Pub.

Peters, K., Elands, B., & Buijs, A. (2010). Social interactions in urban parks: Stimulating social cohesion?. *Urban Forestry & Urban Greening, 9(2)*, 93-100. doi:10.1016/j.ufug.2009.11.003

Pittaluga, I., Schenone, C., & Borelli, D. (2012). Sound absorption of different green roof systems. *Proceedings of Meetings on Acoustics, 14*(1) doi:10.1121/1.3685875

Pomeroy, J. (2012). Room at the top-the roof as an alternative habitable / social space in the Singapore context. *Journal of Urban Design, 17(3)*, 413-424. doi:10.1080/13574809.2012.666176

Rowe, D. B. (2011). Green roofs as a means of pollution abatement. *Environmental Pollution, 159*(8), 2100-2110. doi:10.1016/j.envpol.2010.10.029

Rowe, D. (2018). Green roofs: plant production and installation methods©. *Acta Horticulturae, (1212)*, 97–100. doi: 10.17660/actahortic.2018.1212.19

Rumble, H., Finch, P., & Gange, A. C. (2018). Green roof soil organisms: Anthropogenic assemblages or natural communities? *Applied Soil Ecology, 126*, 11-20. doi:10.1016/j.apsoil.2018.01.010

Saadatian, O., Saadatian, E., Sopian, K., Salleh, E., Lim, C. H., Riffat, S., . . . Sulaiman, M. Y. (2013). A review of energy aspects of green roofs. *Renewable and Sustainable Energy Reviews, 23*, 155-168. doi:10.1016/j.rser.2013.02.022

Sailor, D. J. (2008). A green roof model for building energy simulation programs. *Energy & Buildings, 40*(8), 1466-1478. doi:10.1016/j.enbuild.2008.02.001

Sanchez, L., & Reames, T. G. (2019). Cooling detroit: A socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy. Urban Forestry & Urban Greening, 44, 126331. doi:10.1016/j.ufug.2019.04.014

Schindler, B. Y., Griffith, A. B., & Jones, K. N. (2011). Factors influencing arthropod diversity on green roofs. *Cities and the Environment, 4*(1), Article 5-20 pp.

Schrader, S., & Böning, M. (2006). Soil formation on green roofs and its contribution to urban biodiversity with emphasis on collembolans. *Pedobiologia - International Journal of Soil Biology, 50*(4), 347-356. doi:10.1016/j.pedobi.2006.06.003

Schipperijn, J., Ekholm, O., Stigsdotter, U. K., Toftager, M., Bentsen, P., Kamper-Jørgensen, F., & Randrup, T. B. (2010). Factors influencing the use of green space: Results from a Danish national representative survey. *Landscape and Urban Planning, 95(3)*, 130-137. doi:10.1016/j.landurbplan.2009.12.010

Shafique, M., Kim, R., & Kyung-Ho, K (2018). Green roof for stormwater management in a highly urbanized area: The case of seoul, korea. *Sustainability, 10*(3), 584: doi:10.3390/su10030584

Snodgrass, E. C., & McIntyre, L. (2010). *The green roof manual: A professional guide to design, installation, and maintenance*. Portland: Timber Press.

Snodgrass, E. C., & Snodgrass, L. L. (2006). *Green roof plants: A resource and planting guide*. Portland, Or: Timber Press.

Spehn, E. M., Joshi, J., Schmid, B., Diemer, M., & Korner, C. (2000). Above-ground resource use increases with plant species richness in experimental grassland ecosystems. *Functional Ecology, 14*(3), 326-337. doi:10.1046/j.1365-2435.2000.00437.x

Srivastava, D. S., & Lawton, J. H. (1998). Why more productive sites have more species: An experimental test of theory using Tree□Hole communities. *The American Naturalist, 152*(4), 510-529. doi:10.1086/286187

Sutton, R. K. 2015. *"Introduction to Green Roof Ecosystems." P.1-26. In: R. Sutton (ed.). Green roof ecology.* Springer, NewYork, NY. (ISBN 978-3-319-14982-0)

Tabares-Velasco, P. C., & Srebric, J. (2011). Experimental quantification of heat and mass transfer process through vegetated roof samples in a new laboratory setup. *International Journal of Heat and Mass Transfer, 54*(25), 5149-5162. doi:10.1016/j.ijheatmasstransfer.2011.08.034

Teemusk, A., & Mander, Ü. (2007). Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events. *Ecological Engineering, 30*(3), 271-277. doi:10.1016/j.ecoleng.2007.01.009

The Sylvester Broome Empowerment Village. (n.d.). Retrieved from https://sbev.org/.

Tian, Y., & Jim, C. Y. (2011). Factors influencing the spatial pattern of sky gardens in the compact city of hong kong. Landscape and Urban Planning, 101(4), 299-309. doi:10.1016/j.landurbplan.2011.02.035

Vandegrift, D. A. (2018). *Expanding the Plant Palette for Green Roofs*. Michigan State University.

Van Renterghem, T., & Botteldooren, D. (2008). Numerical evaluation of sound propagating over green roofs. *Journal of Sound and Vibration, 317*(3), 781-799. doi:10.1016/j.jsv.2008.03.025

Van Renterghem, T., & Botteldooren, D. (2009). Reducing the acoustical façade load from road traffic with green roofs. *Building and Environment, 44*(5), 1081-1087. doi:10.1016/j.buildenv.2008.07.013

Wang, M. R. Q. Hyde, J.B. Burley, A. Allen, and T. Machemer. 2015. Low-impact housing: River Rouge, Michigan. *Housing and Society*: 1-14.

Wang, Y. J. B. Burley, and S. Partin. 2013. Case study: post-mining and lands-use planning and design: an overview. *Journal of Mining Reclamation 2(1):*114-135.

Washburn, B. E., Swearingin, R. M., Pullins, C. K., & Rice, M. E. (2016). Composition and diversity of avian communities using a new urban habitat: Green roofs. *Environmental Management, 57*(6), 1230-1239. doi:10.1007/s00267-016-0687-1

Weiler, S. K., & Scholz-Barth, K. (2009). *Green roof systems: A guide to the planning, design, and construction of landscapes over structure*. Hoboken, N.J: John Wiley & Sons.

Whittinghill, L. J. (2012). *Vegetable production using green roof technology and the potential impacts on the benefits provided by conventional green roofs*. Michigan State University. Horticulture.

Whittinghill, L. J., & Rowe, D. B. (2012). The role of green roof technology in urban agriculture. *Renewable Agriculture and Food Systems, 27*(4), 1-9. doi:10.1017/S174217051100038X

Whittinghill, L. J., Rowe, D. B., Andresen, J. A., & Cregg, B. M. (2015). Comparison of stormwater runoff from sedum, native prairie, and vegetable producing green roofs. *Urban Ecosystems, 18*(1), 13-29. doi:http://dx.doi.org.proxy2.cl.msu.edu/10.1007/s11252-014-0386-8

Whittinghill, L. J., Rowe, D. B., Schutzki, R., & Cregg, B. M. (2014). Quantifying carbon sequestration of various green roof and ornamental landscape systems. *Landscape and Urban Planning, 123*, 41-48. doi:10.1016/j.landurbplan.2013.11.015

Wilsey, B. J., Teaschner, T. B., Daneshgar, P. P., Isbell, F. I., & Polley, H. W. (2009). Biodiversity maintenance mechanisms differ between native and novel exotic□ dominated communities. *Ecology Letters, 12*(5), 432-442. doi:10.1111/j.1461-0248.2009.01298.x

Yachi, S., & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Sciences of the United States of America, 96*(4), 1463-1468. doi:10.1073/pnas.96.4.1463