Vertical Gardening in a Northern City; Speculations for Winnipeg

By Tamara Urben-Imbeault

A Practicum submitted to The Faculty of Graduate Studies
of the University of Manitoba, in partial fulfilment of the
requirements of the degree of

Master of Landscape Architecture

Department of Landscape Architecture
Faculty of Architecture,
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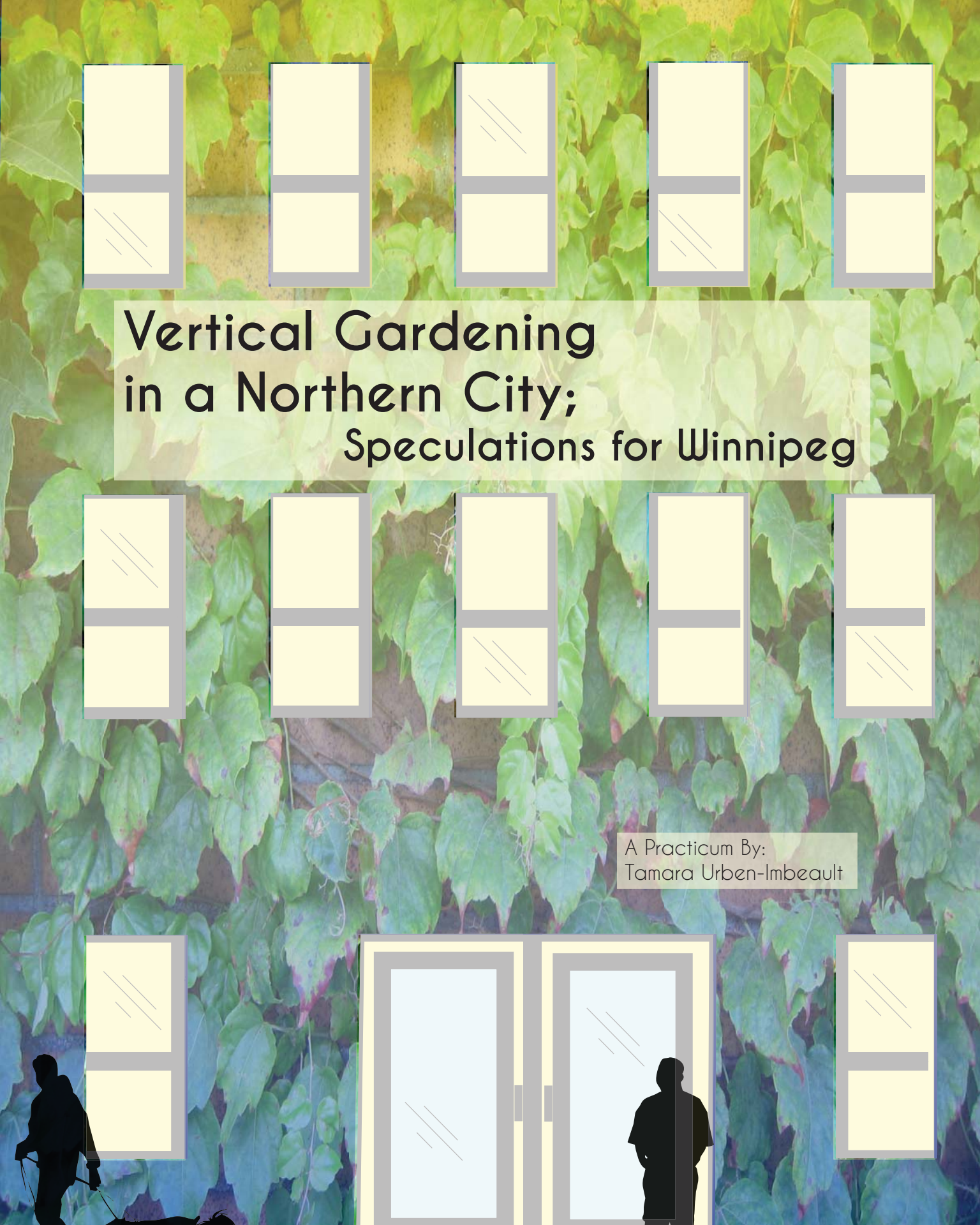

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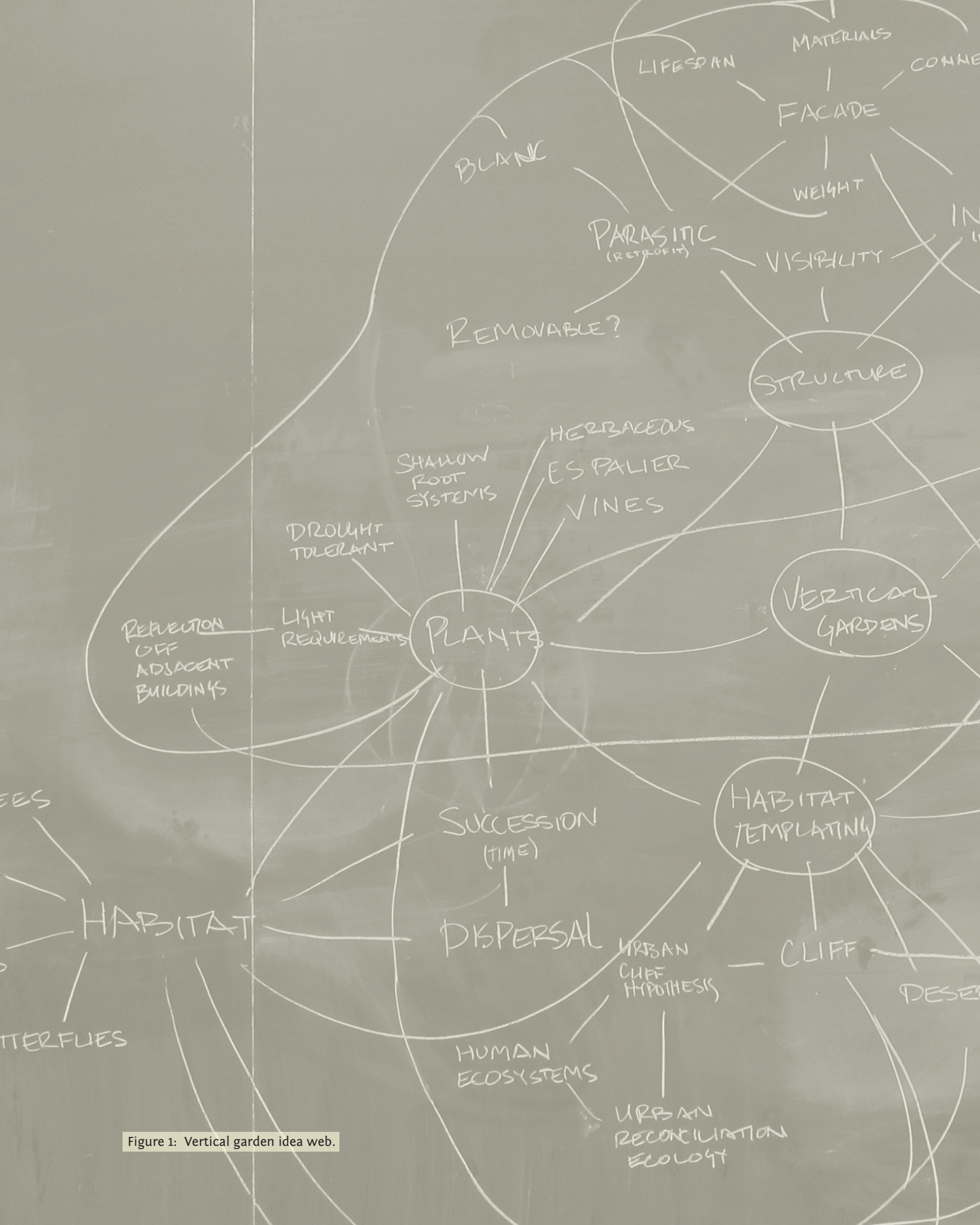
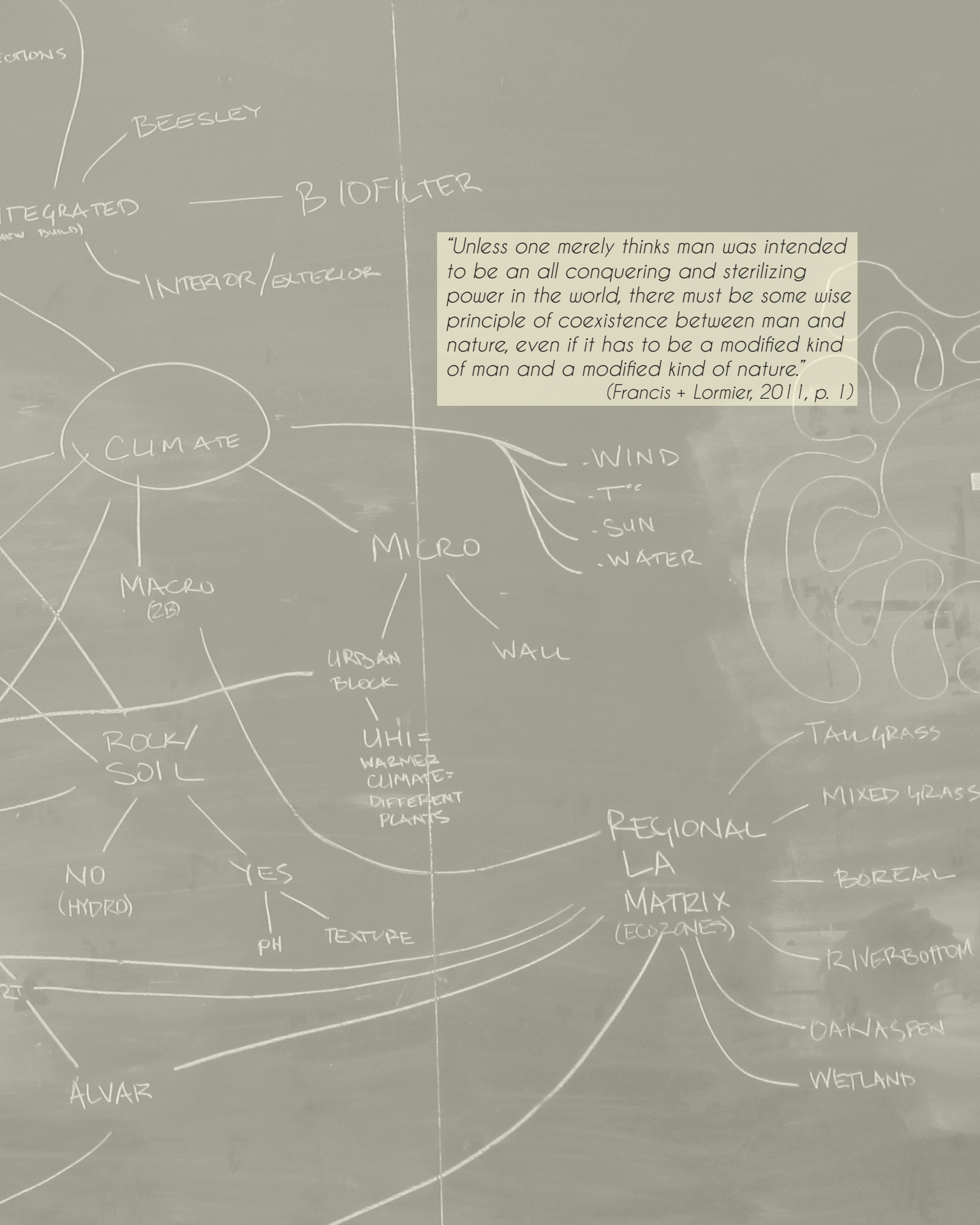


Figure 1: Vertical garden idea web.



"Unless one merely thinks man was intended to be an all conquering and sterilizing power in the world, there must be some wise principle of coexistence between man and nature, even if it has to be a modified kind of man and a modified kind of nature."

(Francis + Lormier, 2011, p. 1)

CONTENTS

Figure 2: Garden design at City Place.

ABSTRACT

This practicum is a reference for vertical gardeners in cold climates. Winnipeg, Manitoba is explored, however findings may be applied to other cities in similar climates. First, the history of vertical gardening is discussed, then the types of vertical gardens currently on the market are described. These can be classified into two categories: soil bearing or non-soil bearing. Most designs are modular pre-planted systems that can be attached to any wall, as long as it satisfies the structural requirements recommended by the manufacturer. The benefits of vertical gardening have been shown to be rather extensive, covering a wide range of areas. Aesthetic improvement, reduction of the Urban Heat Island (UHI) effect, improvement of air quality, stormwater absorption, noise reduction, native habitat integration, reduction of heating and cooling costs for buildings, food production, marketing, and biophilia are all benefits explored in detail. Difficulties associated with vertical gardening are discussed, specifically the lack of knowledge and awareness of vertical gardens, lack of empirical evidence (or missing details in existing research), overall cost and lack of financial incentives, lack of industry codes, and various associated risks. Design framework exists within microclimate conditions unique to vertical gardens, as well as neighbourhood and regional (micro) climates. Theories relating to the study of green walls covered include the human ecosystem model, urban reconciliation ecology, habitat templating, the urban cliff hypothesis, and wall ecology. Suitable habitat templates identified for vertical gardens in Winnipeg are cliffs, sand dunes, alvars, mixed grass prairie and prairie potholes. Design parameters to be followed for vertical garden design in Winnipeg are to ensure that lightweight materials are used, to provide insulation to protect plants from sudden temperature changes, to choose plants that grow in the region and are adapted to grow in areas with limited soil, increased wind, varying degrees of sunlight (depending on orientation), and increased pollution and salt spray depending on location.

ACKNOWLEDGEMENTS

Thank you to everyone who has helped ensure this document made it to reality. To the chair of my committee, Anna Thurmayr for pushing me to consider all options, and for lending a critical eye to my design process. To my internal advisor, Brenda Brown, whose comprehensive editing and sound advice has made this document much better than I could have ever imagined. To my external advisor, Maria Zbigniewicz, who taught me almost everything I know about native plant communities, and who was always available to encourage me when I needed it the most.

Thanks to my makers, Brigitta and Michel. Without you life as I know it wouldn't exist.

Thanks to my friends, both in faculty and out, who understood when I would disappear for months at a time to work on this project, and were always ready with a cold one when I needed to drown my sorrows. To those in faculty, an especially big thank you for your thoughtful critiques and discussion. You continue to be great sources of inspiration - James, Shawn, Lia and Chris, Becca, Amy, Tove, and Fernando.

Thank you to the Faculty Of Architecture for giving me the opportunity to teach, explore and learn way more than what was on the curriculum. Thank you for making me think, and also thank you for paying my rent.

Thank you to those who donated their time, information and copyright releases: Susan at True North Entertainment Ltd., Patty at CentreVenture, and Gail at Number Ten Architecture.

Thank you to Patrick Blanc, Brad Bass and Alan Darlington, whose work inspired me to pursue my interest in vertical gardening.

And finally, to everyone who has told me throughout my life that I should give up and do something else, this is for you. Suck it, you monsters.

DEDICATION

For vertical garden enthusiasts everywhere.

PREFACE

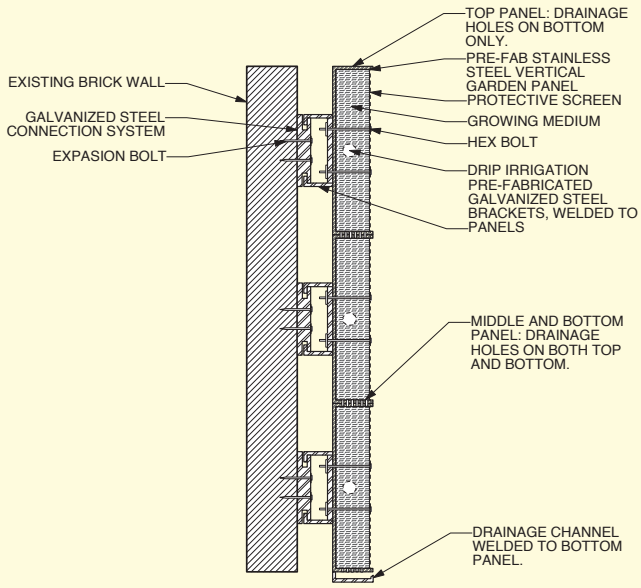
Throughout my graduate studies, I have consistently been interested in how to integrate ecological systems into functioning urban spaces. How can the city of tomorrow take plant communities and adapt them, bend them and twist them so that the city can be more responsive and integrated into its regional context? How can leftover urban spaces become indicators of their bioregions? How can we reconnect people to nature without tearing down existing successful infrastructure? These are all questions I have tried to respond to throughout my graduate studies. In each of my projects I have incorporated native vegetation into a functional economic milieu. In my first graduate studio with professor Brenda Brown I designed a stormwater retention system that was integrated into a parking lot. In my second graduate studio with professor Richard Perron, I looked at how ecological and economic infrastructure in the form of an inter-modal port could co-exist within a regionally sensitive planting pallet. In my final graduate studio with professor Alan Tate, my design was a sculpture park in which a recreation of a local disappearing plant community was the second main attraction (after the art, of course). Looking back, it now only seems natural that this theme would follow me into my practicum.

I began this project hoping to learn and gather as much knowledge as possible on the subject of vertical gardening. From the first moment I saw Patrick Blanc's now famous vertical garden at the Musée Du Quay Branley, I was intrigued. I can't quite explain the attraction that I first felt to the garden. Perhaps it was just the fact that I hadn't really seen a vertical garden of that kind before. Perhaps it was the lusciousness of the garden. Maybe the variety of textures and colours. Perhaps it was subconscious, or instinctual. Maybe looking at this garden somehow brought me back to my childhood, when I used to play on the riverbank behind my house, building mud houses for my Lego people and bending grasses and willow branches for roofs. Maybe looking at it triggered a physiological release of melatonin. Perhaps in my subconscious I was reminded of the pre-settlement ancestral way of life, when a luscious green landscape would have meant that food was nearby, that

I could hide easily from predators, and be sheltered from the elements. Maybe I simply thought it was something 'cool' that I hadn't seen before. Or maybe the true attraction was that I recognized that this project was an example of the integration of the so-called "natural world" with architecture.

When I started my undergraduate degree I was most interested in the intersection between landscape and architecture. This beautiful plant community growing up the side of a building seemed to be a very poetic and powerful way to combine the two fields. It captured my imagination and I started to daydream about the possibilities it held. Since entering the Department of Landscape Architecture at the University of Manitoba, I have been consistently intrigued by how landscapes can enrich cities. During my undergrad, projects were undertaken at an architectural scale, and in graduate school I made the leap to a larger scale. I wanted to make large scale regionally sensitive designs; be it in a Formanian patch/corridor sense, or enriching cities via landscape design to make them more beautiful.

This beauty is created seemingly effortlessly in vertical gardens. Panel style vertical gardens thus far have not been developed to survive outside in cold weather climates. The coldest panel style outdoor vertical garden is in USDA zone 6B (PNC Bank Green Wall, Pittsburgh). This is a large sector of the market that is missing out on these incredible vertical landscapes. I feel that vertical gardening for cold weather climates is something that needs to be explored further, so this practicum is a journey of speculation on vertical garden design in Winnipeg. Ultimately, I hope to provide reference for future vertical garden enthusiasts in cold climates who will continue to explore this topic, in research and construction.



5 / L-6 VERTICAL GARDEN SECTION
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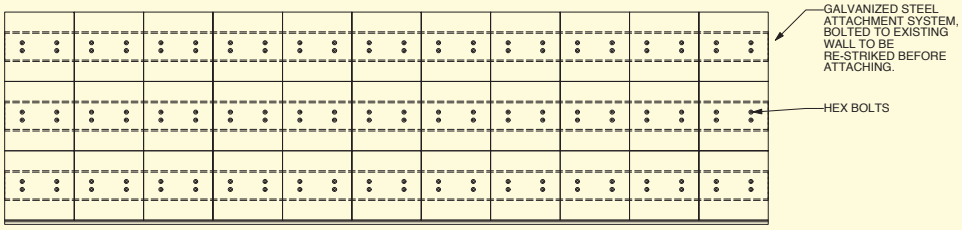

3 / L-6 VERTICAL GARDEN ATTACHMENT SYSTEM (TO WALL)
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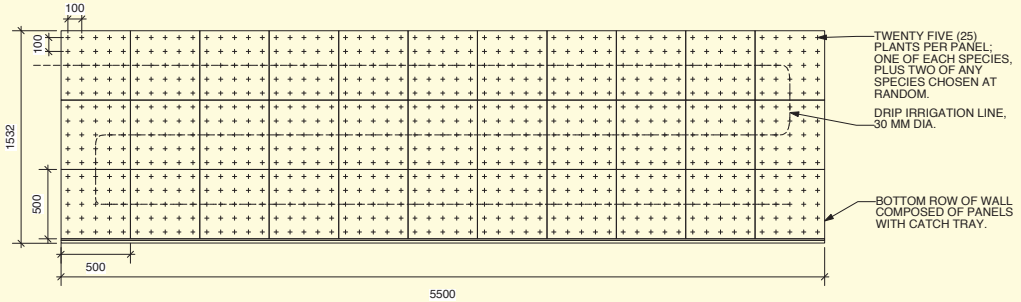

4 / L-6 VERTICAL GARDEN PLANTING AND IRRIGATION
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Figures 3, 4: Design drawings for modular hydroponic vertical garden, made for LA Studio 7.

EXPERIMENTS REVISITED

A few vertical gardens were designed and built before starting this practicum. My first vertical garden system, designed in my final graduate studio in 2012, is a modular hydroponic garden which I enlisted Shape Industries to manufacture. For the reading course in 2013, I made my own DIY-style (Do-It-Yourself) vertical gardens made from recycled drawers. Both projects taught me a lot about designing and building vertical gardens, so I will discuss the outcomes here.

The module made for my last studio was a large square metal element that slid into a frame that held it to the wall. It was to be a hydroponic garden in a park I designed for the studio in Victoria, BC. The end result was bulky, cumbersome, and very heavy. At that stage in my research, I didn't fully understand the system I was designing, so mistakes were made. I now know it could have been much more narrow, and much lighter, given that it was a felt hydroponic system and was located in Victoria - a much warmer climate than Winnipeg. During the manufacturing process, I had a series of discussions with the manufacturers. They made various recommendations about the back portion of the element where it was to connect to the framing support structure. We worked together to simplify the design, however looking back now I can see that we could have easily eliminated much more material and simplified the design even more.

My next vertical garden build resulted from a self-directed reading course intended as the base of knowledge for this practicum. The reading course provided me the platform and inspiration that I needed to build a couple of my own (again, overly complex and cumbersome) vertical garden systems, which all failed in one way or another. Some used a combination of rockwool and soil which was intended to lighten their weight (in that aspect they were successful) but the rockwool dried out too quickly. Rockwool is essentially a sponge, and is usually used only in hydroponic applications where a constant stream of water flows through it. When the rockwool became dry (always much faster than the soil), it soaked up all remaining moisture, drying out the entire system.

Figures 5, 6, 7, 8: DIY vertical garden experiments with recycled drawers, and various growth media.

Even with the use of the rockwool, the planters were heavy and cumbersome; they had too much soil, and not enough structural integrity. I used recycled wooden drawers from a chest of drawers, but they didn't hold together longer than two growing seasons. With only a couple of nails and staples holding them together, the combined weight of the moistened soil and plants was too much to remain intact beyond a couple seasons.

The irrigation design I built made sense to me on paper, but in reality it didn't work the way I had planned, partially because the tubing I had bought was too rigid to bend and curve the way I had planned. Perforated plastic tubes were intended to zig zag through the growing medium, but instead spiraled in a way that made the whole system redundant. The idea was that a bottle would be attached to the opening of the tube, which once filled with water, would trickle through the whole garden. Due to a combination of the hoses being twisted in the wrong direction (in a way that gravity would not facilitate the flow of water) and the size of the perforations being too large, the irrigation system failed quite catastrophically. The gardens, in the end, had to be watered through the front holes that the plants grew through.

Regular store-bought potting soil was used, in rather large amounts, and watering was plentiful, so the plants (strawberries, nasturtiums, and chives) did not die. In this case, the fact that the plants lived is not a good indicator of the success of the design. The environment created for the plants was very similar to a standard potted plant, but in a vertical orientation. Soil was plentiful, water was provided when needed, and solar orientation was carefully considered for each type of plant.

I quickly realised after completing the course that there was a lot more information available than what I had collected, with new projects, research and guides popping up regularly. The final output for the reading course remains as a very good introduction to the world of vertical gardening, and the beginning of my own personal speculation of vertical gardens in Winnipeg. I have since uploaded it to the internet (see http://issuu.com/tamara.urben-imbeault/vertical_garden_sept_25_d). I often receive notices that someone has added the document to their personal digital collection. I can only hope people are referencing it and learning from it as much as I did.

These experiments were a good preliminary foray into the world of vertical gardening, but now I realise many improvements are necessary for them to work properly, and to survive more than a few growing seasons. The practicum work expands on what was learned in these experiments, good, bad, and ugly.

1. INTRODUCTION

This practicum is a speculative work of vertical garden design in a northern city. There are many different types of vertical gardens, ranging from vines, to espaliered trees, to complex hydroponic or soil bearing walls. Vertical gardens are an excellent way to grow plants in places that have limited floor areas, such as high density city centres or apartment blocks. A vertical garden requires a relatively small footprint to grow, and can be installed on underutilised walls. Vertical gardens have many associated benefits including aesthetic improvement, reduction of the Urban Heat Island (UHI), improvement of air quality, stormwater absorption, noise reduction, native habitat integration, reduction of heating and cooling costs for buildings, food production and biophilia. Although these benefits are extensive, there are still many uncertainties associated with vertical gardens; most reflect the need for further scientific study in different climates. Some of the difficulties of vertical gardening include the lack of knowledge and awareness of designers contractors and the general public, lack of empirical evidence, overall cost, lack of incentives, lack of industry standards and codes and various other associated risks. Most of these factors will be minimised as vertical gardening gains in popularity however for the time being these hurdles remain.

Vertical gardens are subjected to a complex assemblage of regional climatic influences, neighbourhood microclimates and the microclimates of walls themselves. Vertical gardens are high stress environments for plants, with limited soil, increased solar exposure, and increased wind. Each of these things can lead to dead plants, which can be unsightly and costly to replace. Understanding reconciliation ecology and habitat templating can help designers design more site sensitive vertical gardens, and hopefully minimize plant death.

Vertical gardens can enrich the landscape matrix of downtown Winnipeg, and create regional habitat links through the city without compromising societal uses. By using the human ecosystems model and urban reconciliation ecology as design framework we can draw inspiration from these principles

and use them as precedents. Planting species from Manitoban plant communities will enrich the regional habitat for species of animals, and various invertebrates including butterflies, birds and bees.

Using the habitat templating approach, plants were selected for their hardiness and tolerance of similar conditions to those existing on a wall. It was important to include native plants from disappearing or rare plant communities in Manitoba, to maintain regional connections.

This document is a preliminary speculation on vertical gardening in Winnipeg, Manitoba. It is not an authoritative guide, but rather a brief introduction to elements concerning the design and influences of vertical gardening. It is a beginning foray into the world of vertical gardening in northern cities. It is hoped that this document will inspire others to continue research and vertical garden related design. It is intended to be a learning tool, and a source of further information that vertical gardening enthusiasts can consult if they desire detailed instruction of elements to be considered.

2. A SHORT HISTORY OF VERTICAL GARDENING

Vertical gardens have been planted for thousands of years. Originally, vertical gardens were mostly composed of vine species and were grown to produce food such as grapes. They were planted in cities as far back as the 10th Century B.C.E.

Figure 2.00: Grape Vines provide shade and fruits on a Greek restaurant patio on Ellice Avenue in Winnipeg.

Common species of vines were often planted on civic buildings, and in some cases remain there still. Vertical garden design and popularity have evolved considerably since the 1990's, and continued refinement and innovation continues. Today, the most popular (but not most common) vertical gardens are hydroponic, hosting various kinds of plants (not necessarily vines) designed for both indoor and outdoor installations.

The Green Roofs For Healthy Cities' (GRHC) *Green Walls 101 Participant's Manual* (2010) gives a very brief overview of the history of vertical gardening, represented visually in figure 2.03. The first documented vertical gardens were planted throughout the Mediterranean from the 10th to 6th centuries B.C.E., Grapevines (*Vitis* spp.) were commonplace in residential architecture. In Pompeii, shopkeepers planted vines on their upstairs balconies (Peck, Callaghan, Bass, and Kuhn, 1999, p. 11). Climbing roses (*Rosa* spp.) also later also became popular, and were often used to denote the entrance to a secret garden (GRHC, 2010). Grapes had an important place in society, demonstrated by remaining

Figure 2.02: Vinalia, the Roman wine harvest festival was celebrated when grapes were harvested in ancient Greece.

mosaics of the Roman Festival of Vine Harvest. An example of one of these mosaics can be seen in figure 2.02.

The best known example of a vertical garden was located in modern day Iraq in 600 B.C.E. and is commonly referred to as the Hanging Gardens of Babylon. Though researchers are not sure what the gardens looked like, they hosted a variety of fruit bearing plants, including grapevines (PBS, 2014).

Peck et al. (1999) present a timeline of vertical gardens in different parts of the world before the 1800's in their article *Greenbacks from Green Roofs*. They explain that vertical gardening started in different parts of the world at different times: Renaissance-era Genoa, pre-Columbian Mexico, 13th Century India, 16th and 17th Century Spain, 17th Century Russia and 18th Century France (p. 11).

Though there were vertical gardens growing around the world already, their widespread distribution in North America and Britain can be mostly attributed to the Garden City Movement in the late 1800's. Vines were first planted in North America during the Arts and Crafts Movement, which spanned the late 1800's to early 1900's (Dunnet and Kingsbury, 2004, p. 129). Dunnet and Kingsbury (2004) explain that the popularity of façade greening has declined since the 1930's, and the development of new technologies is part of a revival movement (p. 129). In the 1960's, terraced green roof technologies were developed in many countries, particularly in Switzerland and Germany (Peck et al., 1999, p. 12), and research in those countries has continued throughout the last 50 years.

In the 1980's, German communities began implementing bylaws that mandated the use of vertical gardens for new developments. For example in Kassel in 1993, a campaign was launched that encouraged citizens to grow climbing plants for their psychological and physical benefits (Peck et al., 1999, p. 32). Munich, Berlin, and Frankfurt have similar campaigns (p. 32). Germany has since commissioned a comprehensive guide to vertical gardening, as a part of their *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau* (FLL) guideline, which roughly translates to "*The Society of Landscape Development and Implementation*." It outlines codes and methods of application and maintenance of landscape elements such as green roofs. The vertical garden section is sold separately, and is known as *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau Richtlimie für die Planning, Ausführung und Pflege von Fassadenbegrünungen* (2000). The vertical garden guide gives an overview of climbing plants suited to the German climate.

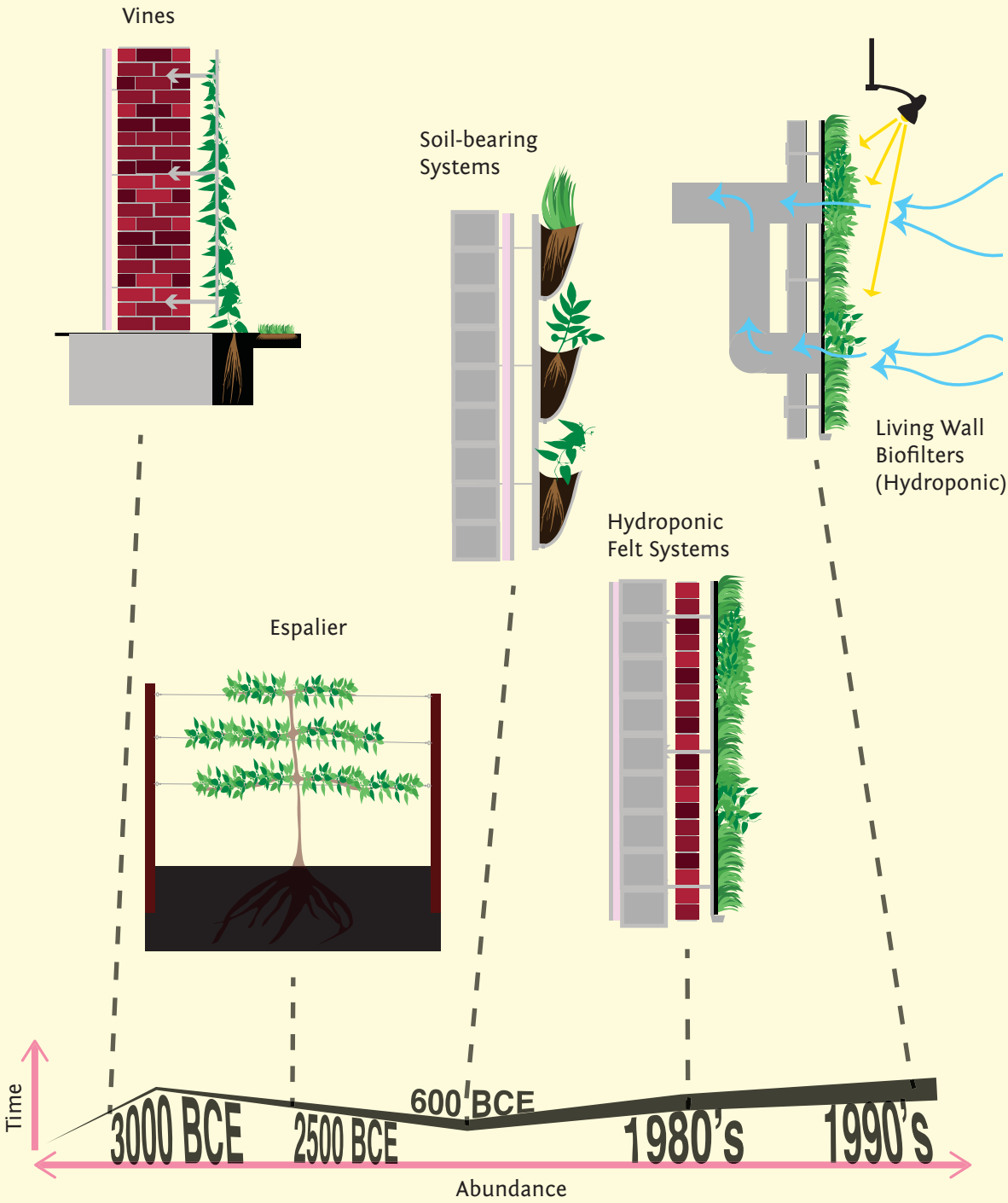


Figure 2.03: Recent resurges in the popularity of vertical gardening have spurred many new innovations in the field.

Currently, it is only available in German, it is unknown if translations are planned.

Dr. Manfred Köhler, a professor of Landscape Ecology at Hochschule Neubrandenburg University of Applied Sciences (in Neubrandenburg, Germany), holds the authoritative voice in vertical garden research and has been involved in committees and research studies both in Europe and in North America since the late 1980's. Since his 1987 doctoral thesis entitled *Experimentelle Untersuchungen zur Funktion von Fassadenbegrünungen* (roughly translated is *Experimental Investigations of the Role of Green Facades*) he has continued to publish scientific studies. His research focus is the measurable effects of green walls on buildings and thermal impact on urban environments as well as decreasing costs associated with the heating and cooling of buildings.

Another influential person in the world of vertical gardening today began his first vertical garden experiments in the 1980's. French botanist Patrick Blanc was inspired by trips to Malaysia where he studied cliff faces and rocky outcrops. Upon returning home to Paris, he hypothesized that he could recreate the luscious cliff faces he had seen in a controlled hydroponic garden in his house (Blanc, 2008, p. 8). His beginnings were very modest: a small closed loop system in which he experimented with a hydroponic wall irrigated with water pumped from a fish tank directly below the wall. The fish provided the plants with vital nutrients, and in turn the plants filtered out chemical elements harmful to the fish (p. 8-9). After many years of experimenting with materials and species of plants and fish, Blanc filed for the first patent of his *mur vegetal* in 1988. In the late 1990's and early 2000's Blanc's work started to gain international recognition, due to the success of his vertical gardens at Chaumont-Sur-Loire in 1994, Pershing Hall Hotel in 2001 and the Musée Du Quay Branley in 2005 (see figure 2.04). The year 2005 was a good one for Blanc. In addition to the opening of the Musée Branley, his *mur vegetal* was named # 31 of *Time Magazine*'s 50 *Most Influential Inventions of the Year*. This propelled him to stardom, and gave him the opportunity to create many other projects on building facades worldwide (Blanc, n.d. a).

In the 1990's then-student Alan Darlington of the University of Guelph-Humber began experimenting with a similar system to that of the *mur vegetal*, but used to filter indoor air. The work began as a project for NASA's *Advanced Life Support Program* where the goal was to "develop technologies that will significantly reduce the resupply of consumables and increase self-sufficiency" (NASA, 2008). Their experimentation started in an academic setting and gradually evolved into a professional company called Nedlaw™. Their systems are hydroponic, and use similar plants to the *mur vegetal* (tropical species) and are commonly referred to as "living wall biofilters". They are available commercially across Canada, with the company's main offices located in Breslau, Ontario.

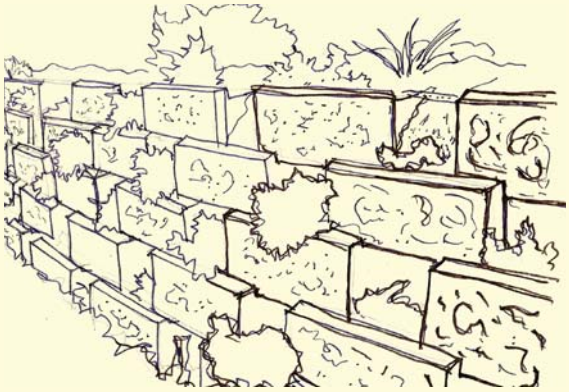
The evolution of vertical gardening has continued through the early part of the 21st century. Due to recent development in growing technologies, a variety of vertical garden design companies have started around the world. In 2001, Tokyo implemented a green wall and roof ordinance (GRHC, 2010) which stimulated incarnations of

Figure 2.04: Vertical garden by Patrick Blanc, Paris.

similar legislation in Victoria, Sydney and Melbourne, Australia; Seattle, Washington; and Portland, Oregon. An ordinance, or law, is an authoritative decree from a municipal government, usually mandated by the city government. Various studies continue on vertical gardening today, and new developments and legislation are being slowly implemented. There has also been a surge in the popularity of residential green walls, with many people building their own hydroponic or soil based systems.

Conclusion

Vertical gardening has come a long way since the Romans first cultivated grapevines in the 10th century B.C.E. From widespread use of ivy and other climbing plants in Europe and North America, to highly complex hydroponic systems first developed in the 1990's, vertical gardening continues to evolve with new technologies still being researched and developed globally. The latest innovation available on the market in Canada is the living wall biofilter which has gained momentum in the 2000s and 2010s. The future of vertical gardening is uncertain, however with legislation and more robust incentives, the potential for further innovation is great.



Clockwise from the top right: Figure 3.01: Vines growing at the University of Manitoba. Figure 3.02: Versa Green® retaining wall system. Figure 3.04: Soil based panel system in Victoria. Figure 3.05 Felt hydroponic garden in Toronto. Figure 3.06: Felt biofilter in Toronto.

3. TYPES OF VERTICAL GARDENS

Vertical gardens are referred to by a variety of names: “green walls”, “living walls,” and “plant walls” are the most common. Some people see each of these names as a different entity, but they will be used herein interchangeably. The concept of a green wall is simple, but the execution is complex. Vertical gardens can be classified into two distinct categories: soil bearing and soil-free systems. The following is a list of the most common types of vertical gardens:

- **Vines or climbing plants** (soil based) are typically planted in planters on grade and trained to grow along trellises up to 10m high, though they will occasionally grow up to 20m high, or higher if elevated containers are employed (Loh & Stav, 2008, p. 16).

- **Retaining wall planters** (soil based) are a type of retaining wall that is made from modular units (often pre-cast concrete) which has an open volume within each unit to contain soil and plants (GRHC, 2010).

- P**anel systems** (soil based) are an assemblage of pre-planted soil-bearing panels that are transported to the site and inserted into structural and mechanical watering systems in situ (Loh and Stav, 2008, p. 6).

- **Felt systems** (soil free) are made of a thin layer of felt attached to a structural system. Pre-grown plants are washed site, and fitted into slits between layers of felt. Panels and felt layers are kept continually moist by a circulating mixture of water and plant nutrients, a method known as hydroponic growing (Loh and Stav, 2008, p. 6).

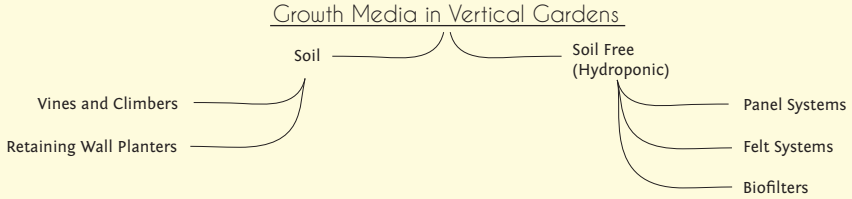
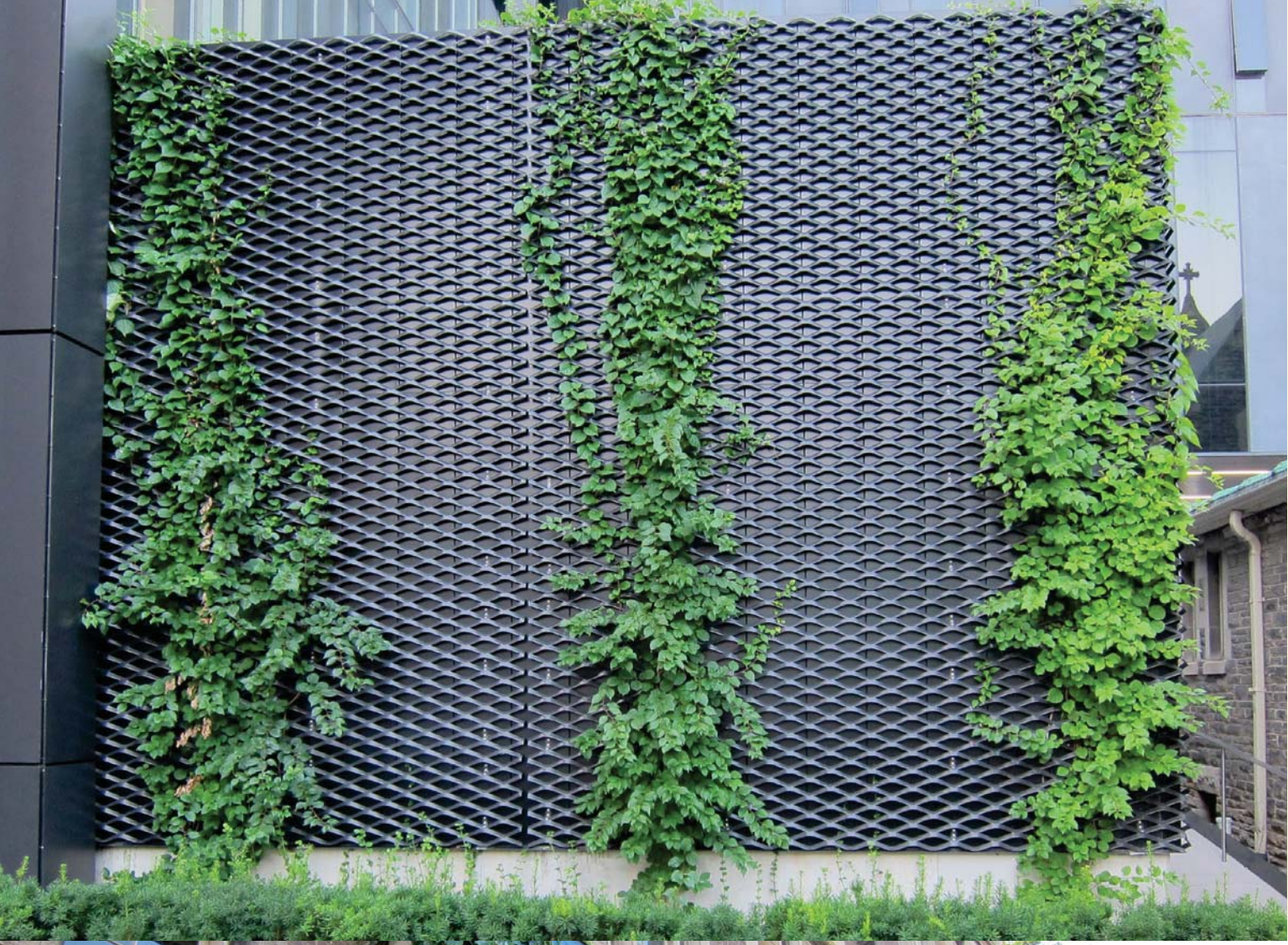


Figure 3.07: Types of vertical gardens vary mostly due to the kind of media they grow in.



Figures 3.08 and 3.09: Vines at the University of Toronto.

- **Living wall biofilters** (soil free) are essentially the same as felt systems described above, but intended for interior air filtering applications. These can be integrated into HVAC systems of a buildings (which pulls air through the roots of the plants).

Each of these different types of vertical gardens can be installed inside or outside, depending on the climate and types of plants specified in the design. For outdoor green walls, soil bearing systems are often less expensive and more resilient to colder temperatures than felt systems. This means that in colder places outdoor gardens will usually be soil systems, while felt systems are usually reserved for more temperate climates. Vines can be found from cold to tropical climates due to their diversity.

Larger scale outdoor systems require consultation with landscape design, engineering, botany and horticulture professionals for the system design itself, as well as for installation and plant selection. It is necessary to ensure that the load/shear capacity of the chosen wall can handle the added load of the garden
(State of Victoria through the Department of Environment and Primary Industries, 2014, p.14). Plants must be carefully selected due to variables in microclimate and hardiness.

The following spreads provide further details of each type of vertical garden.

3.1 Soil Bearing Systems

Vines and Climbing Plants

There are two categories of climbing plants; self-clinging and support climbers. Self-clinging climbers can attach themselves to a surface by either clinging rootlets or creepers. Support climbers require external structures. Some have tendrils that wrap around the structures, while others twist their main stem around it. Scramblers need a trellis to grow on, but they do not wrap around it.
The most common vine species in Manitoba, Virginia Creeper, is a species with tendrils, which allows it to grow on a large variety of surfaces. It will even grow on/ over a window if left untrimmed, winding its tendrils around anything it can get a grip on.

The most commonly used vine structures are modular trellis panels- such as Greenscreen®- and wire/rope and cable net systems- such as Carl Stahl® and Jakob® systems- (GRHC,

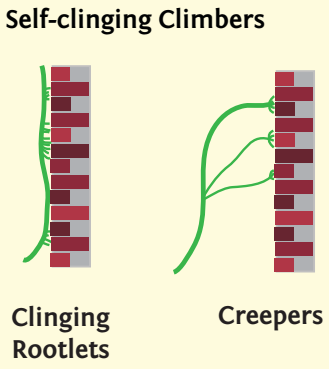


Figure 3.10: Self-Clinging Climbers

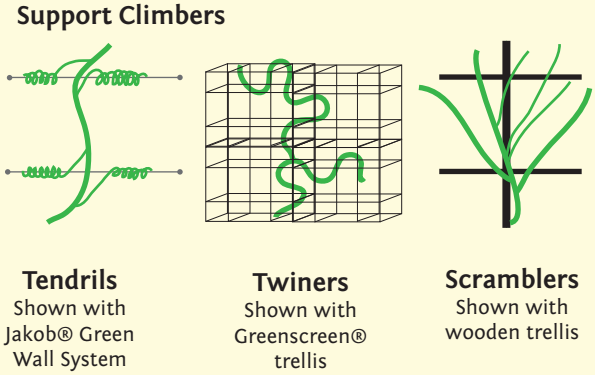


Figure 3.11: Support Climbers

Clockwise from the right: Figure 3.12 ARTLab steel trellis, 3.13 Vines squeeze between a building and a sidewalk in Costa Rica, 3.14: Close up of Virginia creeper growing on the ARTLab trellis, 3.15: Dead vines still cling to a brutalist structure at the University of Toronto, 3.16: Close up of different vines growing on a brick masonry wall at the University of Toronto.

2010). The selection of each of these systems must be based on the type of vine that will be planted there, as vines with differing growth habits will require different support. Figures 3.10 and 3.11 show vine characteristics and the corresponding support system required. Self clinging climbers do not necessarily require a trellis if the wall they are growing on is impervious to rootlets. Other climbers that require support may need both horizontal and vertical support (scramblers and twiners) while others may require either one or the other (plants with tendrils).

The distance at which the trellis is placed from the wall varies based on the type of plant to be grown. A good rule of thumb suggested by The GRHC (2010) is that the distance from the wall should be at least 1" (2.5cm) wider than the diameter of the thickest stem (p. 45). Clematis (a thin stemmed plant), for example would require approximately 4" (10cm) between the trellis and the wall, and Wisteria (a woody plant) may require up to 8" (20cm). The distance at the University of Manitoba shown in figure 3.12 was likely based on the aesthetic preference from the designer, as the vines would probably only require a 2" (5.1 cm) distance from the wall. It is important to note that a mature vine (if desired to grow to its maximum height) will require as much root space as a mature tree, and a planter bed with a width of 5' (1.52 m) and a depth of 18-24" (45-60 cm) deep is recommended (p. 48). In the case of the University of Manitoba because of the proximity of the sidewalk to the facade (about a 1' (30.5cm) distance), the trellis may have been pushed further away due to aesthetics, but also allows the roots more protected growing space.

Careful plant selection is critical to establish a thick and luscious vine wall. Vine species must be selected for the regional climate and wall microclimate. Light requirements, size, weight, growth pattern and rate, seasonal interest, maximum height and soil compatibility should be considered. Epiphytic plants can easily grow in vertical gardens, as they do not require soil to grow. Some of these plants are parasitic, while others are self-sufficient. These are most common in locations where annual temperatures do not dip below 10°C.

Maintenance is often overlooked, but is one of the most important aspects to maintaining a landscape in general, and is especially important with a green wall. Beyond the 12-24 month establishment period, some trellis systems need to be adjusted over time to maintain tension as vines grow. Vines will need to be trimmed along windows or significant architectural features, and be monitored over time to ensure they are growing as planned (and not into the building, for example).

Many building facades around the world are covered with vines. This type of vertical gardening is often seen on residential buildings and older civic or institutional buildings. The University of Toronto campus is a good example of this phenomenon. Various buildings of different ages are covered with English Ivy, *Hedera helix*; Virginia Creeper, *Parthenocissus quinquefolia*; and Grapevines (see figures 3.15 and 3.16). It is unknown whether these were planted specifically for the known benefits of vertical gardening (to be explored in the next chapter), or for strictly aesthetic reasons. The

Above: Figure 3.17 Espaliered tree.

Below: Figures 3.18 and 3.19: Two examples of soil bearing panel gardens. Figure 3.18 is a DIY style garden made from recycled materials. Figure 3.19 is a commercially available system that can be bought pre-planted or plant-free.

University of Manitoba has a few buildings covered in ivy as well, though Virginia creeper is the only species used outside of a few feature *Clematis* spp. that grow on the Agriculture building. The decreased diversity compared to the University of Toronto, is likely due to climatic restrictions and related to the desired amount of wall coverage. There are other vines that would grow on the University of Manitoba campus, but most of them would not grow as vigorously as the Virginia Creeper. The University of Manitoba's ARTLab is the most unusual vine-oriented design on campus (see figures 3.12 and 3.16). It is comprised of a specially-designed trellis system that allows the vines to grow approximately one foot away from the building facade. This allows for maximum thermal and environmental protection benefit for the building, while simultaneously ensuring that it remains undisturbed by the plants sometimes destructive tendrils.

Espalier Trained Trees

Espalier is a growth-training method developed as far back as 2500 B.C.E. and is mostly used on fruit bearing trees (commonly apple and pear). Espaliered trees are trained to grow in specific geometric patterns or shapes. Often this is done through the use of a support or trellis system that will hold the tree as it grows into the desired position. There are dozens of patterns of espalier, ranging from diamonds and candelabras to less formal arrangements. Figure 3.17 shows an espalier in progress. Note the sticks at the top of the tree, guiding it to grow in a straight line.

Retaining Wall Planters

Retaining wall planters are exactly what the name implies. They are generally made from modular concrete units that include an area for a plant to be planted (see figure 3.02). There are various designs available on the market, such as the Versa-Green® unit, Geoweb© wall, and the SmartSlope retaining wall. These products combine the function of a retaining wall with the beauty of vegetation.

Panel Systems

Both professionally designed and off the shelf soil bearing panel systems are available. Soil bearing designs generally offer more versatility and a higher biodiversity than do vines alone. These walls can be installed inside or out, and can host a variety of different plants. Some systems (such as hanging planters, and the Wooly Pocket™) are available in hardware stores, others are custom designed through distributors.

Panel systems are also common in DIY communities of homeowners and urban dwellers with limited space. Homeowners like them because of the compact nature of the system, and the simplicity of the design. Widespread availability of systems and tutorials have made vertical gardening an accessible and easy alternative to traditional horizontal gardening. To see my own experiments with DIY vertical gardens, see "Experiments Revisited" on page 8.

Figure 3.20 Green Over Grey's green wall system installed in a cafe in Toronto.

3.2 Soil-Free Systems

Hydroponic Felt Systems

The most common indoor type of green wall is the felt-based hydroponic system (see Figure 3.20). This type is likely most popular because of the various companies with trademarked designs that they will install and sometimes maintain for a fee. These systems are usually comprised of polypropylene or stainless steel containers, geotextiles, irrigation systems, growing medium, and vegetation (Yang, 2013). Installation of green walls of this type is always a custom design and frequently requires a larger budget compared to soil bearing systems. An irrigation supply with minimum water pressure of 44-55 lbs/sq. in. is also required (GRHC, 2010, p. 56).

Irrigation is one of the most complicated parts of a hydroponic wall. Water must circulate continually, and nutrients must be added. Some designs have closed loop systems in which potable water is added and re-circulated up to 10 times, while others use rainwater or water from a grey-water recycling system. Irrigation lines are usually drip systems or channels running above each planter, with excess water draining through the lower panels. There doesn't seem to be a better or worse option between drip or channel irrigation techniques, although both need to be inspected regularly to ensure they are not blocked. Usually irrigation will include a catchment tray at the bottom of the wall (see Figure 3.21) to gather extra water that is not absorbed by the vertical garden.

Regular monitoring is imperative to avoid nutrient loading, and contamination by pathogens (especially in indoor applications). Interruption in the irrigation supply is one of the most detrimental things that can happen to a hydroponic garden. The irony here is that hydroponic vertical gardens are suspected by some professionals to fail *because* of the constant flow of water. This can inhibit the plant roots' absorption of air which is necessary to their survival. Another problem with hydroponic systems is that watering is time-sensitive. With an incorrectly planned watering schedule, over-watering can easily occur, leading to rot and the eventual disintegration of the growing medium, whether fibrous mats (felt-like) or coco-peat blocks. To ensure adequate drainage, vertical gardens need either a gutter or tank system at the bottom of the wall, to collect (and usually re-circulate) the water that has already passed through the wall. If water efficiency is not important and water is not being re-circulated, it should be piped out either to a landscaped swale or stormwater sewer.

According to George Irwin (2014), founder of Green Living Technologies (GLT), lighting of indoor walls is extremely important to ensure longevity. When natural sunlight is not available, Irwin (2014) recommends full-spectrum lighting. Blue-light or red-light can be used, depending on the plants used. For woody plants, cooler light spectrums are preferred which will encourage leafy growth. For flowering plants, warmer light spectrums help to promote flowering. Flowering can also be controlled by the number of hours of light the plants receive daily. In general, light levels should not drop below 250 foot-candles, otherwise plants will not thrive (2014).

Figure 3.21: Felt Growing medium with water collection tray at bottom of hydroponic garden, Toronto.

Plants in hydroponic walls must also be chosen for their light requirements, size, weight, growth pattern and rate, as well as seasonal interest. The main difference between hydroponic walls (and panel systems in general) and vines is that the plants are started in greenhouses 12-18 months prior to installation, to ensure a desirable aesthetic immediately after installation (GRHC, 2010, p. 59). These plants must be grown horizontally to guarantee that they are firmly rooted before they are turned vertically. In many hydroponic walls, all soil is rinsed away from plants on site before they are slid into pockets in the growing medium.

A leading Canadian manufacturer of hydroponic vertical gardens is Green Over Grey™, out of Vancouver (Green over Grey, 2009). Their system is comprised of a series of layers of felt that sandwich plant roots. The design is very similar to Patrick Blanc's *mur vegetal*. Other Canadian manufacturers include Elevated Landscape Technologies (ELT), GLT, G-Sky Plant Systems Inc., Tournesol Siteworks, and Joe Zazzera.

Living Wall Biofilters

Nedlaw™'s living wall biofilters are similar to other indoor hydroponic gardens, with one exception: they are engineered to pull air through plant roots to filter it. According to Nedlaw™, their biofilters can filter out up to 85% of Volatile Organic Compounds (VOCs) commonly found in the air inside buildings. Their biofilters can be stand-alone systems or can be integrated into a building's HVAC system. Figure 3.22 is an example of a living wall biofilter that has been integrated into the air system of Sun Life Financial in Toronto.

Alan Darlington, the creator of the living wall biofilter, first came up with the idea while studying at the University of Guelph -Humber in Toronto. He worked with Diamond Schmitt Architects to design and build the first prototype which was part of research commissioned by NASA's *Advanced Life Support Program*. The green wall is now over 10 years old and continues to be an integral part of research involving VOC reduction and plants at the university. In contrast to other filtering systems, the wall reduces levels of toluene, dust and airborne fungi without producing toxic byproducts. By circulating air through the root area of the garden, rot is prevented, and plant roots are able to breathe as they normally would. This aspect alone is probably a significant contributing factor to the relatively low plant mortality rate that Nedlaw™ claims.

Plants used in the living wall biofiltration process are common houseplants in North America such as Fig, *Ficus benjamina*; Tree Philodendron, *Philodendron selluom*; Umbrella Plant, *Shefflera arboricola*; Rubber Plant, *Ficus*

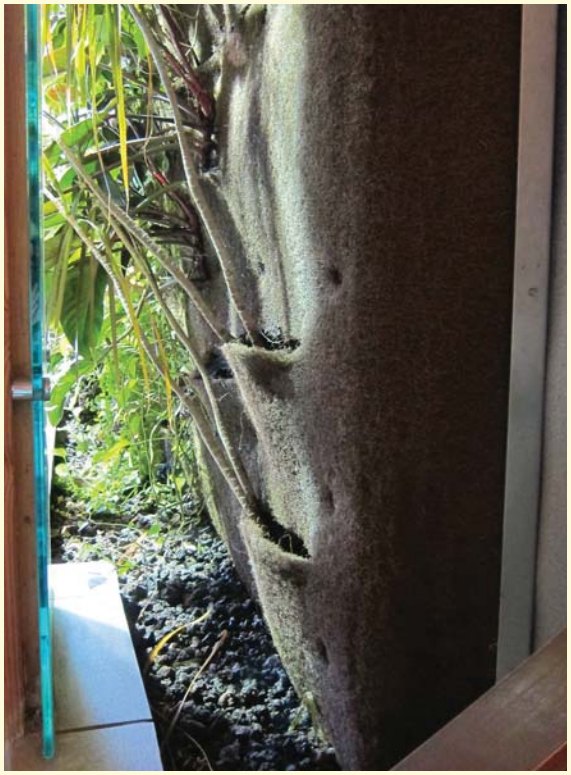
Figure 3.22: Living Wall Biofilter at Sun Life Financial in Toronto.

elastica; *Dracaena* spp.; and Algerian Ivy, *Hedera algeriensis*.

Living wall biofilter systems have to be carefully designed together with the building's HVAC system because of increases in humidity within the building due to the biofilter itself, however their benefits (explained in detail in the next chapter) make them leading products in indoor vertical garden design. Soil-free systems completely eliminate soil dwelling pests, reducing the overall number of pests that the wall is susceptible to. Water and nutrients are controlled through automatic timers, so the only weekly maintenance necessary is to ensure irrigation systems are functioning normally. Plants can still fall victim to diseases like powdery mildew and aphids for example. On average, Nedlaw™ systems lose approximately 10% of their plants annually. Compared to other hydroponic walls that can sometimes have a mortality rate of over 50%, this estimate seems quite low. I imagine this relates to the fact that air is pulled through the roots while it is being irrigated, so lack of root aeration is eliminated.

Conclusion

Outdoor soil bearing gardens are more common in colder climates, while in warmer climates hydroponic gardens are common. Vertical gardens can range from vines growing on a trellis to complex manufactured systems that can host a variety of other plant types. Retaining wall planters offer a nice way to improve the aesthetics of a retaining wall. Soil based planters, and hydroponic planters are often planted in advance and installed after the plants have established. Living wall biofilters, essentially hydroponic systems, allow air to be filtered by the garden itself, and can be integrated into building air systems. The most appropriate choice of vertical garden system for different sites will depend on a variety of factors including but not limited to: cost, climate, and aesthetics.



Above: Figures 4.01 & 4.02: Plants commonly used for indoor vertical gardens. Richardson Building Green Wall.

Left: Figures 4.03 & 4.04: Details of growing media and plants in biofilters.

4. BENEFITS OF VERTICAL GARDENING

Living Walls are quickly gaining in popularity worldwide as their ecological benefits become better known (Centre for Subtropical Design, n.d., p. 2). The benefits of vertical gardening are predicted to be similar to those of green roofs due to the similarities in vegetative cover and substrate thickness/ added insulative value (Köhler, 2008, Köhler and Schmidt, 2002, Köhler et al., 2003). Dr. Yael Stav, in her doctoral thesis at the Faculty of Built Environment and Engineering at Queensland University of Technology explains that they are similar, in terms of thermal and hydrological benefits, protection of the building envelope, pollution control, potential for food production and wildlife habitat, and potential to improve the well-being of people who see the gardens regularly (Stav, 2008, p.22, table 2). Dr. Brad Bass and Dr. Bas Baskaran explain in their report for the National Research Council of Canada that vertical gardens and green roofs could also reduce smog in larger cities (Bass and Baskaran, 2003, p. 91). They conclude that greening walls is a sensible strategy (Bass and Baskaran, 2003, p. 75). Benefits explored in this chapter are aesthetic improvement, reduction of the Urban Heat Island (UHI), reduction of heating and cooling costs for buildings, pollution and dust control, stormwater retention, noise reduction, habitat integration, food production, and biophilia. These numerous benefits have positive wide reaching effects on both human beings and the surrounding landscape.

4.1 Aesthetic Improvement

The poetic nature of growing plants on the side of a building is something I have thought about regularly during this practicum. I am not an especially poetic person, but I remember towards the beginning of this project I met with professor Mark West, formerly of the University of Manitoba, to discuss some of my ideas. He saw the poetry and beauty of my project instantly and shared his view of it with me. Since then, the image he painted for me remains vivid in my mind… I am walking on a quiet street downtown, maybe it's a Sunday - there aren't many other people around. The street is quiet, and all I can hear are the sounds of my own steps and my breaths, in-and-out, on a warm

Figure 4.05: Nedlaw™ Biowall, Sun Life Financial, Toronto

summer day. I turn a corner and suddenly I hear rustling of wind through leaves, making delicate whooshing and fluttering sounds that in the silence of that street fills my ears with intrigue and delight. Looking up, I see a luscious garden filled with different kinds of plants on the side of a building, swaying in the wind. In the garden, I see- or maybe just hear- a few small birds chirping and some bees buzzing contently from flower to flower collecting nectar and spreading pollen. It is as though suddenly my concrete world has been infused with colour and with life, and I marvel at the beauty that is before me… An experience so rare in today's cities.

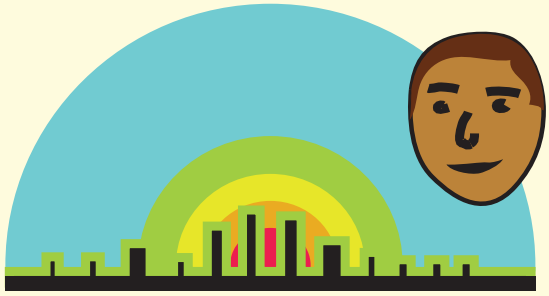
Growing living material on a potentially monotonous facade brings visual interest. Depending on the types of plants used and the local climate, seasonal fluctuations will provide added visual stimulation. Various studies demonstrate the benefits of urban greening (Ulrich, 1979, 1983, 1984, 1986; Smardon, 1988; Lynch and Rivkin, 1959; Thayer and Atwood, 1978). Vegetation in the urban fabric affects us in a variety of ways; from upping real estate values, to reducing feelings of fear and increasing positive emotions, to decreasing healing times (Ulrich, 1986, p. 86). The impacts of vegetation on the human psyche are far reaching. A 1982 study by Getz et al. sampled 250 people in the city of Detroit and determined that the preference for natural views remains consistent across social classes, with inner city residents preferring a woodland scene over a downtown commercial scene. The aesthetic preference of people for vegetation is clear. This preference, as Nassauer (1995) explains in *Messy Ecosystems, Orderly Frames* is that to people who have not been taught to identify pre-settlement landscapes, landscape appreciation is only possible when human intervention is obvious. I find even my own personal preference of nature following this theory. My favourite landscapes are city parks- both ordered and more "natural" design aesthetics, but each highly controlled in their own way. Having grown up in a city and visited the country regularly, I appreciate both the unregulated ecosystem and the highly manicured one, but I feel more comfortable at home in the highly regulated city-nature, the one with the orderly frame.

Vertical gardens are small gardens contained within very specific frames. They contain living plants- sometimes chaotic and sometimes messy- squished into highly controlled and manicured frames. I believe in this sense, that people have an innate positive appreciation for vertical gardens.

4.2 Reduction of the Urban Heat Island Effect

The most widely studied benefit of vertical gardens is the mitigation of the Urban Heat Island effect or UHI. The concept of UHI was originally discovered by Luke Howard (1818) in London; related studies have since been conducted around the world. The UHI can be loosely defined as an increase in temperature in an urban environment relative to cooler surrounding rural areas (Erell, Pearlmutter, Williamson, 2011). These effects can be mitigated by vegetation, as shown in figures 4.06 and 4.07. Cities are generally 2°C (3.6°F) warmer than rural areas, and high density residential areas between 5°C - 7°C (9°F - 12.6°F) warmer on average (Bonan, 2002). There are three different kinds of UHI that

Without extensive green skins



With extensive green skins

Figures 4.06 & 4.07: With a widespread application of green skins in the form of green walls and roofs, temperature variations (the UHI) of cities will fluctuate less, resulting in happier residents.

influence temperatures in the city:

- A Surface Heat Island (SHI) is defined as instances when the temperature urban surfaces is higher than surrounding rural surfaces.
- The Canopy-Layer Heat Island (CLHI) is the warmth observed in the air at the mean height of surrounding buildings.
- The Boundary-Layer Heat Island (BLHI) is the tail of warmer air that extends downwind of the city (Erell et al., 2011 p. 69).

These effects usually occur in direct relation urban geometry, number of impervious surfaces, geographic location, weather, lack of vegetation, high presence of materials with low albedos, and human related released heat (Erell et al., 2011). Each of these factors contribute to an overall effect that can be measured and predicted. This temperature increase not only causes thermal discomfort but also increases smog and thereby respiratory problems and heat stress (Bass and Baskaran, 2003, p. 91). This research indicates that by designing our cities as we have for the last hundred years, we have made cities a much harsher environment both mentally and physically, than they need to be. In the Canadian context, Dr. Brad Bass and Monica Kuhn (Architect) write in their co-authored report *Greenbacks from Green Roofs: Forging a New Industry in Canada* that re-radiated heat, and waste heat from industry, vehicles and mechanical equipment are the most prevalent influences, raising urban temperatures up to 8°C (15°F) at night (Peck et al., 1999, p. 24).

By re-integrating greenery into the urban and architectural fabric we can begin to reduce temperatures by increasing shade from plants and benefiting from the evapotranspirational process that the plants undertake (Alexandri and Jones, 2010, p. 486). On materials like concrete or asphalt solar exposure re-radiates as heat, but only 20% of the sun's rays are reflected from the leaf of a plant (Peck et al., 1999, p. 21). On a hot summer day absorption of heat and light by plants can regulate humidity and temperature fluxes, while reducing the sun's incident energy absorption of hard materials by up to 90% (p. 21).

Nyuk Hien Wong, professor at the University of Singapore, together with Tan, Tan, Chiang, and Wong (2010) have published one of the most thorough research papers available in English of the thermal impact

of vertical gardens. The paper outlines results obtained for eight different vertical garden panels that were installed in HortPark in Singapore in 2008 (p. 663). The article acknowledges the difficulties with quantifying the cooling potentials of gardens by stating that interactions between leaf geometry, area, colour and micro-climatic parameters like solar radiation all affect the differences recorded both during the day and at night (p. 668). They note that changes in foliage density correspond to changes in surface temperatures and conclude that plants with large and dense leaf structures are preferred for vertical greening (p. 670). Examples of other climbing plants with these characteristics are Boston Ivy, *Parthenocissus tricuspidata*, *Clematis* spp., *Vitis* spp., and other *Parthenocissus* spp. (Köhler, 2008).

Findings of facades monitored by Wong et al. (2010) were published, but information on the types of plants was not provided. The walls showed significant heat reduction (p. 664), however, with a warm and humid climate, Singapore is perfectly poised to benefit from green walls. Alexandri and Jones (2008) performed simulations of UHI cooling associated with green roofs and walls in urban canyons in cities around the world and note that green walls will provide greater benefits to cities with hot and dry as well as hot and humid climates. They will provide the least benefit for cities in cold climates- though there still remains a measurable difference of less than 1°C (1°F) between facades with green walls compared to those without (p. 487). In the humid climate of Hong Kong, a maximum temperature decrease of 8.4°C (15°F) has been recorded (p. 493). In Canada, vines have been shown to lower temperatures as effectively as trees grown in front of south or west walls (Peck et al., 1999, p. 20). Studies in Britain have shown that reducing wind exposure by planting a deciduous tree perimeter can provide a 25% reduction in energy (heating and cooling) costs annually. Peck et al. expect vertical gardens to provide similar savings in the winter months in cold cities like Winnipeg's, if coniferous plants are used (p. 20). The greater neighbourhood UHI will minimize fluctuation from daytime to nighttime temperatures, protecting the plants from early frosts or sudden temperature drops.

Studies comparing cooling effects of vertical gardens on surrounding areas (Wong et al, 2010; Bass and Baskaran, 2003; Peck et al., 1999; Schumann, 2007; Hum and Lai, 2007; Alexandri and Jones, 2008; Centre for Subtropical Design, n.d.; Jaafar, Said, Rasidi, n.d.) are based on comparisons between surface measurements of the gardens versus the facades they cover. Though they all conclude that green walls can lower the UHI, exactly how much it will be lowered still remains largely theoretical. The calculations are based on the difference between a vegetated surface and a non-vegetated surface, but due to fluctuations in climate, plant material, and surface coverage, the results vary from one study to another. This is not the fault of the researchers, nor the authors publishing their findings, but rather simply due to the fact that there are so many factors that influence the results that it is very difficult to recreate the same results in different locations. Wong et al. (2010) compared cooling effects in Toronto, Japan, and Africa and Singapore and concluded that "temperature fluctuations at the wall surface can be reduced from between 10 °C

and 60 °C [18-108°F] to between 5°C and 30°C [9-54°F]," (p. 664). This means that overall, globally, there will be a decrease in surface temperatures once they are covered with plants, but the exact figure for a specific location will need to be studied individually.

The potential of vertical gardens to mitigate the UHI is expected to be similar to that of green roofs. Clare Miflin (2007) wrote in an online article for the American Institute of Architecture that if just 6% of Toronto rooftops were greened, that the corresponding reduction in the UHI would be between 2-4°F (~1°C). Since that article was published, in 2010, the city of Toronto became the first city in North America to legislate green roof requirements on new developments (City of Toronto, 2013). It is still too early to study data from Toronto as the number of green roofs must be very high to show a definitive cooling trend. Larger scale cooling trends for neighbourhoods will be found only after multiple green walls have been installed (Peck et al., 1999, p. 35), and are expected to occur over an unknown span of time dependent on the quantity and size of green roofs installed. Impacts may be negligible today will continue to grow over time because of this legislation.

4.3 Reduction of Heating and Cooling Costs in Buildings

Dr. Manfred Köhler (2008), German researcher, determined that the vertical gardens he studied provided up to 3°C (5.5°F) of insulation in the winter, and 3°C (5.5°F) of shade-induced cooling during the summer in Berlin (Köhler, 2008, Table 1). Peck et al. (1999) write that, "a 1.57 in. (4 cm) layer of standing air, trapped between an insulated wall and a 6.3 in. (16 cm) blanket of plants, can increase the R value (unit thermal resistance) of that wall by as much as 30%," (p. 22). Protecting building facades from temperature fluctuations mean that building operation costs can be lower. Bass and Baskaran (2003) found that green walls used for shading can reduce energy used for cooling by 23% and energy used for air circulation by 20% (p. 90). Green walls can reduce the temperature immediately outside a building by 5.5°C (10°F), which would correspondingly reduce the need for air-conditioning by 50-70% (Peck et al., 1999, p. 20). In most of these cases, the calculated savings are inferred from data gathered from a single vertical garden wall during the summer. Studies on savings associated with entire buildings covered in vertical gardens were not found, neither were studies showing temperature variations in negative winter temperatures. This means that, once again, though all studies confirm positive effects (Wong et al, 2010; Bass and Baskaran, 2003; Peck et al., 1999), there may be a change in the predicted outcome of a building completely covered in vertical gardens, versus the implied outcome from a single wall, or portion of a wall. Seasonal variations will also influence outcomes.

One element commonly mentioned in Canadian studies is how the vegetated facade affects wind. By adding vegetation to a facade and including an airspace between the plants and the building, both wind and heat are prevented from reaching the facade, which increases the building's thermal resistance. Wind by itself can decrease the energy efficiency of a building by up to 50%, so by adding a thick layer of vegetation this loss can be lessened (Peck et al., 1999, p. 22). Green

walls reduce wind speeds, or convective heat transfer, along a wall which will cause the heat resistance of the buildings boundary layer to rise from 0.04 to a maximum of 0.17 m^2 K W-1 , depending on the density of the foliage (Oosterlee, 2013, p. 6).

Another aspect of the cooling effect missing in the research is the difference in cooling between different vertical garden systems. In the only explicitly comparative study Oosterlee (2013) found that "the R value of the Greenwave system based on soil varies between 0.1 and 0.2 m^2 K W-1, depending on the wetness of the growing medium. For the Wonderwall® system based on fabric, this ranges between 0.2 and 0.3 m^2 K W-1. The insulating capacity of the LivePanel® system (which uses rock wool) was found to be more significant at 0.9 – 1.5 m^2 K W-1" (p. 6). For comparison, the R value of concrete is 0.2 m^2 K W-1 and standard 2" air spaces in walls are 0.15 m^2 K W-1 respectively (Youcef, Ibos, Feuillet, Balcon, Candau, and Filloux, 2010, p. 1).

Many studies involve large leafed species of vines, but relatively few studies have been conducted comparing systems with different types of vegetation (for example a grass wall versus a succulent wall). Peck et al. note that grass surfaces will not heat up past 25°C (77°F) (1999, p. 24), however similar data for succulents, conifers or other herbaceous covers are not mentioned. Similar studies carried out in Singapore by Wong et al. (2010) demonstrate a difference in temperature on various gardens, however exact species mixes and direct temperature readings are not reported; all presented is the temperature fluctuation between that recorded on the wall and the overall reading of the city. The fact that these gardens are located within a park likely influenced the outcome as well, as plants already present in the park have a cooling effect. It is unclear whether or not this effect was recorded or accounted for.

The reduction of wind and heating/cooling costs cited in some studies is significant, however to achieve these benefits, losses will be found elsewhere in the garden. Wind, for example, poses a big threat to vegetation as it can rapidly dessicate growth media which could either kill plants, or dramatically increase the amount of irrigation needed. Benefits gained through wind-blockage are countered by increases in cost elsewhere.

4.4 Winter Impact On Building Performance

Coniferous species are recommended for cold climates where winter heat loss is an issue, since deciduous species lose their leaves and therefore their thermal impact in the winter (Peck et al. 1999, p. 23). The desired outcome in cold places is to facilitate solar gain, so the loss of foliage during the winter could be more of an advantage than a disadvantage if the wall is carefully designed to allow solar gain. This theory is confirmed by a study by J. A. Oosterlee (2013) in Denmark: "the results show that applying foliage led to a decrease in annual cooling load, but this was balanced by an increase in annual heating load. In every examined situation, the annual energy consumption decreased by a mere 1%," (p. 6). This indicates that in order for a system to be economically viable in cold climates, including Canada it would be most appropriate to develop a system that allows for passive solar radiation to be absorbed

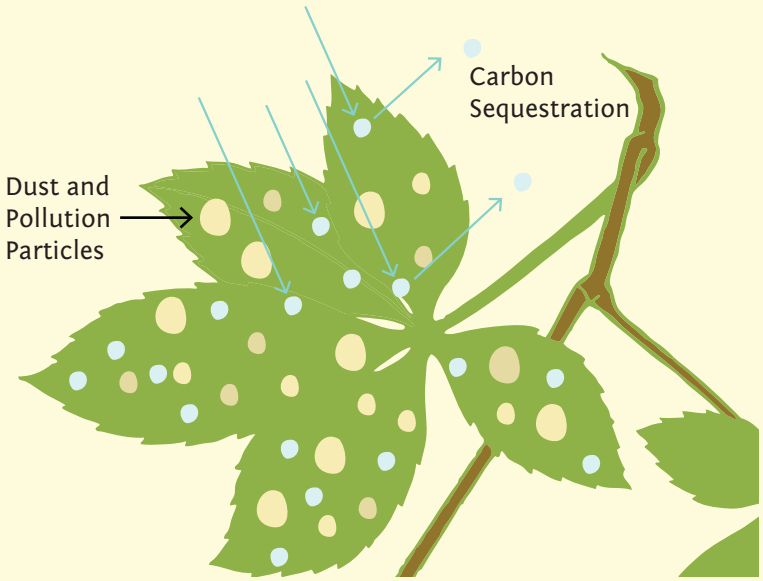


Figure 4.08: Dust and pollution accumulate on the leaves of plants in urban environments. Carbon is also sequestered through the photosynthetic process.

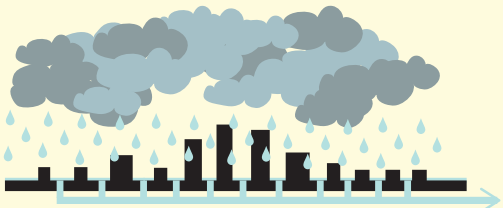
during the winter, but stopped during the summer. Ultimately, more adaptive, thoughtful testing of new designs must be done in urban Canadian contexts.

4.5 Pollution and Dust Control

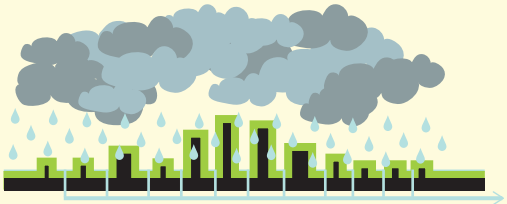
Vertical gardens have been shown to reduce pollution and dust in cities (Thoennessen, 2002; Köhler, 2008). Similarly to studies on temperature variations of vertical gardens, disparate results are found. Details such as plant type, leaf size, and wall coverage all have a noticeable impact on pollution absorption and dust capture.

The accumulation of dust and dirt particles on leaves as seen in figure 4.08, increases air quality. This can benefit people with asthma and environmental allergies, and has been shown to reduce smog and other forms of pollution (Peck et al., 1999, p. 18-19). Results published by M. Thoennessen (2002) indicate various chemical elements (aluminum, cadmium, cobalt, chromium, copper, iron, nickel, lead) become trapped on leaves of Boston Ivy in city centres. It is not mentioned whether any residue is left after rain washes away the elements, or whether leaf texture plays a role in dust capture. It is suspected that hairy versus non hairy leaves would capture differing amounts of dust because of differences in surface area. The amount of dust and heavy metals on leaves increases proportionately to leaf mass (Köhler, 2008, p. 9). According to Köhler (2008), the area best suited to capture dust and pollutants is from 2 - 7.5 m in elevation (p. 430). Dust and particles will be washed away by rain, and end up in a water processing plant. Because of the increase in dust and pollution at these elevations, it is recommended that food be grown outside of this zone.

Though there are not many studies on pollution deposition in outdoor vertical



Without Green Skins



With Green Skins

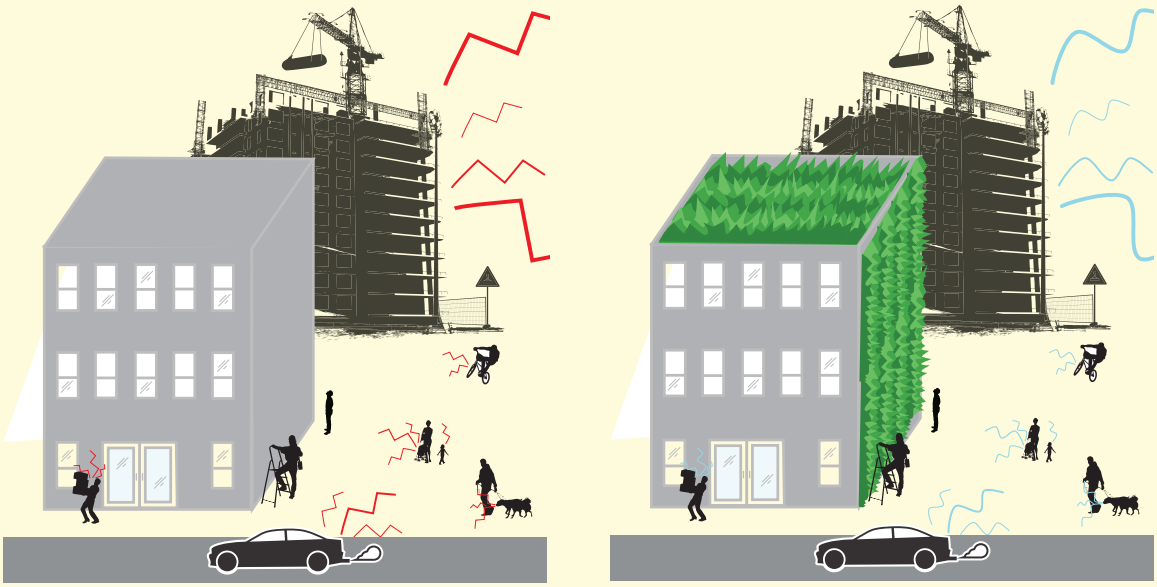
Figure 4.09 & 4.10: Stormwater runoff can be minimized with the use of widespread vegetative skins on buildings.

gardens (it is very difficult to document) it has been proven that indoor biowalls can successfully absorb and filter indoor air contaminants such as VOCs, CO_2, and other harmful gases (Hum And Lai, 2007, p. i-ii). Nedlaw™ describes sick building syndrome as the phenomena of people getting sick because of an estimated 200 different chemicals present in indoor air (Nedlaw™, 2011). These chemicals, known as VOCs originate from chemicals emitted by furniture and building materials such as flooring, paint, fabrics, plywood, carpeting, etc, many of which have been found to be carcinogenic (2011). Oxygen and CO_2 released into the air by plants during the photosynthetic process increase indoor air quality.

Research from Hum and Lai (2007) is more critical of the biowall's ability to filter out contaminants. While they confirm that walls can successfully remove VOCs even at low concentrations, they note that the wall they studied did not reduce CO_2 levels significantly (p. i-ii). They hypothesize that this may be due to the fact that plants produce and emit differing amounts of CO_2 and VOCs themselves and thus may not produce a consistent difference in chemical counts in spaces with or without biowalls. It seems that positive results come from the evaluation of specific chemicals, but Hum and Lai (2007) are looking at the overall result, which may not be as positive as other studies and promotional materials suggest.

4.6 Mitigation of Stormwater Runoff

Vertical gardens can be irrigated with stormwater runoff from rooftops or other surfaces to absorb and delay peak flows as shown in figures 4.09 & 4.10 Because of green walls' limited footprint on grade, the majority of direct absorption will occur when rain is falling horizontally - during a major storm event, where wind blows rain towards the wall (Peck et al., 1999, p. 28). Relying on the wall to absorb water in this way is unpredictable, so when stormwater absorption is desired, it is recommended for water to be collected and stored on site, and released through controlled irrigation. The biggest drawback to this technique is that other surrounding structures must be designed to drain into a holding tank, whether directly via engineered slopes, or indirectly through pipes. Usually this is not a difficult retrofit. If a rainwater harvesting system already exists on site, adapting it to integrate a green wall would be fairly easy.



Without Green Skins

With Green Skins

Figure 4.11 & 4.12: Vegetation can help to reduce noise reverberation.

4.7 Noise reduction and refraction

Vertical greenery has been noted to have a higher noise absorption coefficient compared to common building materials (Wong, n.d., p. 1). Unlike most building materials, the absorption coefficient increases depending on the type of vegetation (p. 1). Throughout my education, I have noted that the impact of vegetation on sound attenuation is sometimes questioned by designers in terms of its efficiency during the winter. Sure, the sound refraction capacity of vegetation could be less than an acoustic panel for example, but it can still produce a noticeable effect in a busy city if widely applied, and if coniferous plants are included in the design. Figures 4.11 and 4.12 are a visualisation of the noise absorption from vertical gardens. Gernot Minke (1982), in his book *Haeuser mit Gruenem Pelz* (Roughly translated to *House with Green Hair*) wrote that tests show that a 5" (12 cm) layer of growth substrate can reduce sound by 40 dB and 8" (20 cm) of substrate by 46 dB (p. 15). Some reductions have shown to be as high as 50 dB (Hooker, 1994, p. 3). For reference, 40dB is equivalent to a slow flowing stream. According to these studies, true noise reduction occurs when sound is absorbed by substrates, not necessarily by the plants themselves. Though it should be noted that the sound refraction properties of plants have proven to be beneficial enough for the Frankfurt Airport in Germany to install green roofs on their buildings as part of their efforts to buffer noise generated from air traffic (Centre for Subtropical Design, n.d., p. 4). This benefit will generally decrease during the winter, unless coniferous plants are used.

Figure 4.13: Integrating native vegetation into urban centres will help bring nature into cities.

4.8 Integration of Native Habitats in Cities

Vertical gardens create habitats for plants, invertebrates, birds, and small mammals. Peck et al. (1999) define a habitat as "specific surroundings within which an organism, species or community lives," (p. 39). Due to the density of the built environment and agricultural expanses, vegetative habitat for animals has been severely disturbed (p. 39). Dr. Dickson Despommier (2010) writes in his book *The Vertical Farm* that through agricultural farming, we have fragmented most of the world's biomes, "rearranging the lives of countless assemblages of plants and animals and causing the extinction of many others," (p. 49). Due to the amount of potentially native or niche-filling vegetation used in vertical gardening, and potential isolation from direct human disturbance (out of reach) these gardens can offer a simple way to integrate vegetative communities back into the city without using space on grade (Peck et al., 1999, p. 39). Dvorak and Volder (2010) explain that living roofs may be used to support species of insects, animals, and plants that have been lost from their natural grassland habitats within agricultural areas in North America (p.206). As there are many parallels between green roofs and vertical gardens it can be assumed that the same inferences can be made for vertical gardens.

Vertical gardens can provide a link between rooftop habitats and habitats on grade, as shown in figure 4.13. Vertical gardens, together with green roofs, can create habitat for species that are either endangered or threatened. Francis and Lormier (2009) note that invertebrate diversity can be particularly high on green roofs; rooftop communities may include insects such as spiders, beetles, wasps, ants and bees, and they observe that some species with very specialized niches are sometimes present. These are often the same species expected to be found on green walls.

4.9 Food Production

Vertical gardens can grow food. Since food deserts are increasingly plaguing North Americans, it is important that we start to grow our own food, and depend less on supermarkets for our sustenance. Despommier (2010) explains that many of the ecosystem disruptions seen in the 21st century are due to agricultural runoff (p. 28). He proposes that urban farming be done vertically rather than horizontally to prevent such disruptions. He introduces many intriguing and thoughtful proposals

throughout the book. His vision of vertical gardens are isolated from the urban environment in hermetically sealed towers, where crops grow one on top of the other. His proposals for wide scale applications have potential. For smaller scale applications, growing vegetables on a wall would give recreational farmers more possibilities to grow their own food at home- especially those living in apartments or places without access to horizontal gardens. Plants grown recreationally on city walls will experience buildup of dust and metals, so it is important that urban farmers remain conscious of potential contamination, and take precautionary measures. It is also necessary to plan to be able to reach all of the plants both for harvesting and for general maintenance, so often personal vertical farms are small.

According to Despommier (2010), the utilization of vertical gardens and rooftop gardens for large scale food production in urban centres could produce enough food to feed the citizens of the area, as well as create many local jobs. An article in the *Toronto Star* describes a single Concord grapevine growing on the façade of a small south-facing house in Cabbagetown that has produced 3 bushels of grapes each year for 3 years in a row (Smith, 1997). The grapevine was only 5 years old at the time of the story and was initially installed primarily to shade the house from the summer sun (1997). Though this is a very small example, the point is clear: the grape production compared to the floor area the plants occupy is very high. Peck et al. (1999) list espalier trained fruit trees and climbing vegetables like squash, beans and tomatoes as particularly suited to verticality. Other vegetables such as lettuce, spinach, other leafy greens are also noted to be well suited to verticality (p. 38) due to their smaller root systems which grow easily in containers.

4.10 Biophilia

There are many psychological benefits associated with exposure to nature in the form of living plants. This concept, called biophilia, was first extensively developed by Edward O. Wilson in his book of the same title (1984). Roger S. Ulrich and R. Parsons in a paper called *Influences of passive experiences with plants on individual well-being and health* (1992), write that a study conducted in the Netherlands of over 10,000 people found a direct correlation between the amount of green elements in living environments and higher levels of perceived physical and mental health. This is echoed in many of the books and papers read for this practicum (Peck et al., 1999; Despommier, 2011; Beatley, 2011; Kellert, 2012; Louv, 2005 and 2012; Ulrich and Parsons, 1992). The level of health has been directly correlated to the level of greenness in frequently visited areas; "10% more greenspace in the living environment leads to a decrease in the number of symptoms that is comparable with a decrease in age by 5 years," (DeVries et al., 2003, p.35). Such studies have led to more plants installed in offices to increase productivity and employee satisfaction (Centre for Subtropical Design, n.d., p. 5). Miflin (2007) explains that as building technology improved in the 20th century, creating more uniform spaces many buildings lost their connections to the environment. People are now beginning to question the desirability of that uniformity (2007).

Vertical gardens are an effective way to integrate natural views into our urban lives, both indoors and out. The Centre for Subtropical Design (n.d.), a group of design researchers of resilient cities in the tropics, note that vertical gardens can increase workplace performance, employee retention and productivity due to the same effects noted in Ulrich and Parsons (1992) (Centre for Subtropical Design, n.d., p. 5). Timothy Beatley (2011) writes in *Biophilic Cities* that "helping a city become more biophilic will rely heavily on environmental education, and creative ways will be needed to build commitment of urban populations to nature and to foster a strong urban environmental ethic," (p. 71). Vertical gardens can increase appreciation of citizens of plant communities and natural events by including informative plaques with each green wall project.

4.11 Marketing

Green walls can be a highly visible way for businesses to improve their image or create intriguing advertisements. Green buildings, products and services now have a competitive edge on the market and are perceived as exceeding building standards (GRHC, 2010, p. 21). Green walls are frequently used in advertising and company signage in order to associate the company with this perception of excellence. Some ads are temporary and others permanent.

The Coca-Cola Company and World Wildlife Fund billboard advertisement from 2011 is a striking example of a temporary vertical garden. Made from recycled Coca-Cola glass bottles each housing a single Fukien tea plant, the ad reads "this billboard absorbs air pollutants"(Palace Green Forum, 2012). Similar campaigns have also emerged from Adidas, HP, and McDonald's.

Green walls can be used as permanent signage for companies. PNC Bank in Pittsburgh, for example, has a vertical garden measuring 2,380 sq. ft. (221 m^2) in which their name and logo are spelled out of different coloured plants. Similar designs can be seen in many buildings today, often with signage floating over top of a green wall.

Conclusion

A vertical garden has the potential to greatly influence its surroundings, benefiting the building it is growing on, the neighbourhood it is located within, and the people that are in the area. The biggest advantages to vertical gardening are aesthetic improvement, reduction in the UHI, improvement of air quality, stormwater absorption, noise reduction, native habitat integration, reduction in heating and cooling costs, food production and biophilia. It is important to understand that these benefits are generally true for all types of vegetation, not just for vertical gardens, so in some cases (if there is enough available ground space) it may be more viable to plant a horizontal garden at grade for a fraction of the cost of a green wall. Vertical gardens are recommended for sites that have limited floor space, or those zoned for medium-high to high density building. Urban centres are therefore prime candidates. Vertical gardens can be built in suburbs and rural communities as well, but sites will benefit most from green walls are high density areas in urban locations.

Initially it was my assumption that all of the benefits listed above justified the potentially outrageous cost of vertical gardens, but an article I read toward the end of my research on benefits quickly put the so-called "benefits" in perspective. The article was Peck et al.'s (1999) *Greenbacks from Green Roofs*. The report compared the benefits of vertical gardening to street trees and trees that grow in front of buildings. The conclusion posited was that though green walls have many associated benefits, planting a tree is not only cheaper, but trees are also more efficient at pollution uptake, reducing the UHI, and reducing heating and cooling costs of the building they front (p. 20). This information had a very negative effect on my outlook for my practicum for a long time, and nearly broke my optimistic, green-wall-loving heart, until I realised there were still other factors that trees alone were not as good at such as creating diverse habitat niches, increased facade coverage and increased plant diversity. In terms of aesthetics, a single tree would have difficulties competing with the variety of colour, texture, shape and size of a green wall.

Figure 4.14: People admiring a living wall biofilter in the Richardson Building, Toronto.

Figure 5.01: Failing green wall, Vancouver.

5. DIFFICULTIES ASSOCIATED WITH VERTICAL GARDENING

There are still many difficulties that plague the green wall industry. Most drawbacks, from a Canadian perspective, are due to the lack of information and research in Canada. Canada has produced some of the leading research in the field in North America, but it is still severely limited. The primary base of information exists, however important aspects of the research is often not mentioned. Aspects such as where the garden was installed (climate - both neighbourhood and region), whether it was in sun or shade, what plants were used, and what materials were used are often not mentioned in detail. Other difficulties include cost and lack of industry codes and standards. Additionally, there are various associated risks such as water-related damage and plant survival that impede vertical gardens from becoming widespread. More published tests in different climates, with different plant species- annual and perennial, native and non-native- on different facades, made from different materials, located on different aspects, in different types of urban canyons, with differing amounts of wind exposure, would help. These are some of the greatest influences and compositional elements of vertical garden design, and yet these are the aspects haven't all been tested in detail yet. Wong (n.d.) notes that building professionals and occupants generally agree on most of the benefits of vertical gardening (p. 3), however they disagree as to whether or not vertical gardens can enhance the lifespan of a building facade and improve rainwater retention (p. 3). He cites high initial and maintenance costs, lack of technical information regarding local plants and maintenance schedules as deterrents (p. 3). The cost of a vertical garden will usually be the most limiting factor, but other influences such as lack of awareness of benefits and performance and lack of grants and subsidies for design/installation/maintenance are additional hurdles that vertical garden enthusiasts face (p. 3). There is often hesitation associated with the unknown, and green wall installation is no exception.

5.1 Lack of Knowledge and Awareness

The drawback that has the biggest impact on the vertical garden industry is an overall lack of knowledge and awareness of the public and of professionals (Urben-Imbeault, August 14, 2014). Although lack of awareness is a huge problem, it is quickly lessening, thanks in part to the work of Patrick Blanc, but also due to the rising number of vertical gardens installed by businesses and governments around the world. Various related businesses have sprung up recently, selling their own relatively inexpensive vertical gardening systems. Larger businesses like Home Depot have also begun offering tutorials on how the average homeowner can build a vertical garden, from big budget to extremely small budget applications. Awareness of vertical gardens in the DIY and homeowner communities is now fairly common, however many professionals in the design and gardening world do not have enough information to properly convince their clients that a vertical garden is a sound investment. In this sense, this lack of awareness on the part of professionals has the biggest impact on commercial vertical gardening projects. Wong (n.d.) found that both landscape architects and suppliers feel that vertical gardening is still in its infancy, and that it is a big challenge to build architects and developers' confidence in vertical greenery (p. 3). He believes that there needs to be more sharing of technical information between contractors, professionals and maintenance crews (p. 3). Admittedly, the right client and the right site are necessary for a green wall to be installed, however there are enough commercially available systems (with warranties) that green walls could be considered more often.

Over the last few years, I have noticed people's awareness of vertical gardens has increased. I have witnessed this in my own life, and online. When I used to tell people I was looking into vertical gardens they would ask me what they were and then the conversation would end. Now when I tell people about my practicum, they get excited and tell me about how they want to make one in their backyard, or how they saw one in Paris a few years ago, or how their friend has one and they absolutely love it, or how they put one into their last design studio project. No matter the story they tell, everyone seems to have a very positive response to the topic. I have witnessed this same evolution online, as for the last three years I have been running a blog called *Aw Yeah Vertical Gardens!* (see http://awyeahverticalgardens.tumblr.com) which is mostly content reposted from other bloggers, or from other online sources. I have seen the number of followers jump from 159 registered followers to over 3,500 registered followers in a little over two years (the current count as of August 2015 is 3,601).

5.2 Lack of Empirical Evidence

A second drawback is a lack of empirical evidence on the benefits of vertical gardening. Wong et al. (2010) explain how many of the significant articles on urban greenery focus on green roofs. These usually include a small section at the end about vertical gardening, that in essence states that vertical gardens are expected share all of the same advantages as green roofs (p. 664). Though this makes sense, green roofs and vertical gardens are obviously quite different, and to properly convince people of their positive impacts, more dedicated research is needed. As noted

previously, even studies that focus directly on vertical gardening often do not include all pertinent information such as climate normals, urban location/influence, UHI factor, density and type of vegetation, or the depth of substrate used. Results that include some of that information are so varied in their results that it is difficult to say what the effect will be on any given project. Because the vertical garden industry is currently unregulated, different companies and design teams develop unique systems, which they trademark, and do not necessarily share with the public or other green wall enthusiasts.

Without solid figures it is difficult to implement new technologies. It would be extremely valuable to have a software into which you could input vegetative types; wall types; soil bearing or hydroponic data, soil depth; climate data; microclimate data, such as aspect, solar orientation, wind speeds and direction, and the relative level of humidity, and have the software calculate a predicted impact or energy savings based on the type of architecture and type of heating and cooling systems in place. This sort of simulation software could be useful on both the architectural scale in terms of individual building energy savings, and on larger scale concerning impact on the UHI.

5.3 Lack of Incentives

A third drawback to vertical gardening in Canada is the lack of incentives and ordinances. Many programs in Europe and a few in the United States have now been established, however Canada has yet to establish any. In 1999, Peck et al. wrote that funding to design/build/maintain vertical gardens was difficult to access, due to a general lack of knowledge in the marketplace (p. 47). While some funding has now been made available for green research in general, there are few funds dedicated solely to vertical gardens. Peck et al. (1999) describe green roof programs that have been successful in Europe, and recommend that Canada:

- "Establish a financial incentive program of grants or indirect subsidies to encourage implementation by reducing payback periods and associated economic uncertainties. Government investment will make up for the market failure to acknowledge the significant social and environmental benefits (air quality, amenity space, climate change, biodiversity, water quality, etc.).
- Make it mandatory through legislation, planning instruments or amendments to the building code to fit new buildings with green roofs and vertical gardens. This would create a strong market for green roof and vertical garden technologies, as was the case in Germany," (p.52).

German municipal governments established incentives for developers to build green technologies at various times throughout the 20th century, though most centered on green roofs. It is generally acknowledged that green walls and roofs share many of the same benefits, often green wall legislation will fall under the same guideline as green roof legislation. The *Seattle Green Factor* is a prime example of this sort of umbrella legislation. A general LEED-like guide to landscaping in the city, The *Seattle Green Factor* assigns a predetermined number of points to a project for specific designs. According to the City of Seattle (2013), 0.7 points are scored for

every sq. ft. of vertical garden or green roof with over 4" of substrate. Green roofs with 2"-4" substrate, for example, score only 0.4 points per sq. ft. (Score Sheet). The City of Seattle remains one of just a handful of cities with legislation directly related to vertical gardening. North American cities with specific green wall ordinances are currently limited to Seattle, Houston, and Orlando.

In 2010, Toronto took first steps toward green wall bylaws by mandating green roofs for buildings with roofs larger than 200 sq. m. Toronto also has an Eco-Roof Incentive Program, which gives money back to those who invest a minimum amount, but do not qualify for the green roof bylaw. Though legally and design-wise, green roofs and vertical gardens are not the same, as mentioned before they are often thrown into the same general category so it would be beneficial for ordinances to include vertical gardens. Since 2010, a variety of cities have voted to implement green roof legislation including Vancouver, Chicago, Milwaukee, Portland, and New York (Plant Connection, 2014). Each of these cities have different ordinances, some of which are cash rebates, tax credits or point systems.

5.4 Cost

There are few grants, or incentives available specifically for green walls, so the fourth drawback of vertical gardening is associated with the cost incurred for materials, installation and maintenance. Francis and Lormier (2009) note that living walls are generally quite expensive, citing figures of between "£260 [$465 CAD] or $390 [$696 CAD] per m^2" These initial costs, combined with the fact that green walls can require significant maintenance programs can add up very quickly (p. 5). A Canadian example is the initial prototype of the Nedlaw™ system. Vice Provost at Guelph University Michael Nightingale explained in an article for *Business Edge Magazine* that he encountered a lot of skepticism when trying to sell the idea to his colleagues at the University of Guelph (Stauffer, 2005). Part of the resistance, he noted was due to the cost: $500,000 for the design/installation, followed by an annual cost of $21,000 for maintenance, (Stauffer, 2005). Since then, Dr. Darlington took his work into the commercial world, associated costs have decreased significantly. "Since he installed the Guelph-Humber wall, Darlington has managed to reduce the costs of a biofilter by 40%. A square metre now costs $1,200 and can [filter the air in] 100 m^2 of floor space," (Stauffer, 2005). It should be noted that this cost is for a biowall, so costs for hydroponic gardens will be lower. Peck et al. (1999) also raise a very pertinent point about gardens being much easier to sell to clients when they can be integrated into the original building design (p. 45). Perhaps the sticker price of the garden is easier to justify when building an entire building from scratch.

5.5 Lack of Industry Standards and Codes

Code books and industry standards are important guides for designers and contractors. They are in place primarily to ensure safety requirements and standard construction methods appropriate to the given locale. Because vertical gardens have yet to be integrated into most codebooks, many designers feel uncomfortable specifying

them in their projects, as they will often have to design their own system and methods of construction. There are many technical aspects to green wall design and construction that require knowledge of a wide array of aspects such as structural engineering, horticulture, biological science, ecology, and architecture. Weight is one concern. One cubic foot of wet soil can weigh up to 100 lbs or 1,597 kg per cubic metre (Peck et al., 1999, p. 16). This means a lot of added weight on a wall that, without proper reinforcement, could easily bring a wall crumbling down. Bass and Baskaran (2001) also note that additional consideration must be made for plants located above 8 stories high due to increased wind (p. 4). This consideration is not specified in any code books so the average designer might not be aware of it, or how to design for it. Given soil weight, as well as the delicate balance of other elements such as irrigation, structural membranes, general materials- both living and nonliving- together with external elements such as sun exposure, wind, desiccation, and disturbance, designing a successful vertical garden is quite difficult. Back in 2001, Bass and Baskaran wrote that there are no current widely accepted standards for green walls (p. 80). Unfortunately, 14 years later, this is still the case. There are more companies that will design and install green walls, but there are also many failed green walls out there. If there were codes and regulations for vertical gardens, many concerns from both designers and clients would be minimized.

5.6 High Visibility of Failed Vertical Gardens

As with all living landscapes, failed vertical gardens can be caused by a number of different factors, though inadequate maintenance is often partisan. Other factors such as failure of the irrigation system, lack of fertiliser or improper application of fertiliser, lack of proper lighting conditions, choice of unsuitable plants, high degree of disturbance, and human error can all be contributing factors. Failed green walls dissuade clients and designers alike from installing or designing their own.

When a garden fails, the whole industry suffers. When a failing vertical garden is seen, there are often no investigations into why or how the system failed, but just the knowledge that it failed. Failed vertical gardens can sometimes be traced back to something as simple as a maintenance worker forgetting to turn a valve back on when they left for the long weekend, but this is not something often considered by someone observing a failed garden. The perception is that the garden as a whole has failed by design. As awareness increases and codes and standards are established, hopefully the success rate of vertical gardens will also increase.

5.7 Associated Risks and Unknown Factors

Canadians have been slow to adopt green wall technology, so there are still many risks associated with construction. These uncertainties include whether or not the systems will work as designed, whether the plants will survive, if irrigation will function as intended (be frequent or infrequent enough to thoroughly water but not oversaturate) how the project will weather over the years, as well as unknown factors that may only become known after installation.

What kind of maintenance does it need? Will it leak? What kind of damage will be incurred on the building if something goes wrong? Will it survive in a cold climate? What is the hardiness of the system? Will it survive if it is in a high traffic area, be it either vehicular or human touch? These are all questions whose answers come from different sources. Different systems will be appropriate in different climates and spaces. Perhaps a significant limitation to the widespread application of green walls is that none of this information has been properly categorized or even organised into one single cohesive document. The document that comes the closest is the *Growing Green Guide of Victoria and Melbourne Australia*. It provides a clear outline of all of the basics of green wall and roof design in two major Australian cities. The *Growing Green Guide* together with a translation of the German *FLL* and Peck et al.'s *Greenbacks from Green Roofs* would form a comprehensive guide that would be a major asset to the industry if available globally.

Another reason why people are nervous to install these systems could have to do with mostly unknown reactions of plants to being on the sides of skyscrapers. Tim DeChant (2013) wrote a particularly interesting rant for *ArchDaily* discussing the boundary layer of plants in relation to their comfort living on a skyscraper. He describes in detail the environment that plants are up against;

> "Life sucks up there. For you, for me, for trees, and just about everything else except peregrine falcons. It's hot, cold, windy, the rain lashes at you, and the snow and sleet pelt you at high velocity. [..] Wind is perhaps the most formidable force trees face at that elevation. Wind also interrupts the thin layer of air between a leaf and the atmosphere, known as the boundary layer. For plants, the boundary layer serves to control evapotranspiration, or the loss of gas and water through the tiny pores on a leaf's underside, known as stomata. In calm conditions, a comfortably thick boundary layer can exist on a perfectly smooth leaf. But plants that live in hot or windy places often have adaptations to deal with the harsh conditions, including tiny hairs on their leaves that expand each leaf's surface area and thus its boundary layer. Still, plants in these environments aren't usually tall and graceful. In other words, not the tall trees we see in architectural drawings," (DeChant, 2013).

Though this article is obviously written by someone who is extremely frustrated with the architectural community's willingness to plaster trees on any available surface in

the name of aesthetics, the author raises a very good point. The boundary layer is not a concept that landscape architects generally have to consider when designing most of our gardens. On the side of a building there are factors that normally don't really exist on grade. The boundary layer is such a factor; Planting at elevated altitudes could wreak havoc on the species there, and potentially cause the vertical garden to fail. There are a variety of projects in various states of construction throughout the world that are planned to have small plants and trees at high elevations. The most famous is probably the *Bosque Verticale* in Milan by Stefano Boeri Studio, which has now finished construction. *The Central Towers* project in Sydney, Australia by Jean Nouvel and Patrick Blanc has vertical gardens planned for the whole facade, which is 380' (116m) tall. While I don't doubt the aptitude of either Blanc, Nouvel or Boeri, I am nervous to see how their vertical gardens turn out. I want to see if the plants survive over time. Judging by the renderings, there doesn't appear to be additional consideration for the gardens at higher elevations. These, however, are drawings produced for publicity, intended in all likelihood to sell to the client and the public, so it will be interesting to see the construction drawings once (if) they are released. Climate will play a big roll in the success of these gardens.

Conclusion

Most of the drawbacks associated with vertical gardening centre around an incomplete knowledge base. This is due to a lack of general awareness on the part of designers and the public, but also due to important information being left out of many research papers. There is also a lack of significant conclusive studies on the economic benefits of vertical gardens; lack of incentives- the cost of products and of installation are very high; and lack of a standard guide to construction or code for vertical gardens. The ultimate goal of my writing this practicum is to provide a reference detailing knowledge currently available on the topic. In this section, the focus has been identifying things that are hindrances to vertical gardening, so that enthusiasts can tackle these issues through further research and promotion. For a complete list of topics recommended for further investigation, see the end of the closing chapter on pages 152-153.

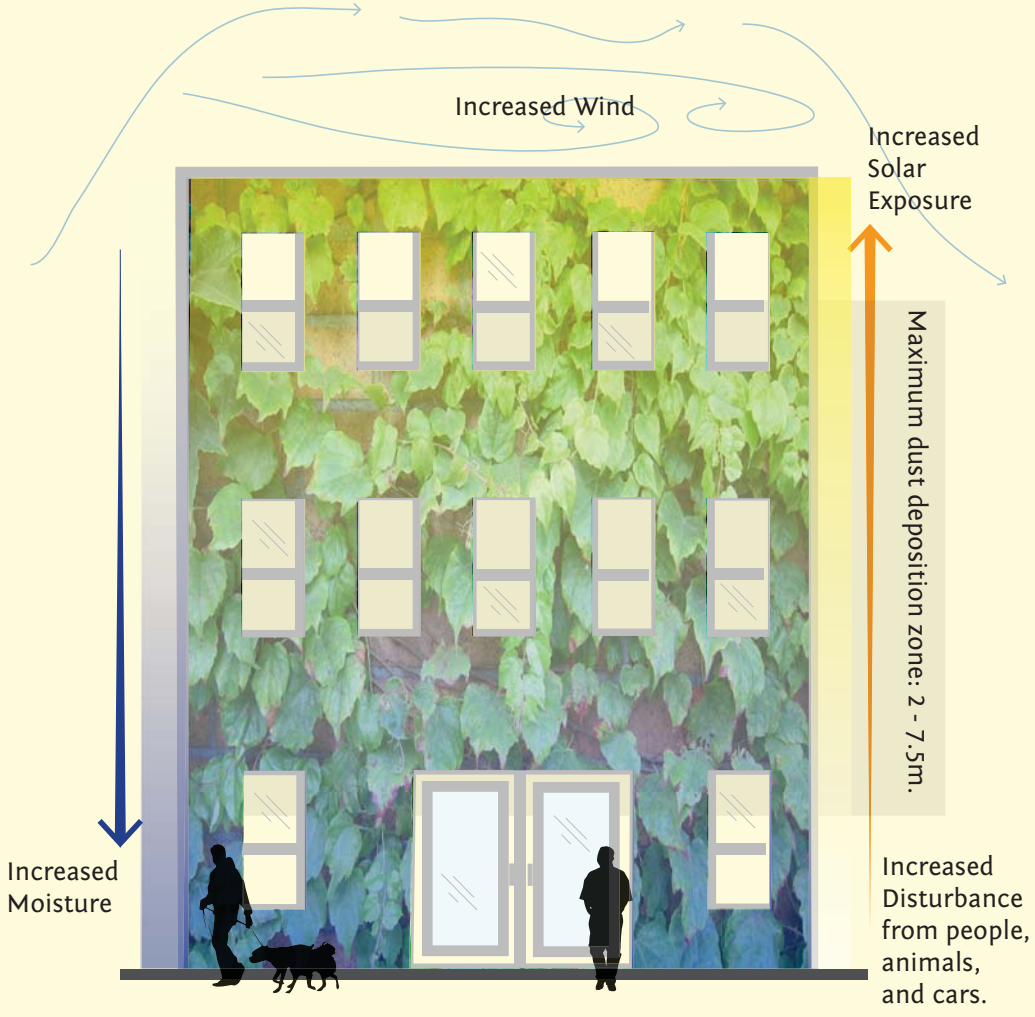


Figure 6.01: Wall microclimates vary tremendously in levels of disturbance, moisture and solar exposure. The top of the wall will generally have more disturbance from wind, and be exposed to more sun, whereas the bottom of the wall will have more disturbance from people, animals and cars, and be exposed to less sun. Because of these factors and due to gravity, moisture levels at the bottom of the wall are usually the highest, while the top of the wall is relatively dry.

6. MICROCLIMATE OF A VERTICAL GARDEN

Though each garden is different, the following aspects tend to be true for most green walls. Green walls can be influenced by a variety of different climatic scenarios. These scenarios will vary from wall to wall depending on the surrounding macroclimate, microclimate of the neighbourhood and microclimate of the wall, and the influence of surrounding plants (Urben-Imbeault, August 28, 2014).

Usually gardens will be drier and have more sun exposure at the top of the wall. At the bottom, more shade and moisture is commonly found. Increased disturbance from people and animals will be exerted on areas of the garden that are within reach of the average person. The most dust and pollution capture will occur from 2-7.5 m in elevation (Köhler, 2008, p. 430), so it is advisable to plant species with large leaves in this zone.

Plants and adjacent buildings have a great influence on the wind patterns, temperatures, drying and shading of a wall. Trees and shrubs in a green wall will provide plants below them with more shade, while walls without trees and shrubs may have more consistent exposure. Variances in wall microclimates can be controlled or modified through material texture, architectural shape (protrusions and depressions) and changing surrounding wind patterns by installing natural or artificial shelter-belts. Altering the microclimate of a wall is a very complex undertaking, and will need to be studied and designed case by case.

The microclimate of an interconnected vertical garden (one with connected rather than isolated planters) is generally a gradient of temperature and moisture. It ranges from hot and dry at the top, to slightly cooler, and more moist at the bottom (Urben-Imbeault August 28, 2014). At the top of the wall there is often increased solar exposure (depending on the prevalence of shadows cast by adjacent buildings), and increased wind. These two factors typically result in decreased moisture (August 14, 2014).

More shade is often prevalent towards the bottom of the wall (due again to neighbouring buildings), as well as lower wind speeds, which result in increased moisture and humidity (Urben-Imbeault, August 28 2014).

Figure 6.02: Located directly beside the Granville bridge freeway in Vancouver, this garden is perfectly located to capture unwanted dust from the freeway.

Water within the vertical garden will accumulate at the bottom of the wall and contribute to higher moisture levels (August 28, 2014).

The first storey of a facade will also face increased disturbance from people, animals and passing cars (Urben-Imbeault, August 28 2014). If gardens are within reach of people, often they stand a chance at being vandalised or harmed. Passing cars will contribute to higher salt levels in the garden during spring melt, making it necessary to increase irrigation to remove pollution and salts from the garden. After spring melt, it will be necessary to fertilise the garden.

Between 2-7.5 m in elevation, the most dust will be captured on leaves (Köhler, 2008, p. 430), demonstrated in figure 6.01. If dust deposition is a priority, plant species with large leaves should be chosen, as the amount of dust accrued is directly relative to the size of the leaf itself (p. 430). A good example is shown in figure 6.02, which shows a green wall in Vancouver located beside a freeway. This wall is composed of large-leaved vines which are best suited to capture dust.

The orientation of the wall will affect all of the details listed above. South facing walls, for example, will heat up more during the day (solar gain) and will tend to be drier than a North facing wall which wouldn't be exposed directly to the sun and thus would retain moisture. If the wall is within a particularly windy zone, however, it may lose moisture.

During the habitat template studies of various cliffs in the Ottawa and Manitoba regions (see chapter 9, section 1), it was noted that cliffs facing West had the highest plant species diversity. This is due to insolation received, which is enough to allow plants requiring more light to grow, but not enough for rapid dessication. It could also be due to the heat of the sun being absorbed and stored in the cliff face, extending the growing season for plants there. It is for this reason that walls chosen for vertical garden speculation in Winnipeg were predominantly western facing facades.

Conclusion

Every niche of a green wall is the result of the influence of multiple environmental factors, and therefore all of the information given here should be used as a guide only. Green walls tend to be dry and sunny at the top, and moist and shaded at the bottom. Wind varies by height, nearby structures and region, but generally tends to increase in frequency and velocity at higher elevations. Dust and pollution are mostly trapped between 2-7.5 m in height (Köhler, 2008, p. 430). The orientation of the wall, and its location within a given region will impact all of these aspects.

Figure 7.01 Location of Winnipeg, Manitoba.

7. REGIONAL AND NEIGHBOURHOOD CLIMATES IN WINNIPEG

Winnipeg, Manitoba has been chosen as the location of study. Winnipeg's downtown has been studied on a macro-scale and micro-scale. First, a brief introduction of what this city means to me will be given, and following that, an explanation of what the Agriculture and Agri-Food Canada classification of Zone 2B means in terms of seasonal temperature highs, lows, averages, precipitation, humidity, and sun, and wind exposure. The microclimate (focusing on sun and wind) in the downtown core will then be examined in further detail. The influence of the UHI, wind pattern interactions with skyscrapers, stormwater drainage, building albedo, and other human-related factors will be examined.

7.1 The Place and its Influence: Winnipeg, One Great City!

In the summer of 2013, while I was staying in Costa Rica, I took a trip to Nicaragua, where I was warned by many people that it was "hotter than hell." All of the people who warned me were Ticos (Costa Ricans), so I expected a blistering 50°C+ and full sun, no wind, full humidity and no relief in sight. I was surprised, however to find out when I arrived, that it was only in the mid 30's and a cooling rain fell every afternoon like clockwork. This kind of weather was not new or even uncommon to me. In fact, it regularly gets to 30°C and over in Winnipeg in the summer, which I explained to my Tico friends; "But doesn't it go down to -40°C there?" they would ask. "Yes, it does. But it also goes up to 40°C in the summertime, and it is very humid and the air doesn't move at all. It's like living in a giant bowl of steam," I told them. They were floored. For some, I even had to explain it multiple times before they really got it. In Costa Rica, the temperature is always 32°C during the day and about 21°C at night, fluctuating only according to elevation. It rains everyday at about 2pm during the rainy season. It has the most predictable weather I've ever experienced, which is, I suspect, why it was so hard for them to understand our extreme climate. When you come from a place where it is always the same temperature year round, it is very hard to understand such drastic fluctuations. I learned through those conversations that what distinguishes our climate from so many others is not solely how

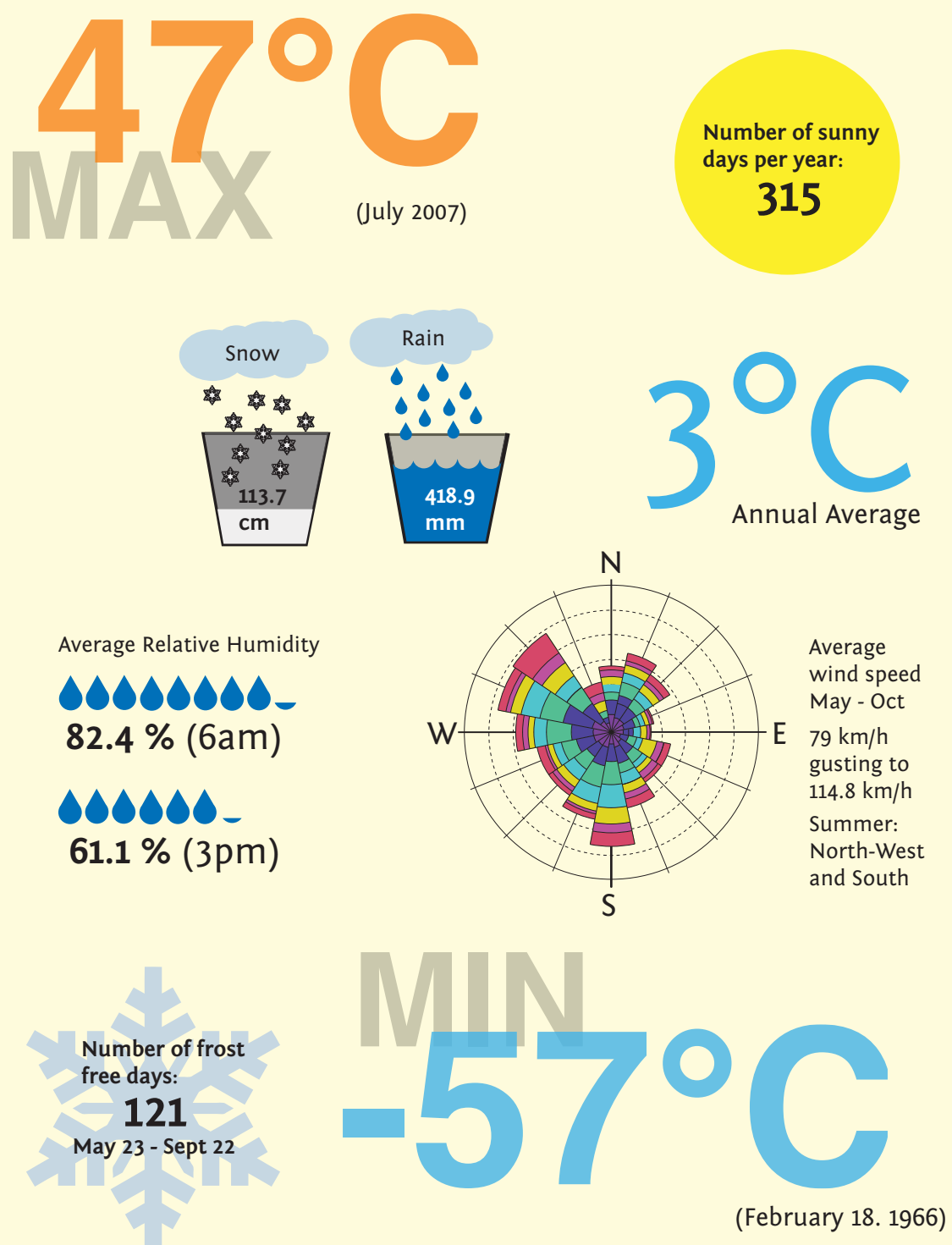


Figure 7.02: Winnipeg's regional climate: Cold Continental. Numbers shown are maximums and minimums collected throughout the last 100 years.

cold or hot it gets, but that we experience both extremes, and often within a short period.

I grew up in Winnipeg. From Charleswood to St. Boniface, the West End and the downtown area, I have moved around the city a fair bit in my nearly 30 years here. It is a very interesting place. When people ask me about it, I often tell them an anecdotal story about how it feels to be a Winnipegger: "You know that couch that you bought for cheap from a friend? At first it's not very comfortable at all, but then a nice personal sized groove starts to form, and sucks you in. Then one day you try to get up, and realise you can't. That's what living in Winnipeg is like." I love to hate this town, but I also love to love it.

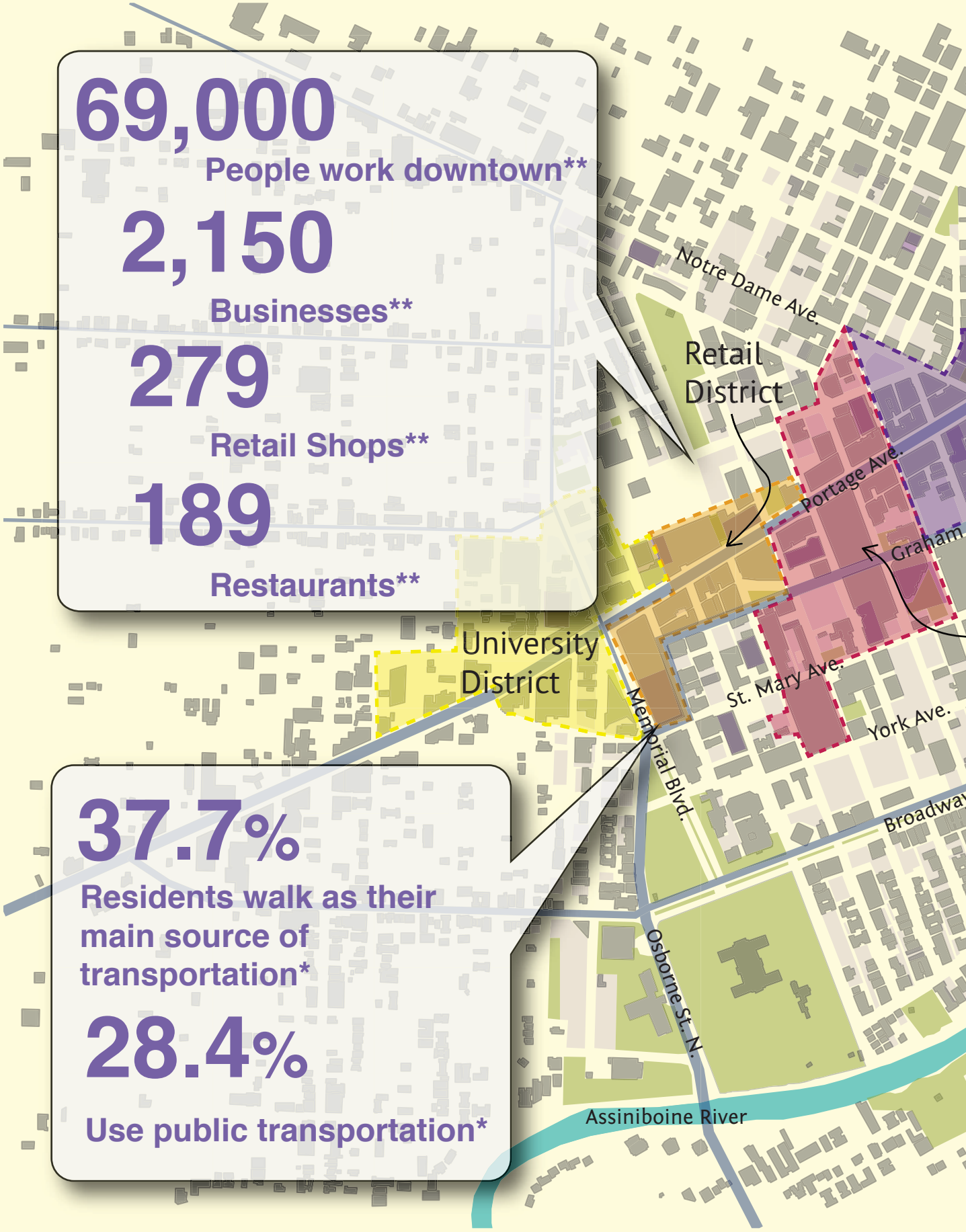
7.2 Zone 2B

Winnipeg is located at the geographic location of 49°55'00.000" N 97°14'00.000" W at an elevation of 238.7m above sea level (Government of Canada). It is located in a prehistoric lake bed, known as Lake Agassiz. Due to Lake Agassiz, the centre of Canada is a continuous large, flat, muddy region. Winnipeg is located almost directly in the centre of the North American continent and was founded first as a trading post, and then later as a train cargo port. It is currently the 8th largest city in Canada, with a population of 730,018 in the 2011 census, with an average density of 137.7 people square kilometre, occupying a total land area of 343.6 square kilometres (Government of Canada).

In its infancy, the city of Winnipeg was poised to be the largest Canadian metropolis. Rail lines and roads all lead to Winnipeg at the time, because of its convenient location in the middle of the continent. It boomed in the early part of the century, but the opening of the Panama Canal began its slow decline, which continued through the 20th century (Levine, 2014). The advent of the automobile gave rise to the trucking industry and with advances in aeronautics, Winnipeg became an unnecessary stop on the way west, as ships could now pass through Panama, completely avoiding central North America (Levine, 2014). These economic factors, along with sprawling suburbs and other typical North American planning issues, have given rise to a city that is now, in many ways, a mere shadow of its former self.

Winnipeg is located in the Agriculture and Agri-Food Canada's zone 2b, which means that the weather in Winnipeg fluctuates from an average of -20°C during the winter months to 25°C during the summer months (The Weather Network), however those temperatures do not take into account the winter windchill, nor the summer humidex, which makes these temperatures feel a lot more extreme. With the humidex, temperatures have reached up to 47.3°C (in July 2007) and down to -57.1°C with the windchill (in February 1996) (Government of Canada). This 90°C difference is bigger than what Winnipeggers usually see in a year. There was a variance of between 70°C to 80°C from summer to winter between 1981 to 2010 documented by the Government of Canada.

The average annual precipitation Winnipeg receives is 521.1mm, 418.9mm of which is rain, the remaining 113.7mm is snow. Precipitation levels are highest during the months of June and July, with averages of 90mm and 79.5mm respectfully (Government


69,000
People work downtown**
2,150
Businesses**
279
Retail Shops**
189
Restaurants**
Retail District
University District
Notre Dame Ave.
Portage Ave.
Graham
St. Mary Ave.
York Ave.
Broadway
Memorial Blvd.
Osborne St. N.
Assiniboine River
37.7%
Residents walk as their main source of transportation*
28.4%
Use public transportation*

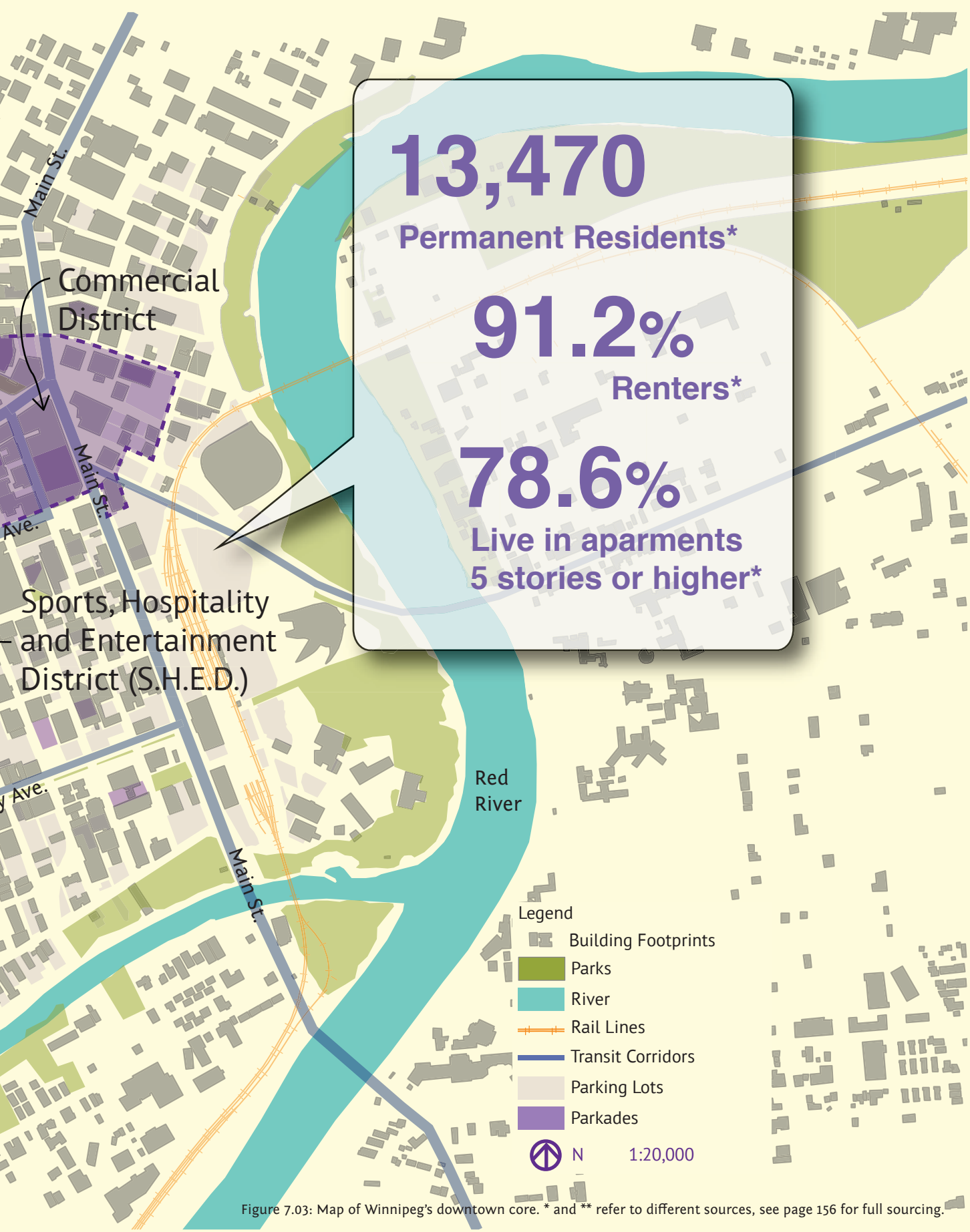


Figure 7.03: Map of Winnipeg's downtown core. * and ** refer to different sources, see page 156 for full sourcing.

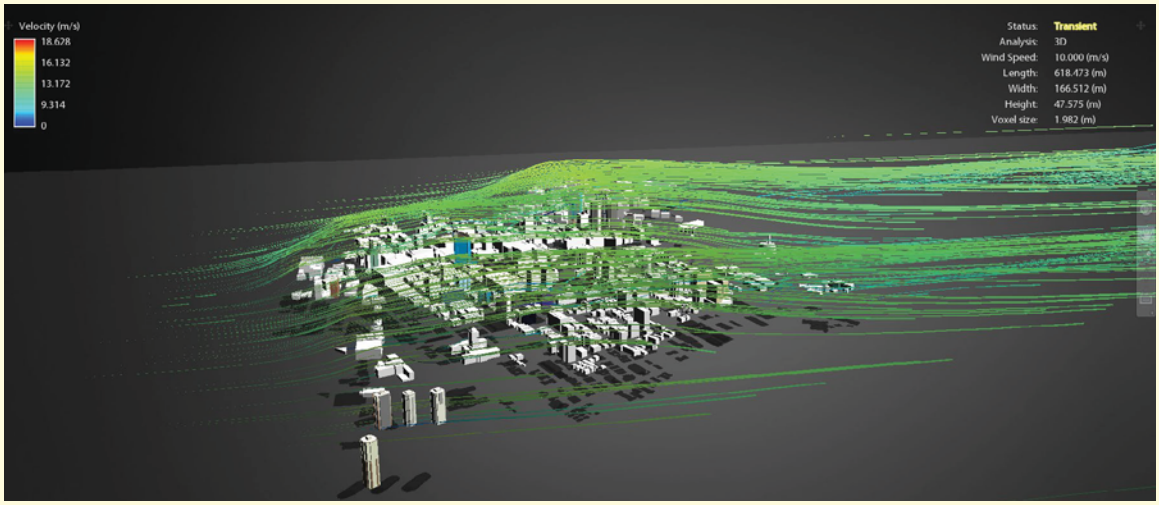


Figure 7.04: Screen shot showing boundary layer of downtown Winnipeg.

of Canada). Winter months generally have the least precipitation, with February receiving the least at 13.8mm for the entire month (Government of Canada).

The average humidity level ranges from 34% to 87%, but rarely goes below 21% or above 97% (Weather Spark). April 20th generally has the lowest humidity with an average of 34%. Generally August 28th has the highest level of humidity at 87% (Weather Spark).

Most days in Winnipeg are fairly windy. Speeds of 79 km/h are common, with gusts of up to 114.8 km/h (Government of Canada). Figure 7.04 shows a digital simulation of the average boundary layer of the downtown on a moderately windy day. The important aspect to note is that wind force and speed are altered significantly by built form.

Sun exposure in Winnipeg is generally high, with the darkest months concentrated during the winter (Government of Canada). In a single year, Winnipeg will experience measurable sun exposure an average of 315 days out of 365. Bright sunshine is only recorded about 51% of the time (Government of Canada). Average shadow casting of downtown shown in Figure 7.05.

Because of all of these factors, the growing season in Winnipeg is very short. Generally, the last frost occurs around May 23rd, and the first frost of winter around September 22nd (Government of Canada). The natural growing season is just over four months long, which severely limits the number of plants that can grow.

7.3 Neighbourhood Microclimate; Urban Geometry, Materials and the UHI

The UHI is a phenomena found in many cities around the world, as well as in downtown Winnipeg. In recent years the UHI has become a concern to environmentalists, as it can be a significant factor in climate change, and global warming. For landscape architects, the UHI is of particular concern, in terms of the level of human comfort in cities, plant

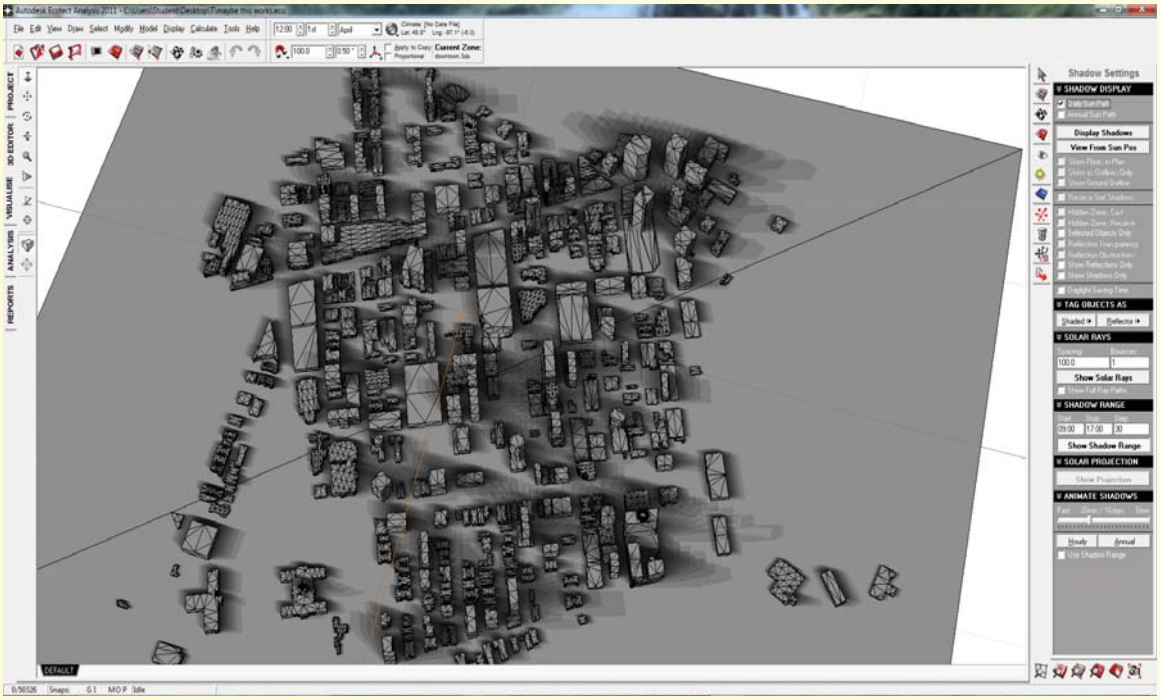


Figure 7.05: Shade analysis of downtown Winnipeg. Combined shadows for an entire day are shown.

hardiness (what can be grown in cities), and our desires to positively impact the world - to decrease the UHI through design.

Urban geometry can affect the UHI in a variety of ways. The density of buildings, and their placement relative to one another is one of the largest and best understood influences of the UHI. Urban canyons (or streets lined with tall buildings on both sides) can be contributors because they can lower the reflectivity and absorption of solar radiation. These factors combined with materials having low albedos, lower wind speeds (air flow) at ground level and restricted sky views (inhibition of emission of longwave radiation back to the sky) can drastically increase the amount of heat stored in an urban area (Erell et al., 2011, p. 67-84). The urban geometry in Winnipeg does not have as many deep, cavernous urban canyons as cities with higher densities and more towers (like Toronto or Vancouver), however the effect is still present. It may be more easily felt in areas like back alleys. Because of the geometry of Winnipeg streets, light is still able to permeate most of the downtown, demonstrated in figure 7.05.

Impervious surfaces contribute to UHI based on how well or poorly they drain. After a rain event, if water is drained quickly, evaporation is limited. Evaporation and high humidity levels can contribute to the lessening of the UHI. Clear days have a higher instance of UHI, on cloudy days it is lower (Erell et al., 2011, p.73).

Perhaps one of the most anecdotally well known influences of mitigating the UHI is vegetation. It helps reduce the UHI in a variety of ways; it aids in blocking incoming longwave radiation and outgoing radiation from the ground; it can block solar radiation

and create cooling shadows; it can decrease wind speed and adds moisture through evapotranspiration, all of which can result in a more pleasant-feeling environment for people (Erell et al., 2011, p.73).

Material albedo is directly related to the amount of solar gain a material accepts. If it has a low albedo, it will absorb more solar radiation, whereas if it has a high albedo, more radiation will be reflected back out into the sky. This is why it is desirable to use materials that are lighter in colour- materials with a high albedo (Erell et al., 2011, p.74). In order for the albedo to make a difference, however, sun must permeate the urban condition. The penetration of sunlight to the bottom of urban canyons is often much more limited in Northern cities like Winnipeg, because the azimuth of the sun is much lower, and therefore sunlight is more easily obstructed by buildings. This phenomenon is lessened in Winnipeg due to the limited height of most buildings.

The influence of human related heat affects UHI conditions. In colder climates, extra heat may be accidentally lost through leaky buildings. Similarly in warm climates, cooling may result from cool air escaping from buildings with air conditioning. Fossil fuel emissions and industrial pollutants can also contribute to warming (Erell et al., 2011, p.74).

The effects of the UHI are mostly felt at night, when the heat of the day is retained within each of the boundary layers above (see Chapter 4, section 2). For that reason, some people refer to the UHI as the Nocturnal Heat Island. There is also a somewhat less studied counterpart to the UHI called the Daytime Cool Island. This effect tends to be less drastic, and is therefore not observed so directly (Erell et al., 2011, p.76). The UHI and daytime cool island effect are directly related, and share all of the influences listed for the UHI.

The UHI and daytime cool island effect can be mitigated through control of solar gain, use of materials with high albedos, and through landscaping. The influence of the UHI is felt throughout the city and can vary from neighbourhood to neighbourhood. It is especially important to understand its influence when choosing plants for landscape projects such as vertical gardens, as these plants will be especially vulnerable to microclimate influences. They will experience more extreme changes in temperature and solar gain compared to horizontal gardens because they are less directly affected by the Earth's inherent heat. In areas affected by a significant UHI, the differences will be less extreme. During the winter, plants will also be subjected to rapid desiccation and scouring from high wind speeds.

The UHI can be beneficial for plants. They benefit from smaller fluctuations in temperature during the winter when the UHI is present. Any change of the UHI may ultimately dictate plants used in vertical gardens. Decreased UHI will require hardier plants than seasonal normals dictate now. Gardens planted within close proximity to parks may, for example, experience extreme fluctuation of ambient weather conditions, and will require hardier plant varieties.

Conclusion

Climate has a overreaching influence on vertical gardens. Regional climates can be dry, wet, hot, cold or any combination thereof. A vertical garden must be designed for the climate it will be located within. If proper planning is not followed there will be failures, either with the design, or plants.

Winnipeg is located in the middle of North America and enjoys a climate that is warm during the summer, and cold during the winter. This variance must be planned for in vertical gardens here. The UHI affects downtown Winnipeg due to the prevalence of sun and urban geometry that allows it to permeate down to the streets. Winnipeg UHI is increased by the abundance of hardscaping, rapid drainage after storm events, and low albedo materials absorbing the sun's heat.

The UHI helps mitigate temperature fluctuation in the downtown, and therefore the range of temperatures plants are exposed to is less in areas highly affected by UHI.

Figure 8.01: Roadside cliffs in the cloud forest of central Costa Rica.

8. FOUNDATIONS

There are many foundational theories that have been significant to my development as a designer and a student of ecology. The Human Ecosystem Model is in accord with my own personal landscape philosophy. Now that humans have arguably influenced every place on the planet, we need to re-evaluate our notions of ecosystems to include ourselves, because we are and will remain to be a massive influence on the planet. Urban Reconciliation Ecology told me that there was a way to integrate ecosystems into cities without having to make many adjustments or compromises with existing infrastructure. The Urban Cliff Hypothesis directed me to the study of cliffs as precedents for vertical garden design. Habitat templating gave me the direction I needed to design the plant pallet. With the information gathered about the microclimate of a vertical garden (see Chapter 6), I found suitable plant communities that thrive within similar environmental conditions and stresses. Finally, wall ecology tied all of these theories together seamlessly. Each of these theories contributed to my understanding of green walls and the interaction of cities and plants.

Humankind's quest for colonization and control over nature has lead to exponential growth of cities throughout the last century. Dr. Marina Alberti, a professor in the Department of Urban Design and Planning and adjunct professor in Landscape Architecture at the University of Washington writes in the preface to her book *Advances in Urban Ecology* (2008) that people have transformed landscapes into human-dominated environments, changing energy flows, nutrient cycles, hydrology, species and plant communities (preface, xi). She notes that the populations of 20 of the world's largest cities are now over 20 million, compared to the populations of just two cities in 1950 (p.4). This rapid densification and large scale development has given rise to a new set of complexities in the urban environment. Increased hardscaping and decreased biotic diversity are drastically modifying microclimates and air quality in our cities (p.4). According to Alberti (2008) we can develop a new understanding of the role of people and cities in the natural world by looking at cities as a hybrid phenomena involving human, ecological and artificial

"Nature has all the answers. What is your question?"
- Howard Odum in Despommier 2010

Figure 8.02: Corktown Commons, Toronto. Design by Michael Van Valkenburg Associates.

processes (p. 6). She is not specifically referring to Urban Reconciliation Ecology, but the core belief is the same: human beings need to start working with Mother Nature to develop a new way of developing urban areas.

One of the challenges of integrating pre-settlement ecosystems into urban sites is that few ecosystems are suitable to the conditions of North American cities today. Theories like Doug Larson's Urban Cliff Hypothesis and habitat templates thus become critical to understanding how to integrate new vegetation and habitats into existing cities. Using these theories for guidance, I hypothesize the most appropriate naturally occurring ecosystems for urban walls are those naturally located on cliffs, in alvars (rock outcrops) and in deserts. Patrick Blanc (n.d.) writes that, "plants can grow on tree trunks and branches (epiphytic habit) as well as on soil-less habitats: sandstone or granitic outcrops, limestone cliffs, caves, waterfalls as well as natural or man-made slopes" (p. 1).

Should living roofs and vertical gardens be engineered to replicate 'natural' or semi-natural habitats or should they be used as a tool to create spontaneous, novel 'recombinant' assemblages (Hinchliffe and Whatmore, 2006)? I have chosen to follow the principle of Francis and Lormier's Urban Reconciliation Ecology as opposed to the traditional preservation or restoration paradigms (Francis & Lormier, 2011, p. 143). Designing systems for varied and functional assemblages of species to colonise is the best approach (Hobbs et al., 2006).

8.1 Human Ecosystems Model

The human ecosystems model is based on a desire to manage ecosystems affected by humans and development in a way that responds to and accounts for human interference in the ecosystem (Machlis, Force and Burch, 1997). It has become obvious that the ecology in cities is highly altered by human intervention, and that urban ecosystem models must acknowledge this. Ecologists and natural scientists have realised that leaving humans out of ecosystem models is akin to not including a particular animal, plant or invertebrate (Alberti, 2008, p. 15). Since urban ecosystems differ so drastically from other ecosystems in so many ways (isolated patch habitats, propensity of non-native species, controlled successionary patterns, varying microclimates, increased runoff, and various differences in soils) the Human Ecosystems Model determined that they should be studied independently, not forced to conform to a historic/pre-settlement interpretation of ecological communities (p. 63).

8.2 Urban Reconciliation Ecology

Robert Francis and Jamie Lormier of Oxford and King's College London, respectively, published an article in the *Journal of Environment* in 2011 in which they define urban reconciliation ecology as the study of how "the anthropogenic environment may be modified to encourage non-human use and biodiversity preservation without compromising societal utilization," (p. 1). They propose that reconciliation ecology will be especially relevant to cities that have a highly modified and/or cosmopolitan biodiversity that is lower than the pre-urban

ecosystem and that wish to improve these aspects (p. 1). Reconciliation ecology is essentially a design and planning oriented twist on the established field of ecological engineering which deals with the design, monitoring and construction of ecosystems.

Urban Reconciliation Ecology intrigues me most in that it would allow for the integration of landscape infrastructure in cities, without compromising existing land uses. This means businesses can continue to grow and profit while a layer of ecological infrastructure is added to/in/around them. Two relatively low impact kinds of this type of design are green roofs and vertical gardens (in terms of their disturbance to existing buildings or spaces). Each exist within horizontal, vertical and frequently unnoticed spaces in the urban matrix. Both walls and roofs are typically considered containing elements (shelter) and ideally provide an aesthetic amenity to the area or the street they occupy. Beyond that, roofs and walls are considered as boundaries and billboards. Vertical gardens and green roofs are a responsible way to integrate plants into otherwise mostly plant-free areas in cities. They can be symbiotic, residing on or on top of a building, using some of the amenities of the building such as added heat, water, and shelter from wind, but also providing the building with an added cooling layer, dust and pollution control, and stormwater absorption.

Francis and Lormier (2011) mention a couple other leading scholars on the topic; "[Jeremy] Lundholm and [Paul] Richardson (in press) have recently argued for greater consideration of artificial urban habitats such as walls and pavement as 'analogue' habitats that can support species from comparable natural habitats (in this case rock pavements and cliffs)" (p. 1). Lundholm and Richardson are re-interpreting the urban landscape in terms of similar naturally occurring ecosystems on the planet, or "habitat templates." Some urban habitat templates found in the naturally occurring world are cliff faces, alvars and desert-like areas (see chapter 9). The most limiting factors in these ecosystems are soil depth, potential for drought and/or flood conditions, high solar exposure, and high solar radiation absorption (thus high surface temperatures), and limited propagule dispersal, all of which bear striking resemblances to urban conditions. Other influences found in cities that may or may not be present in natural communities: increased pollution, salt, dust, VOCs, acid rain, wind, and of course direct human disturbance (picking flowers, digging up plants, and our seemingly inherent desire to limit plant growth to designated areas only).

8.3 Habitat Templates

Habitat templating is the design tool used to select the plants in the vertical garden design. Habitat templating was originally proposed by T.R.E. (Richard) Southwood, a zoologist and entomologist, and adviser to governments on the scientific aspects of health and environment policies (Prof Sir Richard Southwood Obituary, 2005). His theory, as described by Lundholm (2006), is that in order to create successful habitats, we need to study existing habitats (p. 140). The key is to find habitats that thrive within similar environmental parameters as the site in question. In this practicum, this approach was used to more closely understand the

dynamics of plant communities on walls (whether manmade or not) to create a successful novel landscape patch that could integrate the city into the regional matrix.

From the point of view of a plant, cities have become similar to deserts. *Merriam Webster* (2013) defines a desert as, "arid land with usually sparse vegetation; especially: such land having a very warm climate and receiving less than 25 centimetres (10 inches) of sporadic rainfall annually," but for the purpose of this practicum, a desert will be defined as an area that receives very little precipitation. Though not all of these conditions apply to cities, the most critical condition, lack of precipitation, is applicable due to the lack of permeable surfaces. Much of the ground cover in cities is concrete or asphalt or occupied by a building - all of which have very high runoff coefficients. High runoff coefficients mean that very little stormwater runoff can be absorbed by the ground underneath the concrete. This can lead to drought-like, or desert-like conditions. This effect occurs on walls as well, though it is mostly due to the limited floor area that the wall occupies. Unless surrounding runoff is designed to drain into the vertical gardens nearby, the amount of precipitation absorbed from the sky will be minimal. On days when wind pushes rain in towards the façade, a vertical garden will receive some natural irrigation but such events are not predictable, nor are they frequent enough to be counted on.

Integrating pre-settlement landscapes or native habitats like prairie grasslands into cities will require the re-evaluation what a 21st century urban habitat matrix can be. Communities that thrive in unbuilt areas adapt and change drastically to thrive in urban environments. A grassland community that grows in an unbuilt area will be different from that same grassland community growing in the city. They will be composed of different plants that have specific adaptations necessary for survival in the city such as pollution, drought, and flood tolerances and will occur in different abundances compared to their rural counterparts. Pre-settlement re-creations would likely be more suited to public parks, for example, because of the amount of care needed to maintain them in an urban environment.

For vertical gardens in Winnipeg, the anticipated outcome of this design practicum will be a hybrid of various Manitoba plant communities- cliff, alvar, desert-like sand dunes, mixed grass prairie and prairie pothole- designed to host specific invertebrates like butterflies or small birds. The mix will use plants from each community that will be the hardiest and most well adapted to the stresses of living on an urban wall, explored in detail in chapter 9.

8.4 Urban Cliff Hypothesis

Larson's Urban Cliff Hypothesis provides many clues as to how skyscrapers and roads can be similar to cliffs and valleys. The number of plants that can survive in cities is limited, but the Urban Cliff Hypothesis posits that the plants and animals that we now find to be nuisances in cities were once endemic to cliffs and caves and have evolved out of prehistoric caves with us. The environments we tend to create are arguably similar to those prehistoric spaces - mostly hardscapes with minimal plants (Larson, Matthes and Kelly,

"The urban cliff hypothesis makes you respect all the stuff you've always hated."
- Doug Larson in Vowles, 2004

Figure 8.03: Weeds growing in a crack in the pavement.

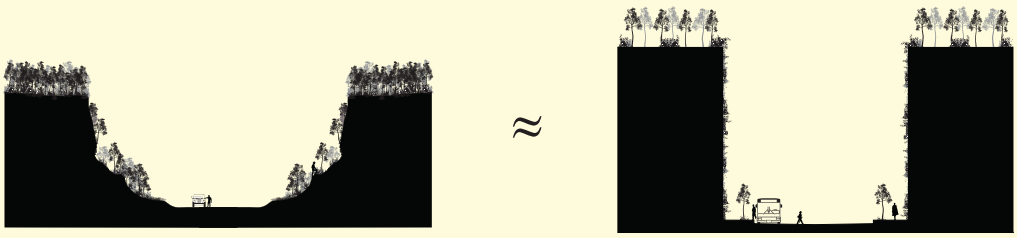


Figure 8.04: Similar geometry and material composition make a naturally formed canyon similar to an urban streetscape.

2000). According Larson et al. in their 2000 book entitled *Cliff Ecology*, creatures such as rats, mice, pigeons, bats and many plants that were once much less common have followed us through time, from one kind of cliff habitat to another, the most recent made of concrete, stone and glass (p. 156). Figure 8.04 depicts this similarity in terms of the overall geometry. If we plan to integrate plant matter into our city environments, we should look to these ancient communities for inspiration, not only in terms of species diversity, but also in terms of the structure and overall function of the habitat. Cliffs are the most obvious habitat template for urban canyons. Steep rock faces, often almost perfectly vertical, occur frequently and are usually composed of rock and sediments that have been formed over time by water and air. Walls are similar to cliffs both in terms of their structure, orientation, and the types of plants and animals/invertebrates found on them.

One of the unfortunate aspects of the Urban Cliff Hypothesis, in terms of its implications for design in cities, is that cliffs in general have not been widely studied. Larson et al. (2000) gathered all the information that was available, and assembled it in *Cliff Ecology (*p. 156). That book, therefore, will be the main source for information regarding these often underestimated and misunderstood ecotypes. Manitoba hosts relatively few of the large cliff-type ecologies described in the book. A similar, more widely studied Manitoban community is alvar. Manitoba it is home to nearly 9,700 acres (3925 ha) of alvar habitat (Nature Conservancy Canada, 2013), an environment similar to cliffs, existing on the horizontal plane rather than vertical.

The Nature Conservancy of Canada (NCC) defines alvars as communities which occur in areas with 10 cm or less soil over unbroken limestone 'pavement' that are susceptible to both flooding and extremely arid conditions (2013). Such communities exist in only a few provinces and states in North America. In Manitoba there are four different types of alvar communities; savannah alvar, shrubland alvar, grassland alvar, and wetland alvar (2013). The type of outcrop researched in this practicum is the grassland alvar, even though alvars are known to host a mix of both boreal and prairie plants (2013). The main reason for studying the grassland alvar is that it most closely resembles the desired aesthetic outcome of the vertical garden.

Figure 8.05: Plants growing on a wall in Britain.

8.5 Wall Ecology

Wall Ecology is the study of vegetation's colonisation of man-made walls (Darlington, 1981, preface). In 1969, S. Segal's *Ecological Notes on Wall Vegetation* catalogued and examined what some urban ecologists had been noticing in Europe for a while - the seemingly spontaneous growth of plants on ancient walls (p. 9). Segal writes in detail about specific plant species examined and situations observed through his study of over 1,200 walls in various parts of Europe (p. 9). This study remains one of the most influential writing on the topic. Segal's study sites were mostly ancient brick or stone walls (most commonly castles, fortifications, and river walls) which were partially decayed, later adding cracks in paved roads to the inventory (p. 9).

Arnold Darlington notes in his book *Wall Ecology* (1981) that the reason vegetation is not as commonly found on newer construction is not just because of their shorter lifetimes, but also to the chemical properties of the wall (p. 5). Walls built before the mid-19th century were generally stone or masonry joined with a soft calcareous mortar, a mixture of lime, sand, loam, straw and often cattle dung with proportions varying depending on local availability (p. 4). Until the discovery of Portland Cement around 1870, mortars cracked relatively easily and retained more water than they do now, making them more hospitable environments for plant colonization (p. 4). Brick and concrete materials used now are mostly alkaline, with pH values generally between 7 and 9 (Darlington, 1981, 5; Francis, 2010, p. 47). For comparison, Portland Cement has a pH of between 11 and 12 (Francis, 2010, p. 47).

Figure 8.05 shows a historic wall in Europe that is well lined with plants, while figures 8.06 and 8.07 show a much newer example of spontaneous wall colonisation of a fairly new retaining wall in Toronto. Plants growing here are not squeezing their roots into the wall itself, but rather growing out from the soil behind the wall. Though different than Segal and Darlington's studies, the end result is similar: spontaneous colonization of a wall by plants.

Lichens and mosses typically aid in the breakdown of wall materials. They hold water which helps to quickly break down lime, creating suitable niches for plants (Darlington, 1981, p. 10). Additional influences from animal excrement can be corrosive, or nutritive (p. 10). Solitary bees are sometimes found nesting in mortar, while ants frequently occupy the inside of a wall, altering its shape and chemical composition (p. 10). Each of these influences aid colonization by plants.

Segal's colonizations of wall microenvironments are similar to those identified in cliff studies (see chapter 9, section 1): wall base, middle level, upper level and wall top (1969). Of these, the base is generally the wettest, and where many mosses and some liverworts colonize (Darlington, 1981, p. 5). As Darlington explains, there is frequently a ledge that separates the upper and middle levels (sometimes made of different materials) that provides the niche necessary for the first growth of vascular plants. Vascular plants retain moisture and with the overshadowing from the ledge, usually result in a more humid upper level than middle. Conditions of the wall top are noted to be potentially quite different from site to site depending

Figure 8.06: Colonisation of a steel wall by plants on a southern facing street-side retaining wall, Toronto.

Figure 8.07: Unplanned colonisation of a steel wall by plants on a southern facing street-side retaining wall, Toronto. Note species of yarrow, nightshade and grasses.

on human and animal disturbance. On walls with a perfect 90° inclination, typically few vascular plants are found (p. 5).

Southern exposure is much less hospitable to plants on walls, than on cliffs (Darlington, 1981, p. 12). Northern exposures are generally more rich (p. 12). Darlington explains that a south wall is exposed to desiccation by direct sunlight, while a west-facing wall is exposed to the prevailing winds. North and east walls are more sheltered from the sun so they retain higher humidity level. They are more suitable to hosting plant life as their temperature variations tend to be less great (p. 12). Lower temperatures are found to be reached more quickly on wall surfaces than other nearby surfaces (p. 13) so often the range of annual temperature differences can be more extreme than on other surfaces. Darlington is very careful to mention that these are generalised observations that are subject to modification by local conditions (p.12).

Similarly to cliffs, wall decomposition and separation of cleavage and bedding planes are some of the key factors in creating suitable niches for plant growth in walls. Darlington explains, "cavities form in limestones, schists split along cleavage-planes, sandstones crumble, granites become fine gravel" (p.14). He observes that the breakdown of lime mortar is similar to limestone, while cement, mortar and concrete behave more similarly to granite. This breakdown, combined with added aeolian and fluvial particulates from the surrounding area strongly influence what can grow on the wall (1981, p. 14).

The successionary evolution of wall vegetation happens over many years, depending on the conditions of the wall. Unlike cliff succession it is well documented, likely due to a comparatively accelerated timeline (hundreds of years versus decades). It begins with lichens and bryophytes as pioneering species. They incite erosion and substrate formation, which eventually leads the way for the establishment of higher plants (Darlington, 1981, p. 18-19).

Conclusion

The human ecosystems model, urban reconciliation ecology, the urban cliff hypothesis, habitat templates and wall ecology have been paramount to the evolution of this practicum. Acknowledging that change is inevitable in today's human influenced word according to the principle of the human ecosystems model is merely the beginning. Urban Reconciliation Ecology helps to encourage a fresh way of thinking of human activities in relation to natural ones, and how the two can coexist in a mutually beneficial way. The Urban Cliff Hypothesis further emphasizes the connections between man made infrastructure and natural ecosystems, principally cliffs. Once the city is understood as though it is a natural community, habitat templating can provide further insight into potentials for habitat creation within the city. Wall ecology is the embodiment of all of these theories combined helping to clarify many different aspects of growing plants on walls, such as how they are colonized, why and by whom.

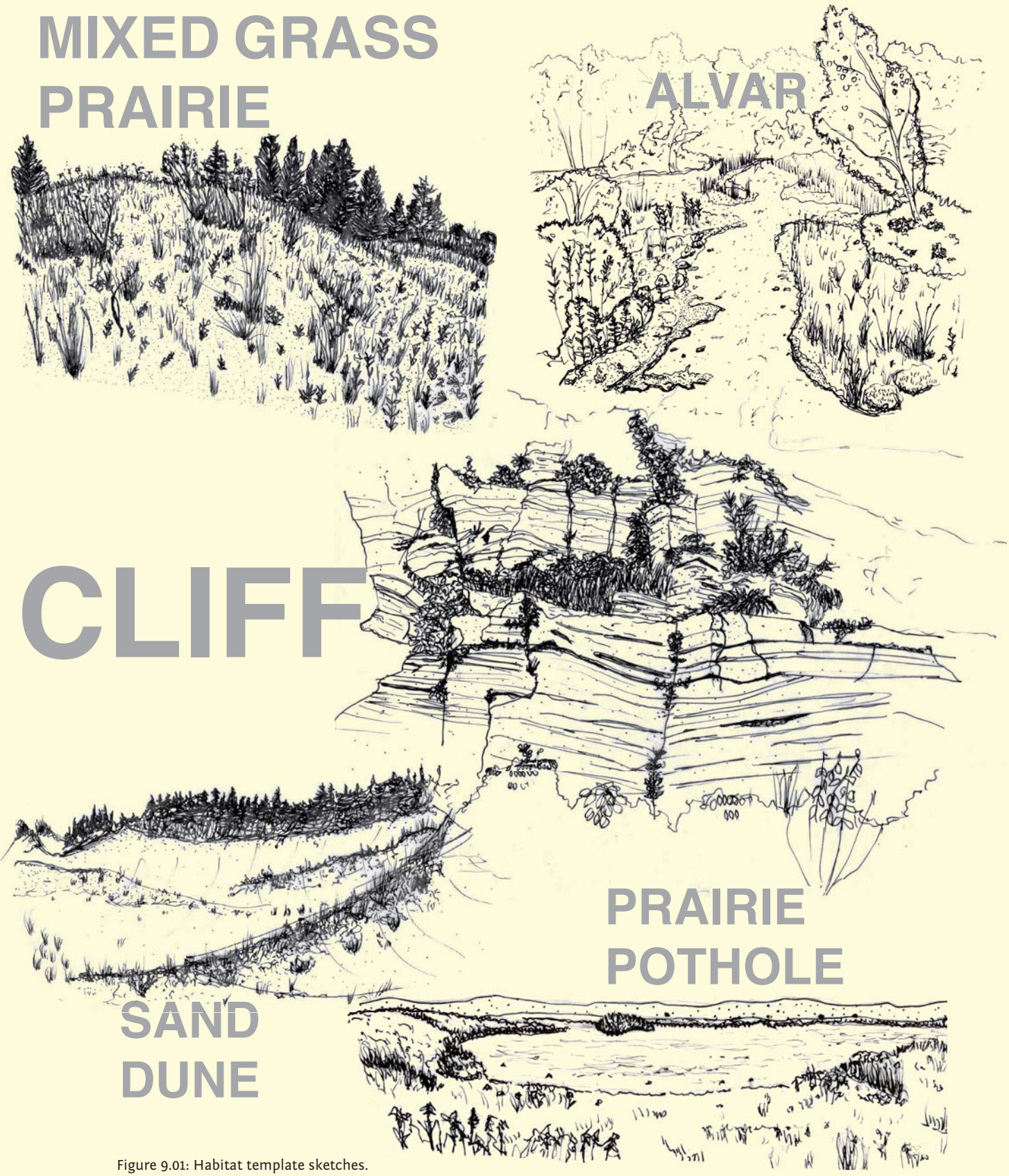


Figure 9.01: Habitat template sketches.

9. SUITABLE HABITAT TEMPLATES FOR WINNIPEG

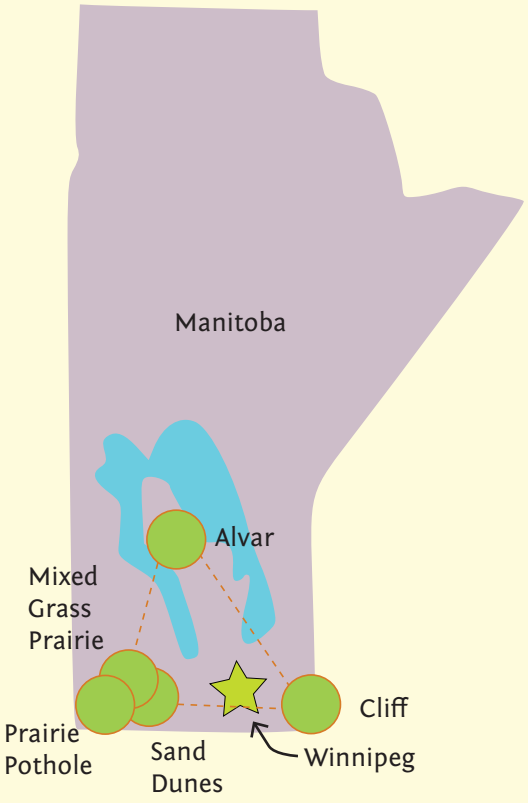


Figure 9.02: Locations of habitat templates.

When designing landscapes, it is important to know the conditions of the site you are designing for, so that you can pick appropriate materials that will tolerate or thrive in the natural condition of the site. Because walls are a distinctive environment, it is important to study naturally occurring plant communities in similar situations. This approach is called habitat templating. There are five habitat templates for vertical gardens in downtown Winnipeg; cliffs, alvars, desert-like sand dunes, mixed prairies and prairie potholes. These have been selected because of their native classification, abundance in Manitoba and their defining microclimates that are similar to those of a vertical garden.

A successful vertical garden in Winnipeg will be composed of a variety of different plants from each habitat template. This will enrich the surrounding landscape matrix and provide habitat for solitary bees, among other invertebrates. The following section will explore the habitat templates used in depth. Some local and national case studies will be cited and different aspects learned from each case study will be discussed.

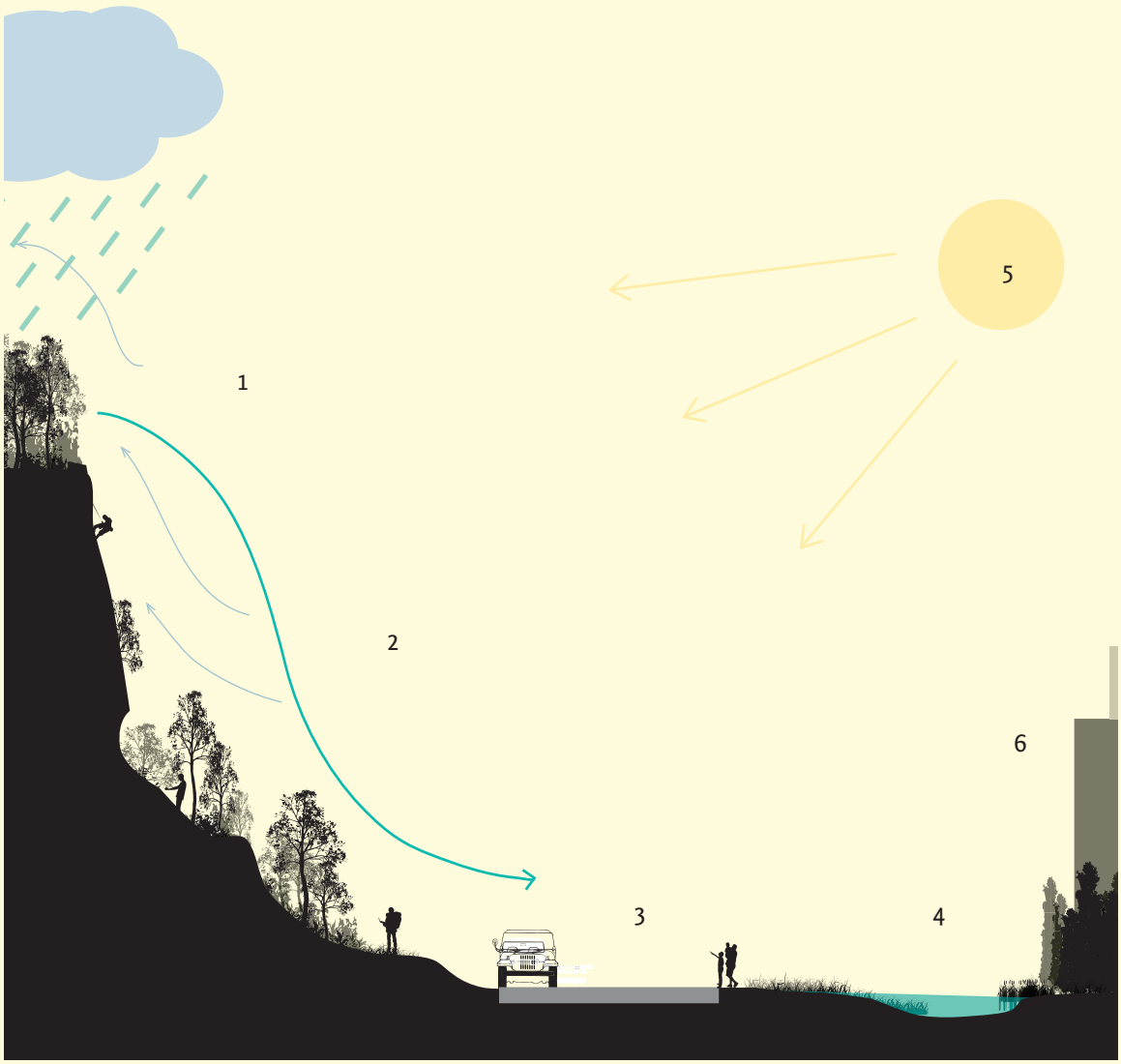


Figure 9.03: Influences observed on cliffs include: 1) wind exposure, 2) drainage from surrounding area, 3) disturbance from people, animals, and other natural occurrences 4) nearby waterbodies (increased humidity levels), 5) solar exposure and 6) regional context both in terms of flora and fauna communities and whether located in a city or in a rural area.

9.1 Cliffs

Cliffs are a very compelling assemblage of flora and fauna, often overlooked by biologists and designers. There are many parts of the world that people go to visit cliffs, both inland; such as those in Moher, Ireland, the Troll Wall of Norway, the Great Trango in Pakistan; and coastal cliffs, the largest and most famous of which can be found in New Zealand, Scotland, Hawaii and Baffin Island. Some cliffs hold great cultural significance, such as the vertical cemetery cliffs in the Philippines.

Unless you are a rock climber or a base jumper, you may or may not have heard of many of these places. You may even see cliffs regularly in your everyday life, but if you do not climb them and see them up close, many aspects and complexities are hidden from view. Unfortunately, the same is true for many professionals who study landscapes directly. Larson et al. (2000) write that cliffs haven't been studied extensively because they are not seen as 'places' with a unique ecological structure and process (p. 12-13). They are thought of as an accidental scattering of plants and as boundary conditions between different communities (p. 13). This attitude could be due cliff faces being difficult to access without rock climbing equipment and experience.

Cliffs are some of the most interesting places I have ever studied, and are highly relevant to vertical garden design as precedents. I find it amazing that such a wide variety of vegetation can grow on a cliff face, and go virtually unrecognized by most people as unique assemblages. Various types of vegetation, from lichens and mosses, to grasses and sedges, to shrubs and even large trees, multiple stories high, can grow on cliffs! Some of the most influential elements are geology, flora and fauna, and controlling processes such as climate, exposure, and long periods of time resulting in slow succession.

Cliffs provide an excellent view into the complexities associated with growing plants vertically. Plants growing on cliffs require "physiological and morphological adaptations to water stress, skeletal soils and a predominantly vertical substrate, as well as an ability to re-establish after disturbance from both exogenous and endogenous processes," (Coates and Kirkpatrick, 1992, p. 441). Plants that have these adaptations are called lithophytes. Given the restrictions, the variety of plants that can grow, and the communities that have colonized cliffs are surprisingly numerous, though plants are often physically small. Because of increased stress from the limited amount of soil and growing space, plant growth (especially that of trees and shrubs) is usually stunted. Individuals are much smaller than the same species would be at the same age, growing in a less stressful environment. Research found that Eastern White Cedars, *Thuja occidentalis*, growing on cliffs in the Niagara region of Ontario were centuries old (Larson et al., 2000, p. 218). Eastern White Cedar has been found to be the only plant that can grow unimpeded, completely upside down, with their canopies below their root systems (p. 218). Cliff dwelling plants in the Niagara region have also been proven among the most ancient communities in the world (p. 281).

Cliff microclimates can vary immensely. Sometimes they are protected by adjacent

Figure 9.04: Variance in disturbance from rock climbing shown in pink, Lily Pond rock wall.

Figure 9.05: Ground water drips from moss in a crack in the Lily Pond rock wall.

cliffs. Sometimes they face south and are baked in the mid-day sun. Sometimes they face north, where they receive only ambient light. Sometimes they are located in particularly windy areas that can inhibit or alter plant growth. Texture, in terms of both architectural and chemical composition of the cliff, is a major influence on the community. Whether the rock is smooth or rough, and whether or not it gives plants a texture to hold onto, has a role in the establishment of larger plants other than lichens and mosses. Ledges, or shelves, found on cliff faces will often host a variety of medium to larger herbaceous plants. Cracks with a minimum width of 5mm will often host mature trees or shrubs. Generally plants will only be able to establish in areas which are slightly protected and where nutrients and sediment can accumulate (see figure 9.16). Undercuts and areas that have ground water flow, or which act as drainage zones for surrounding areas are typically some of the most favourable areas for plant growth. Disturbance influences vegetative growth, as seen in figure 9.04 of the Lily Pond rock wall. Disturbance in this case, is indicated by a lack of vegetation (shown in red). This is due to recreational rock climbing. Areas of the Lily Pond rock wall that are left undisturbed host a complex array of vegetation from small perennials to large trees. The effect of disturbance on the cliff is significant, so prior assumptions that vegetative growth is hindered in highly disturbed cliffs was confirmed by this study (see Lily Pond Rock Wall Study, page 104-105), as well as by Robert Francis' (2011) article *Wall Ecology: A Frontier of Urban Biodiversity and Ecological Engineering*.

The type of rock, pH, texture and composition are very important to natural cliffs. Depending on the type of rock, plants will either be calcifuges ('lime avoiders') or calcicoles ('lime seekers'). Calcifuges generally are found in siliceous rock which produces acidic soils. Calcareous rocks produce chalky soils with neutral to high pH values, and thus will only host calcicole plants (Larson et al., 2000, p. 175).

Cliff communities vary greatly depending on water availability. Water will either come from surrounding drainage, from groundwater percolating through the rock itself, or through faults (see figure 9.05). Cliffs with waterfalls running down them will often host a higher variety of plant species than ones without, due to the addition of moisture loving plants. These plants depend on spray from falling water to survive. Desert species may be found just a few metres from the waterfall, where water is scarce.

Many cliff-dwelling plants are unable to compete with other plants in regular terrestrial conditions (Larson et al., 2000, p. 228). The fierce competitors present in horizontal communities often lack the adaptations necessary to survive on a cliff (p. 228). The succession of cliff communities is different than succession of ground-dwelling communities. On a cliff, succession will begin with lichens which will break down some of the rock and decaying plant matter creating small pockets of nutrients, water and lower pH, giving a perfect niche for mosses which then continue the cycle for small vascular plants, herbs and finally shrubs. Vegetation will diversify and grow larger with additional soil and detritus, until the weight of the vegetation becomes higher than the amount

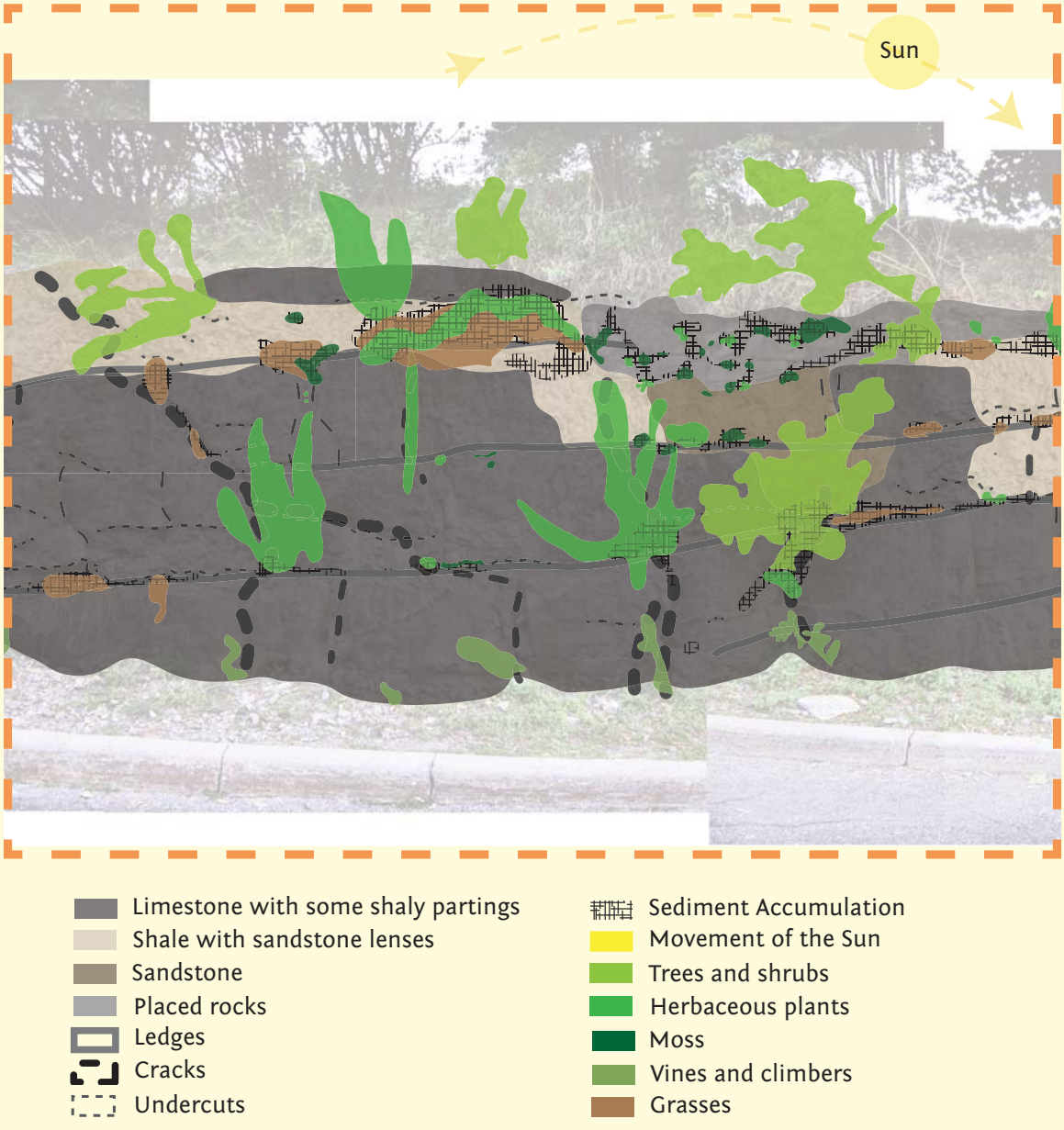


Figure 9.06: Composition of a small cliff in Major's Hill park, Ottawa.

Figure 9.07Appearance of the same cliff shown in Figure 9.06 without dissection layers.

Figure 9.08: Large roadside cliff in Kenora, Ontario.

Figure 9.09: Large roadside cliff in Rockliffe Park, Ottawa, Ontario.

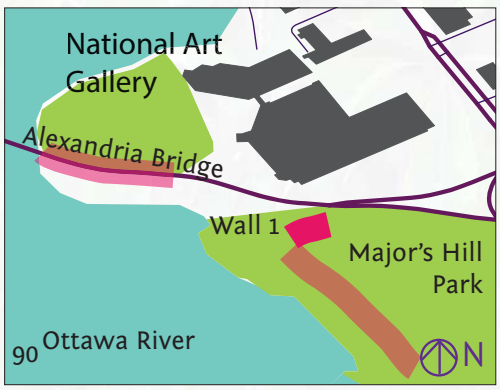
the roots can hold (Coates and Kirkpatrick, 1992, p. 447). Vegetation can sometimes peel off the cliff like a root-bound mat, (p. 447), after which the succession process will begin once more. Because the accumulation of soil is never substantial, the essential characteristics of the cliff are maintained. Thus, succession on cliffs is both truncated and cyclic (Coates and Kirkpatrick, 1992, p. 447).

The following spreads show detailed analysis of small cliffs found in Ontario and Manitoba, chosen for their accessibility. Species of plants were identified and effort was made to understand the community as a whole at each site. Quadratic sampling was not undertaken, and should be included in future research. Neighbourhood context, proximity to water, sun exposure, disturbance and regional climate were studied in each case and can be seen represented graphically in the following.

Case Study:

MAJOR'S HILL ROCK WALL 1

USDA Zone 5a

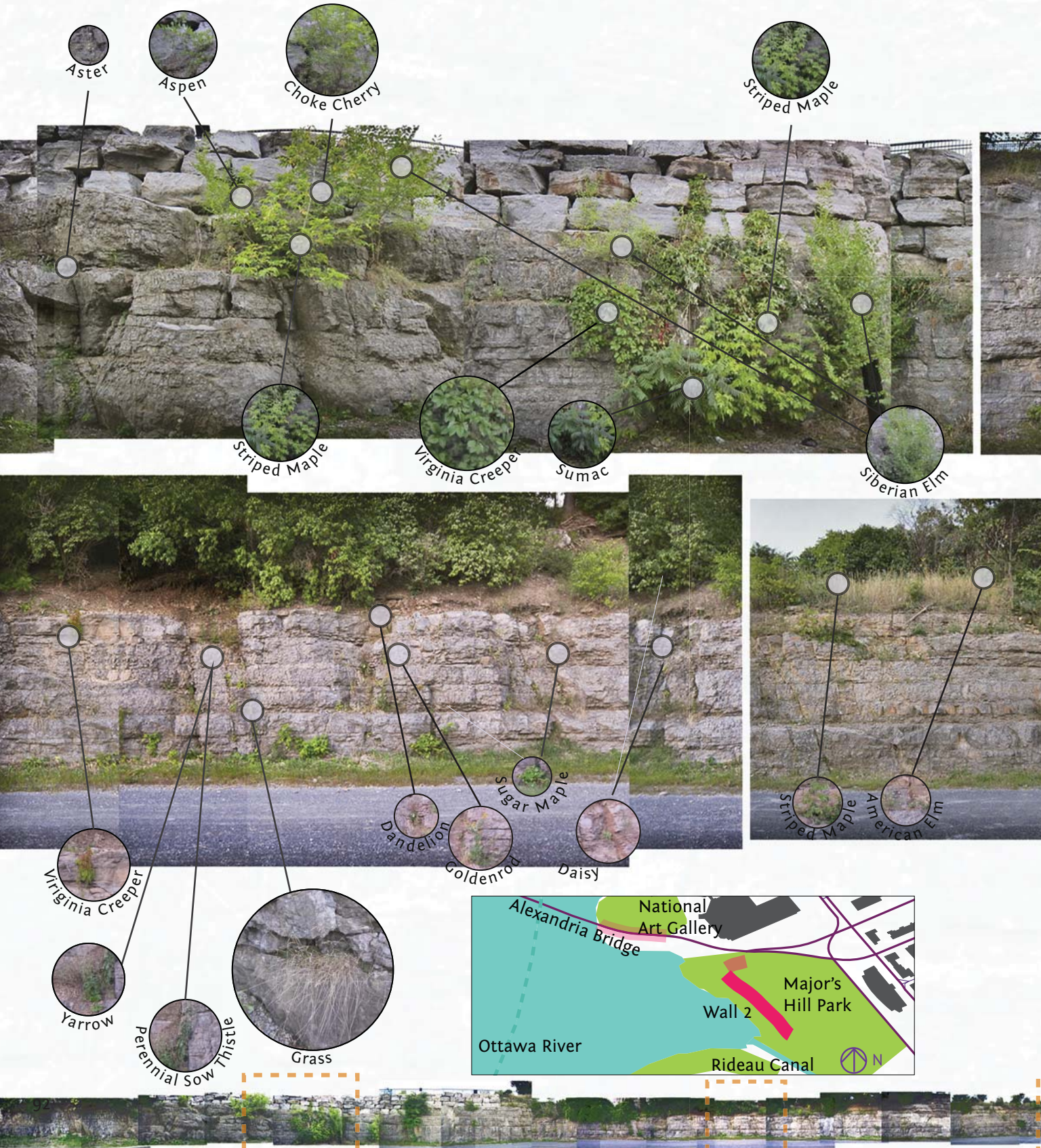


Located in a parkland forested city park, Major's Hill Rockwall 1 benefits from a North aspect and surrounding area drainage water. Directly beside a walking path, it is a high disturbance area that is likely weed controlled. It is very close to a high traffic road as well, so it is likely subjected to salt spray, dust and other urban pollution.

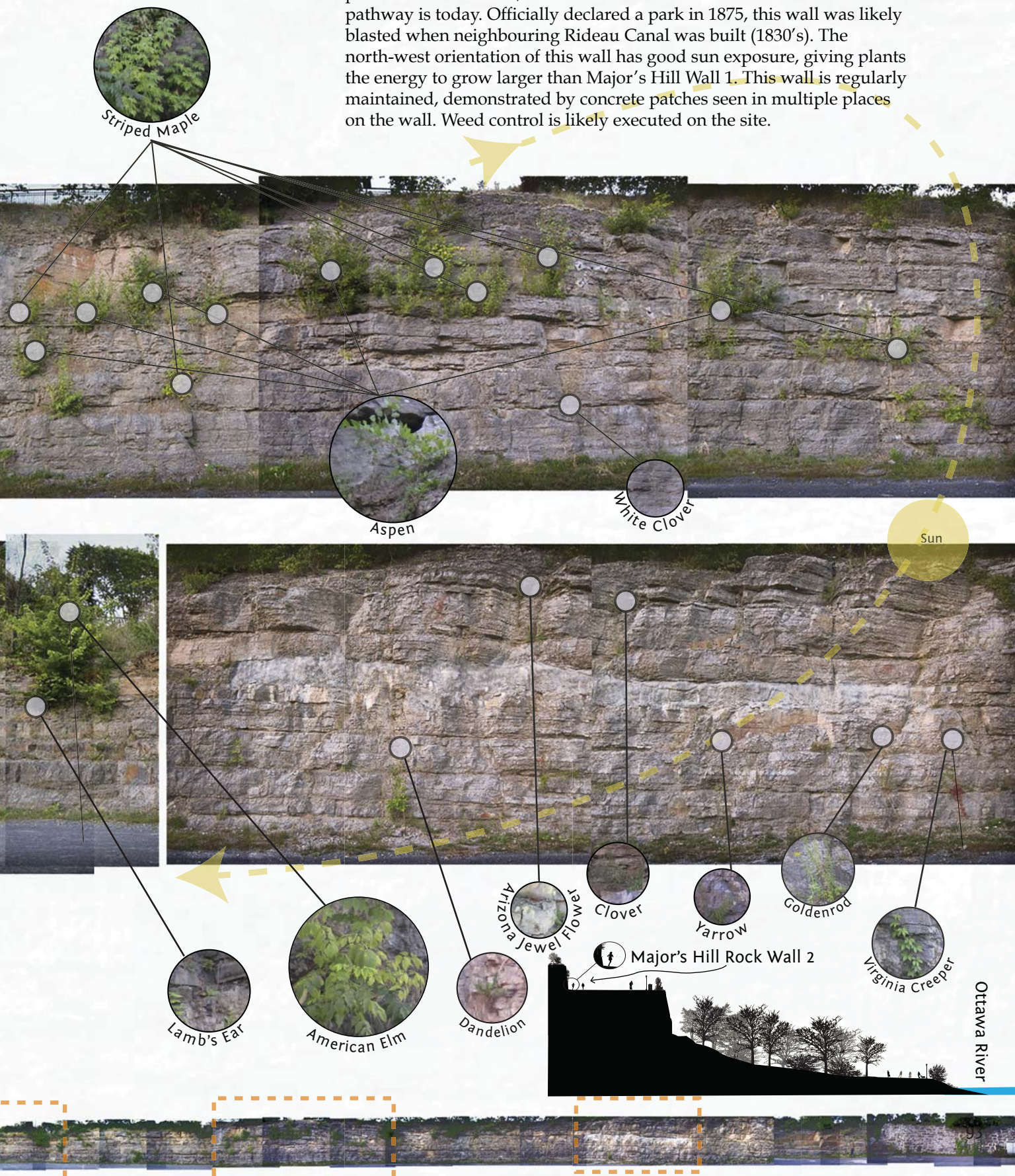
Case Study:

MAJOR'S HILL ROCK WALL 2

USDA Zone 5a



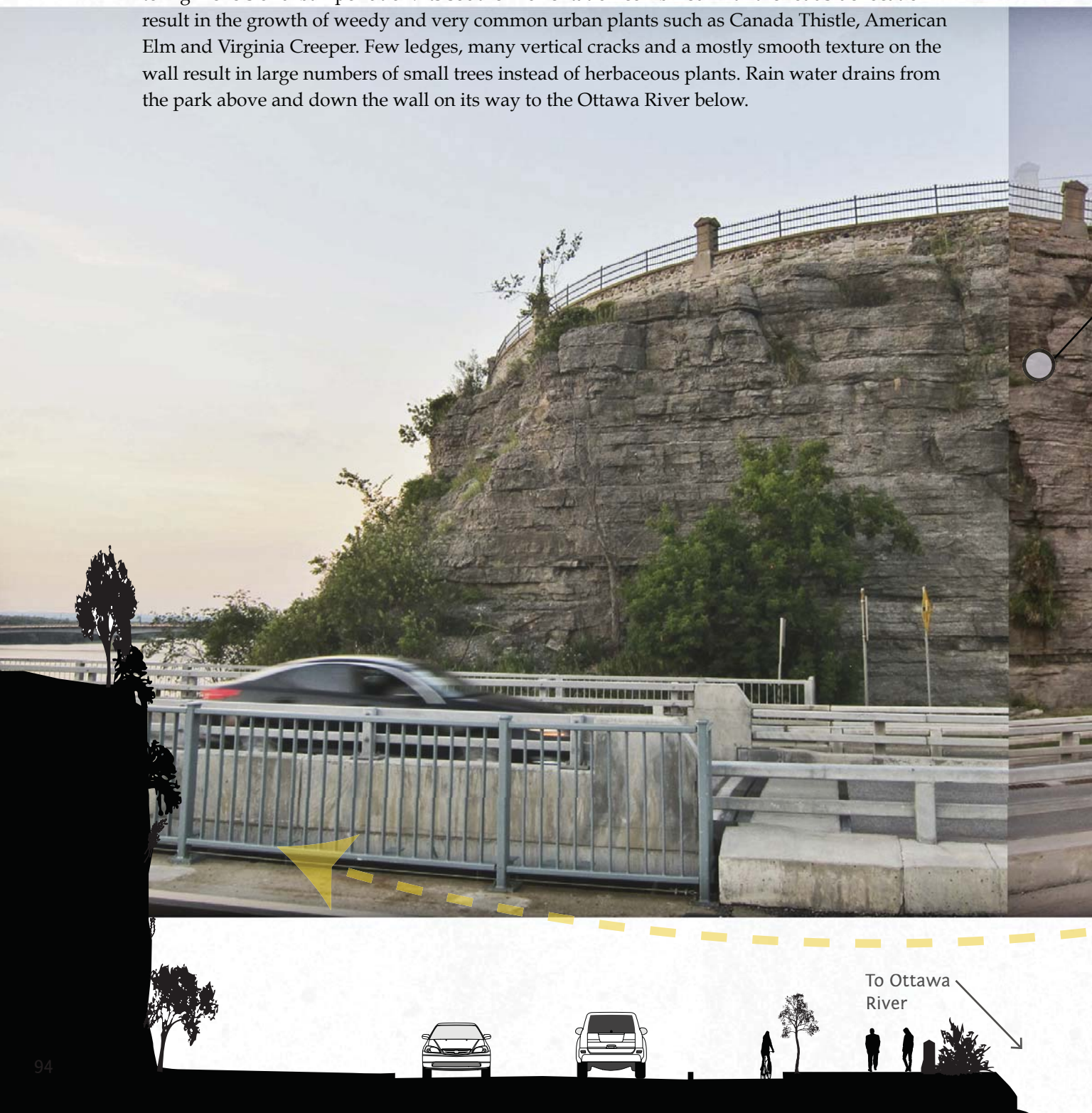
The second study in Major's Hill Park, this rockwall is but one small piece a two tiered cliff, beside a former rail line which ran where the pathway is today. Officially declared a park in 1875, this wall was likely blasted when neighbouring Rideau Canal was built (1830's). The north-west orientation of this wall has good sun exposure, giving plants the energy to grow larger than Major's Hill Wall 1. This wall is regularly maintained, demonstrated by concrete patches seen in multiple places on the wall. Weed control is likely executed on the site.



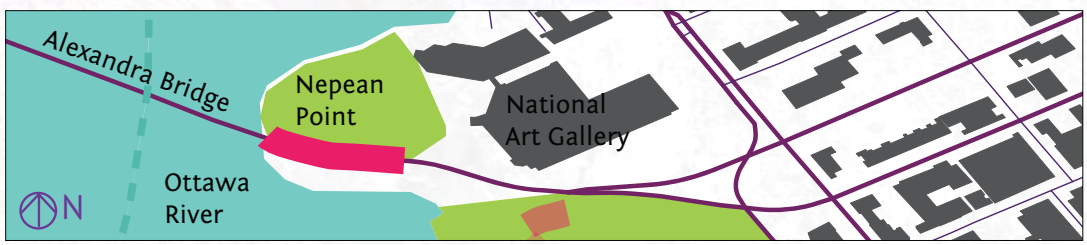
Case Study:

NEPEAN POINT ROCK WALL USDA Zone 5a

This wall is on the edge of Nepean Point Park behind the National Art Gallery in Ottawa. Located approximately 10 feet from a high traffic bridge between Hull and Ottawa, it is exposed to high levels of urban pollution. Its southern orientation combined with the roadside location result in the growth of weedy and very common urban plants such as Canada Thistle, American Elm and Virginia Creeper. Few ledges, many vertical cracks and a mostly smooth texture on the wall result in large numbers of small trees instead of herbaceous plants. Rain water drains from the park above and down the wall on its way to the Ottawa River below.




Grass
Virginia Creeper
Choke Cherry
Sumac
Clover
Canada Thistle
American Elm
Poplar
50
Sun

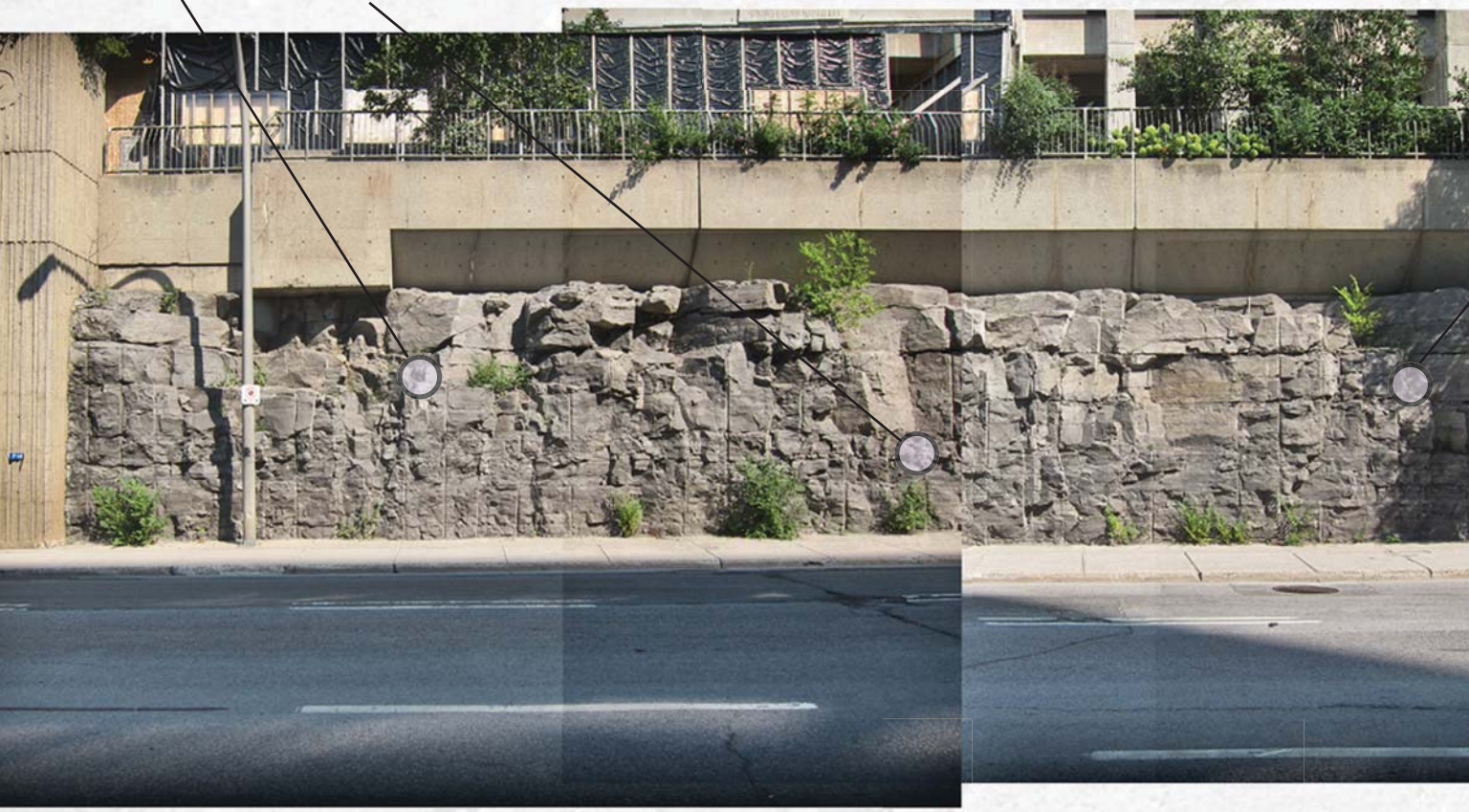

Alexandra Bridge
Nepean Point
National Art Gallery
Ottawa River
N

Case Study:

BOULEVARD MAISONNEUVE ROCK WALL

USDA Zone 5a

Located on one of the busiest roads on Hull Island, this rock wall is the most urban case study examined. Buildings tower over the wall. It faces an 8 lane street, flanked on either side by highrise mixed-use developments. The building above/behind this cliff recently underwent improvements during which the wall was covered causing a significant amount of disturbance to the wall. Aside from one large specimen of Siberian Elm, only invasive weeds are present. The cliff faces West, but most of the exposure it receives is from the South, due to shadows of adjacent buildings.



Field Bindweed

Siberian Elm

Sun

Storeys

East-West Section through Boulevard Maisonneuve

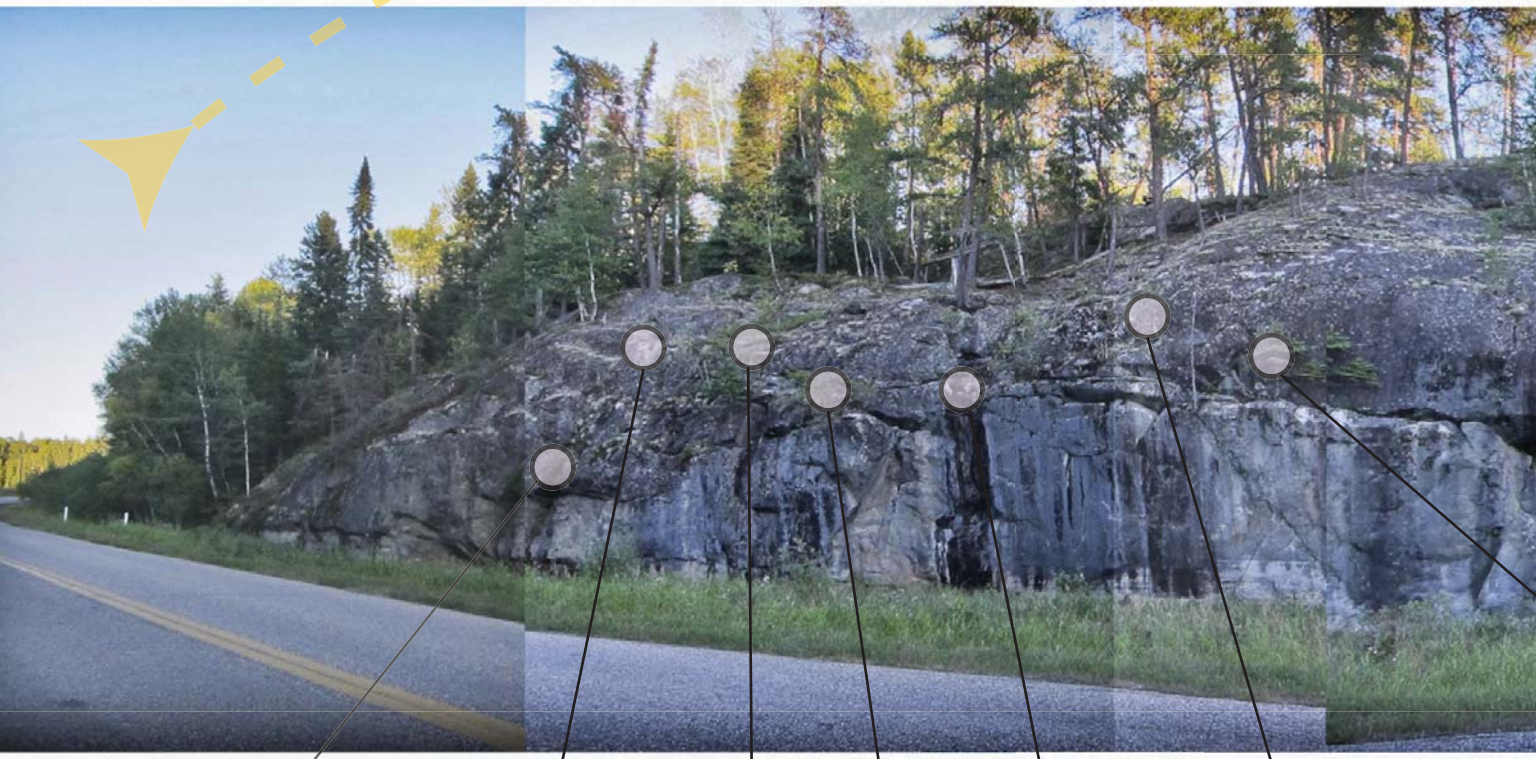
97

Case Study:

WHITESHELL PROVINCIAL PARK ROADSIDE WALL

USDA Zone 2b

Near the Mantario trail in the Whiteshell Provincial park, along a low traffic highway and adjacent to a large pond is this north-facing cliff . It is well protected from human related disturbance. The number of lichens on the face of this cliff clearly show where water flows down the cliff into the water below. Few ledges are present so most plant species present are trees, lichens and mosses. Common trees are Pine, Juniper, and Birch, a similar mix to what occurrs on the rocky outcrop above but noticeably smaller.



Rock Polypody

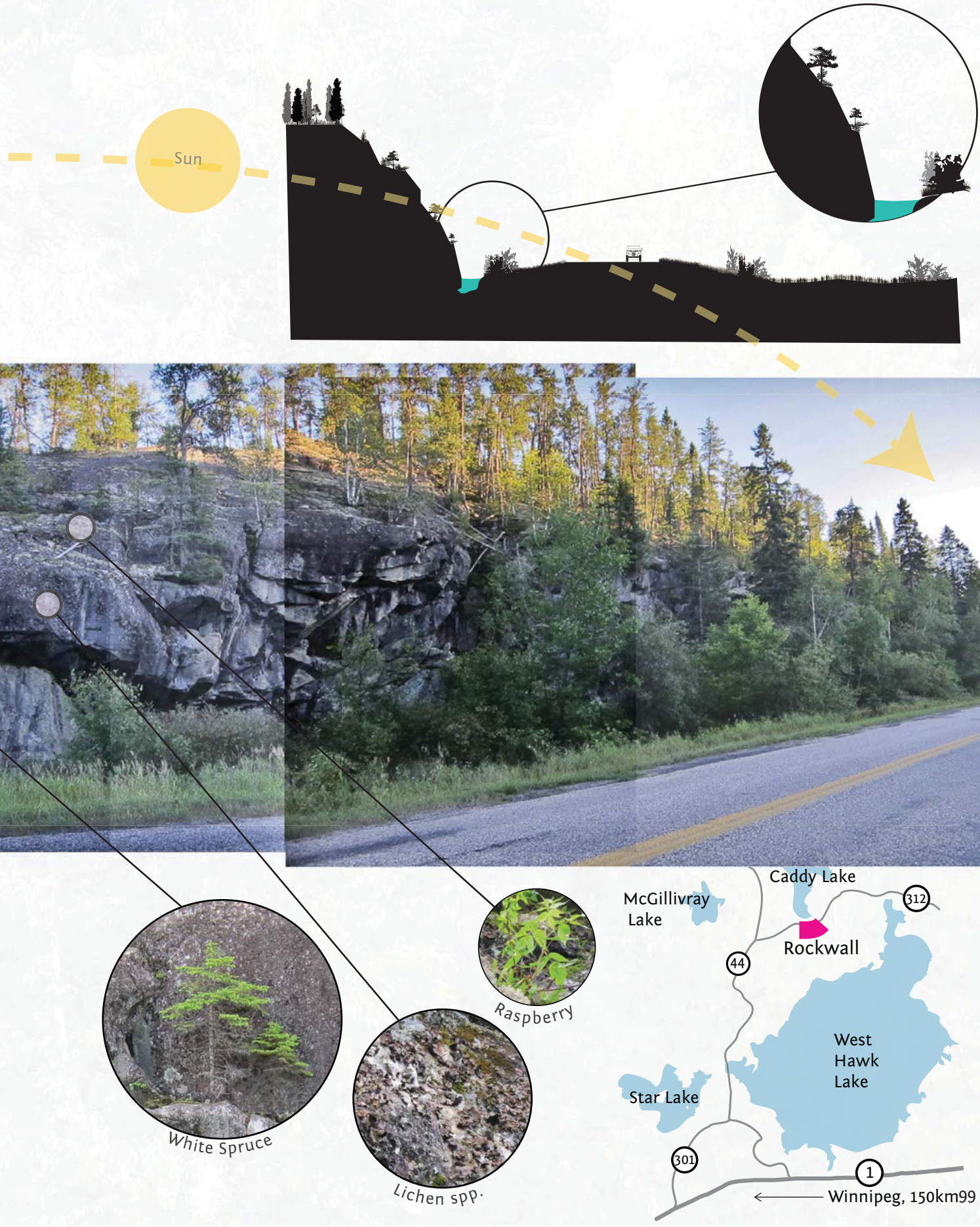
Reindeer Lichen

Grass

Juniper

Moss

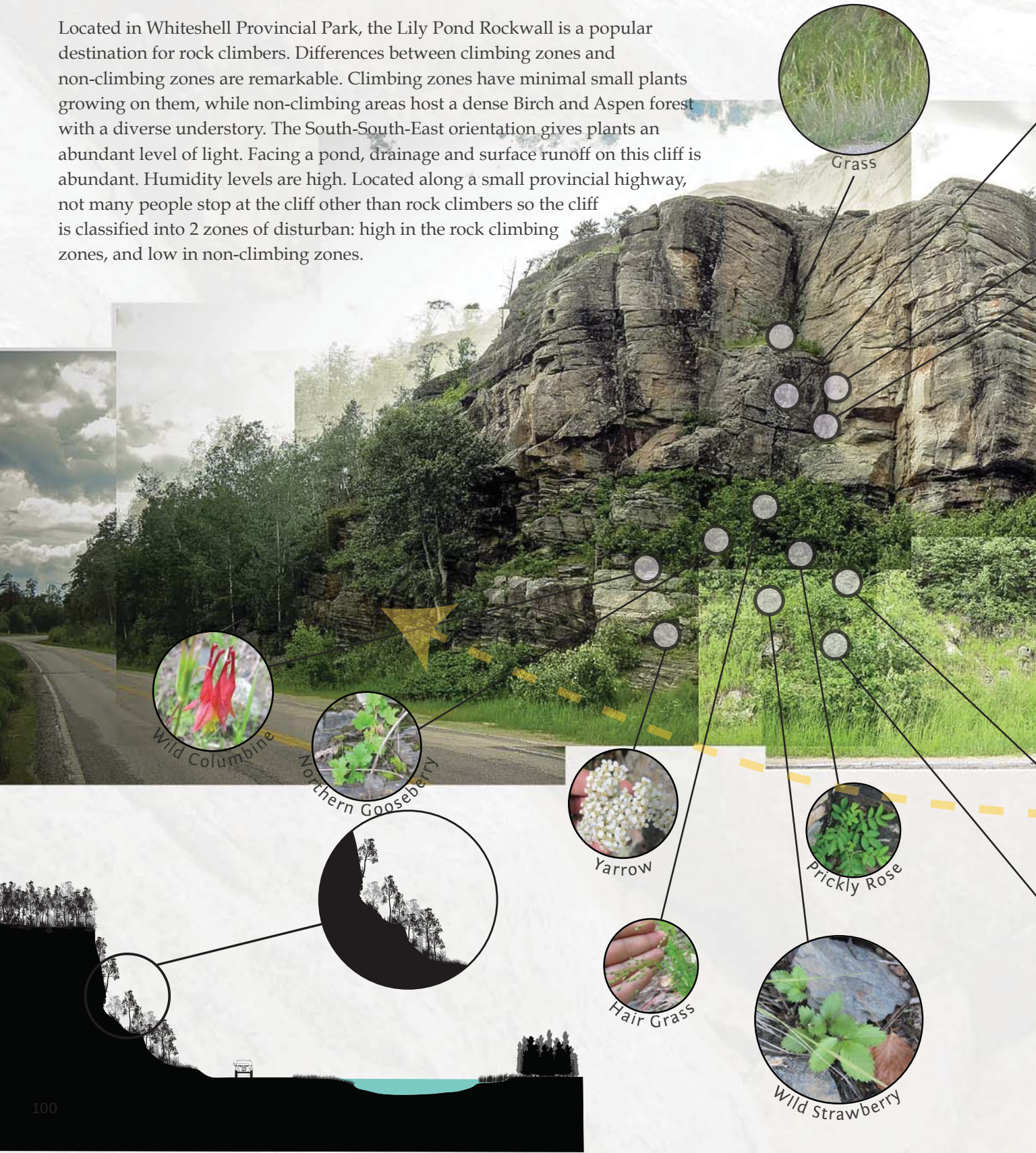
Paper Birch


Sun
White Spruce
Lichen spp.
Raspberry
Caddy Lake
McGillivray Lake
312
Rockwall
44
West Hawk Lake
Star Lake
301
1
Winnipeg, 150km99

Case Study:

THE LILY POND ROCK WALL USDA Zone 2b

Located in Whiteshell Provincial Park, the Lily Pond Rockwall is a popular destination for rock climbers. Differences between climbing zones and non-climbing zones are remarkable. Climbing zones have minimal small plants growing on them, while non-climbing areas host a dense Birch and Aspen forest with a diverse understory. The South-South-East orientation gives plants an abundant level of light. Facing a pond, drainage and surface runoff on this cliff is abundant. Humidity levels are high. Located along a small provincial highway, not many people stop at the cliff other than rock climbers so the cliff is classified into 2 zones of disturban: high in the rock climbing zones, and low in non-climbing zones.




Stocking Moss
Ferns
Rolled-Leaf Pigtail Moss
Lichen
Bear Lake
South Cross Lake
44
Lily Pond Rockwall
Caddy Lake
McGillivray Lake
44
West Hawk Lake
Star Lake
301
1
Winnipeg, 150km
Virginia Creeper
Sun
Raspberry
Red-Osier Dogwood
Betula spp.
Shrubby Penstemon
Canada Anemone
Hazelnut

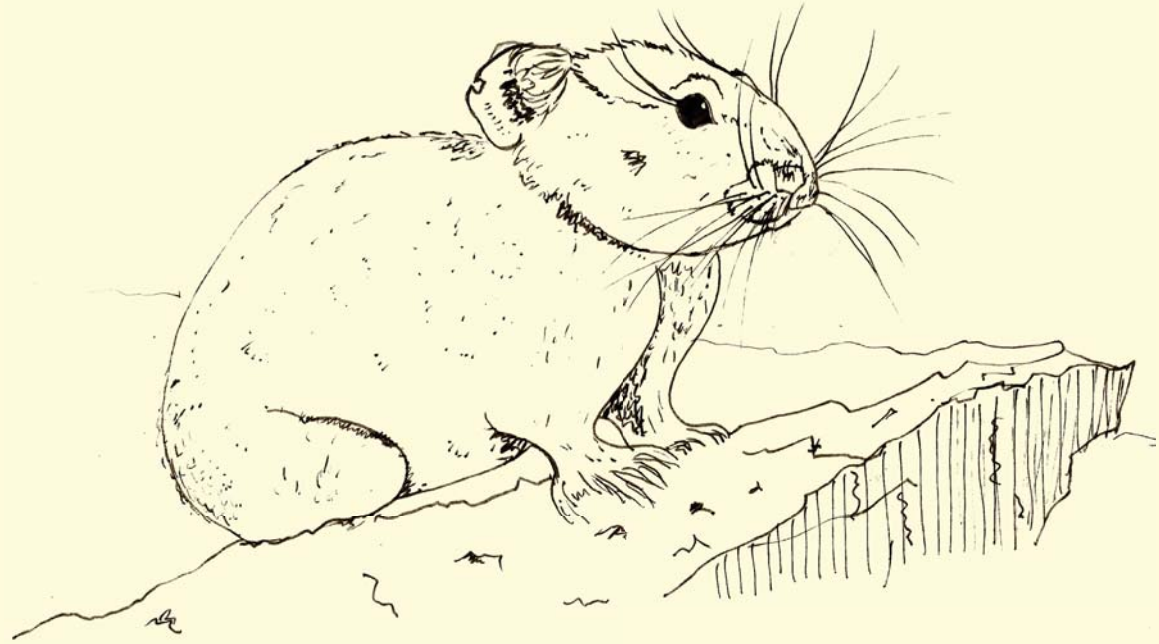


Figure 9.16: Pika, *Ochotona princeps*

Figure 9.17: A rare glimpse of what a natural talus would look like. Roadside, Costa Rican highway.

Amphibians, reptiles, rodents, birds and invertebrates are ubiquitous to cliffs, regardless of location. Amphibians such as snakes, salamanders, and spiders are the most common residents, found in cliffs worldwide. Larger mammals such as coyotes, sheep, bobcats, and pumas may also be found depending on location and structure of the cliff face (Larson et al., 2000). In the Blue Mountains of Oregon and Washington, Maser, Rodiek and Thomas (1979) found 36 mammal species inhabiting the talus (the rock pile often found at the base of a cliff), and another 20 species using caves in cliffs for breeding, reproduction or both (p. 100). The presence of any mammal, of course, is scale dependent. Small mammals can move more freely on smaller ledges and trees, but larger animals need a larger cliff. Rodents are especially common on cliff faces, because of the amount of smaller cracks and holes they can retreat to when in danger of predation (Larson et al., 2000, p. 152). Rodents commonly found in cliff habitats are mice and rats, but a more traditionally adorable rodent lives there too, the Pika, *Ochotona princeps*, a rabbit-like mammal shown in figure 9.16. It is the only animal that requires the talus habitat for survival (p. 152). Without a network of tali, these animals would go extinct. Larger mammalian species can also be found on cliffs, such as the yellow-footed rock-wallaby, bighorn sheep, sheep, and cougars.

Generally, there will be more birds on cliffs than on non-cliff sites, the majority of the species belonging to two broad taxonomic groups: raptors and sea-birds (Larson et al., 2000, p. 126). Falcons, ravens, eagles, hawks, owls, and vultures, are all common cliff residents. Species vary by location. Land dwelling birds include wrens, cliff swallows, rock doves and common pigeons.

Figure 9.18: Alvar on the edge of the Whiteshell region of Manitoba.

9.2 Alvar

Alvar communities are very similar to cliff communities, but are much more rare. Both are formed in karst topographic zones, areas formed by the dissolution of soft sedimentary rock, characterized by underground drainage systems with sinkholes, and caves. The biggest difference between an alvar and a cliff is that alvars occur on the horizontal plane instead of the vertical plane. In many areas, limestone cliffs are associated with alvars (Manitoba Alvar Initiative (MAI), 2012). An alvar is characterized by a thin layer of soil- and in some cases no soil at all- over limestone or dolomite bedrock pavement (Catling & Brownell, 1995). Because the bedrock is so close to the surface, water retention and drainage is limited, so alvars are susceptible to both flooding and drought.

There are four types of alvar communities in Manitoba; alvar grassland, alvar savannah, alvar shrubland, and alvar wetland (MAI, 2012). Figure 9.18 shows alvar grassland in the Whiteshell region of Manitoba. Most Canadian alvar communities occur on the edge of the Canadian Shield and in Manitoba, mostly in the Interlake region (MAI, 2012). Sixty-seven percent of those areas directly observed by the Manitoba Alvar Initiative or MAI are grazed by cattle, horses and bison (2012). Soil depth in each of the alvars range, from 5-10cm (2-4"), but often is 5cm (2") or less. Many rare plant species are found there, and a surprisingly low number of invasive species. Within all the alvar communities sampled in the MAI 2012 survey, only 6 invasive or exotic species were documented, and they were never dominant. Thirteen rare and uncommon species were found including Gastony's cliffbrake, *Pellaea gastonyi*; Rough Fescue, *Festuca hallii*; Wild White Onion, *Allium textile*; Porter's Chess, *Bromus porteri*; as well as with various types of mosses and lichens (MAI, 2012).

Alvars in Manitoba extend over 9,721 acres (3934 ha), covering only 0.3% of the south Interlake, and occur on both public (crown) and private land. None of the alvars documented in Manitoba are currently protected from development, and 26% of them are in areas under mining and/ or quarry leases (MAI, 2012, p. 26). The Manitoba Association of Plant Biologists (MAPB) has recommended only one alvar site known as Marble Ridge for designation as an ecological reserve. It is located between Fisher Branch and Hodgson in Manitoba's Interlake.

9.3 Manitoba Sand Dunes

Manitoba communities known as the Spirit Sands in Spruce Woods Provincial Park, and the Sandy Lands near Whiteshell Provincial Park, are somewhat desert-like. The Spirit Sands (see figure 9.19) has parabolic sand dunes, and the high temperatures commonly associated with deserts (Manitoba Conservation, n.d.2; Acorn, 2011). However, because of the amount of annual precipitation (Manitoba averages range from 300-500mm per year) neither Spirit Sands nor Sandy Lands can be classified as deserts. The Spirit Sands was chosen for further analysis for this practicum because of the diversity of its topography and the variety and type of its ecological communities.

Figure 9.19: Sand dunes in the Sandy Lands at Spruce Woods Park, Manitoba.

Figure 9.20 &9.21: Sand dunes at Spruce Woods.

The active upland dunes at the Spirit Sands are features typically formed from the erosion of sandstone from water or wind. They can often be traced back to water-sorted deposits of sand from beaches, deltas or sandbars (Acorn, 2011; Wolfe, Huntley and Ollerhead, 2002). The upland dunes at the Spirit Sands were created by the ancient Lake Agassiz that once covered most of Manitoba. The Spirit Sands host a variety of plant communities, ranging from spruce parkland, upland deciduous forest, mixed-grass prairie, to open and stabilized sand dunes and riverbottom/ riparian forest (Manitoba Conservation, n.d.). Some of the fauna are rare or endangered in Manitoba, such as the Northern Prairie Skink *Plestiodon septentrionalis*; Western Hog-Nosed Snake, *Heterodon nasicus*; the White Flower Moth *Schinia bimatris*, and the Hairy-Necked Tiger Beetle, *Cicindela hirticollis* (Redekop, 2013). Zones known as "blowouts," (see figure 9.23) are characteristic of upland dunes.

Plants in the dune area of the Spirit Sands are exposed to very high temperatures during the summer, and correspondingly cold temperatures during the winter. Because of the amount of sand that is not covered by vegetation, temperatures can dramatically increase in the summer and moisture levels are very low. Dunes are especially vulnerable to wind. Wind can move entire dunes up to 1m per year (Information board, Spirit Sands). The Spirit Sands also host rare plant species such as Ball Cactus, *Mamillaria vivipara*.

Larry Robinson, who has been running horse drawn tours of the Spirit Sands for over two decades, reports that the Spirit Sands are changing very quickly (Redekop, 2013). His opinion was corroborated by a land survey that determined 400 ha of dunes were present in 1950, and only 175 ha in 1990 (Wolfe et al., 2000). Robinson notes that most of the area used to be open sand dunes, with significantly less forest. He is concerned that the dunes may soon become completely covered in vegetation (Redekop, 2013). He says that if the government has enough of a desire

Figure 9.22: Mixed grass prairie in Manitoba.

Figure 9.23: Upland dune blow out. Generally wind caused, a roughly oval shaped area of the side of the dune will move downward, sometimes starting new dunes (Acorn, 2011).

to keep the rare species there that they will have to devise a plan to maintain the open sandy areas that the species depend on to live (Redekop, 2013). The fact that this unique community is quickly disappearing presents an interesting opportunity to plant sand dune adapted plants in the vertical garden. Perhaps some insects and animals would find the vertical garden and colonise it. Species such as the hog-nosed snake and the skink may not find a vertical garden especially hospitable, but perhaps the white flower moth, and the hairy-necked tiger beetle could find new homes in vertical gardens in the city.

9.4 Mixed Grass Prairie

The mixed grass community grows in sandy, well-drained soils in areas receiving 250 mm and 500 mm of precipitation annually (MNR, 2001, p.4; Manitoba Conservation, n.d. 3). It is a combination of tall grass prairie and short grass prairie (see figure 9.22) (Lindgren and De Smet, 2001, p. 23). Historically, prairie covered a significant part of Manitoba, but due to widespread fragmentation from agricultural farming and other human interference, poor conditions/degradation and invasion of shrubs trees and exotics, much of the original prairie has been lost (Nernberg and Ingstrup, 2005, p. 480). It is estimated that the original grassland region in Manitoba was 14,700 km^2, of which only 18% of mixed grass and 0.1% of tall grass prairie regions remain today (p. 480).

The mixed grass prairie is located in the south-western corner of Manitoba, between the short grass prairies of Saskatchewan and tall grass prairie of inner Manitoba (Manitoba Natural Resources (MNR), 2001, p. 4). It is critical habitat for the Ferruginous Hawk, *Buteo regalis*; Burrowing Owl, *Athene cunicularia*; Loggerhead Shrike, *Lanius ludovicianus exucubitories*; Baird's Sparrow, *Ammodramus bairdii*; and Sprague's Pipit, *Anthus spragueii*; each of which are listed as "at risk" nationally or provincially (Lindgren and De Smet, 2001, p. 5). The Manitoba mixed grass prairie is known to host 1-2% of the national population of these birds (p. 5).

The mixed grass prairie is a hardy and climate adapted community (MNR, 2001, p. 4). Plants including Prairie Crocus, *Anemone patens*; Spear Grass, *Stipa comata*; Indian Breadroot, *Psoralea esculenta*; Dotted Blazing Star, *Liatris punctata*; Blue Grama Grass, *Bouteloua gracilis*;

Figure 9.24: Prairie Potholes in the Minnedosa area.

and Purple Coneflower, *Echinacea angustifolia*; are considered characteristic (Manitoba Conservation, n.d., p. 3). These plants are all specially adapted to extreme seasonal temperature variances, and include cool-season plants which emerge in spring and fall, and warm-season plants which grow during the hot summer months (MNR, 2001, p. 4). This special community is also home to the endangered White Lady's Slipper, *Cypripedium candidum*, one of Manitoba's seven listed endangered plants. Both burning and rotational grazing are necessary to ensure a healthy mixed grass prairie (Manitoba Conservation, N.D., p. 3).

9.5 Prairie Potholes

The central region of the North American prairies is dotted with small wetlands, called prairie potholes, that are leftover from glaciation (see figure 9.24). According to Ducks Unlimited, they are the most important and threatened waterfowl habitat in North America (N.D.). They range from freshwater to saline depending on surrounding drainage. Plants range from wetland water species like pondweed, *Potamogeton* spp.; and widgeon grass, *Ruppia* spp.; to emergent species like bulrushes, *Scirpus* spp.; and cattails, *Typha* spp.; and plants that grow in seasonal marshes like bluegrass fowl, *Poa palustris*, bluestem, *Andropogon* spp.; Canada anemone, *Anemone canadensis*; and mint, *Mentha arvensis* (Eldridge, 1990). The types of plants found will vary depending on the water depth of the zone of the pothole they occupy. The zones are dictated by moisture, standing water levels, salinity, and the size of the pothole. Potholes that are larger in size have more complex zonation, while smaller ones may have less variance from side to side. Prairie potholes can be temporarily or semipermanently filled with water. They are usually filled by snow melt, and not connected by surface streams. Because of this, older more permanent water bodies can be brackish or saline, because the only escape for the water trapped in the pothole is evaporation, which leaves behind minerals causing salination (Eldgridge, 1990, p. 2). In general, the amount of water contained is correlated to the water table of the area.

More than half of the prairie potholes have been drained to make way for agricultural fields, however preservation efforts by Ducks Unlimited Canada are abundant due to the potholes' importance for waterfowl habitat. Many invertebrates also live in the edges of the potholes, providing food for the laying hens and brood present. Their abundance is directly related to the amount of plant material present, however plants with more complex structures provide the most cover and habitat for invertebrates (Eldridge, 1990, p. 3).

Prairie pothole zones are somewhat similar to standard zones found in marshes and other water-dominated communities. Typically, they extend from the outer drier areas (upland) to the semi submerged or seasonally submerged zones (riparian), into the deep water areas where plants are entirely submerged (aquatic) (Government of Alberta, n.d., p. 1). These zones each host different plants and invertebrates.

Plants selected for the vertical garden design have been selected mostly from the upland zone, however some also grow in seasonally flooded areas. These species are located at the bottom of the wall, where the most

Figure 9.25: Cliff with groundwater flow encouraging plant growth.

accumulation of water naturally occurs due to irrigation and gravity. These plants are particularly suited to grow on the bottom of the wall as plants in this zone are the most directly affected by salt spray and pollutants from the road below.

Conclusion

Each of these communities provides further insight into different conditions present in a vertical garden. Cliff studies reveal the bare necessities for plant life growing on a vertical plane, and succession patterns and variances associated with microtopography. The information gathered about lithophytes present in both cliff and alvar communities is the basis for a set of parameters for plant selection, and the amount of soil, sun exposure and water needed. Alvars provide further insight into how plants can adapt to limited soil and stressful water-related conditions. The Manitoba sand dune community is tolerant of highly variable temperatures similar to those that will occur on a wall, while prairie pothole plants adapt to a variety of water-related influences- floods and droughts. Plants from each of the cliff, alvar, sand dunes, mixed prairie and prairie pothole communities were chosen for the final design. This plant pallet will form a site specific and regionally sensitive gradient of plants for a Winnipeg vertical garden.

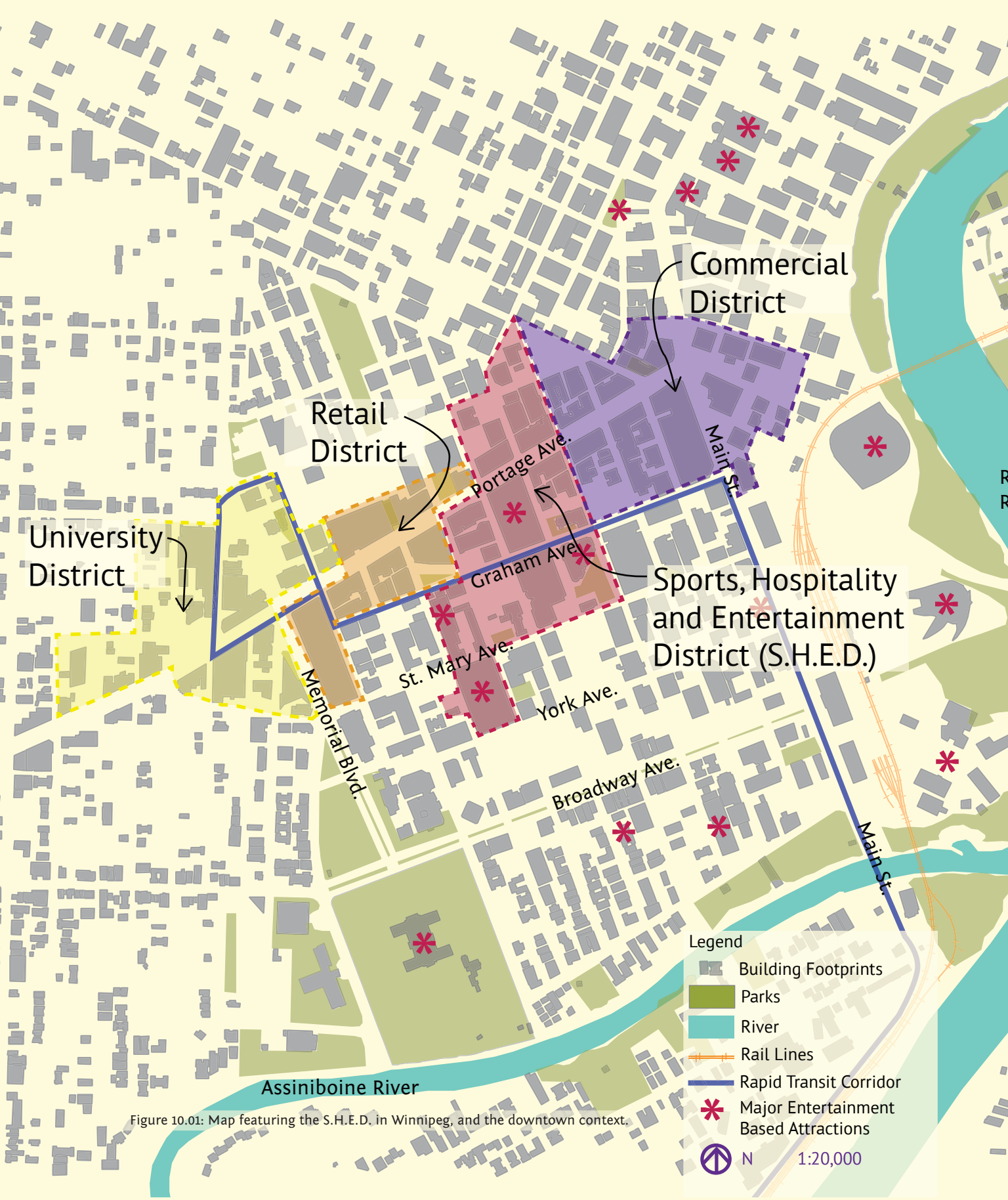


Figure 10.01: Map featuring the S.H.E.D. in Winnipeg, and the downtown context.

10. DESIGN PARAMETERS AND INITIAL SKETCHES

Throughout the process of researching and designing the vertical garden, five things quickly grew to be dictating forces in the design. They are habitat templating, sun and wind exposure, the amount of soil given for each plant, Winnipeg winters, and the form of the structure itself. The habitat templates selected have similar microclimates to the zone of the vertical garden to be planted. Sun and wind exposure must be considered for the health of plants, so western walls isolated from the wind but also warmed by the sun were chosen for further consideration. Individual plants are planted in individual pots to facilitate removal. Each different size directly correlates to the plants' sizes, both in terms of spread and root mass. Provision for the winter was considered, and the decision was made to cover the plants during the cold season. The desire to create a site specific garden installation inspired for the creation of a dynamic and responsive form.

10.1 Selecting Realistic Habitat Templates

I recognized that habitat templating was going to be a critical element to my research early. I had originally wanted to create a tall grass prairie community on the side of the building, but as I did more and more research, I realised that this was not ideal. Root space and maintenance requirements of a tall grass prairie would be hard to replicate on the side of a building. Annual burns were of particular concern. The fantasy of annual green wall burns remained with me for a long time. It would appear that a whole building was on fire, but in reality the building would be completely protected and safe. This would be a huge event for Winnipeg, people would come from far and wide to see the building go up in flames (but not really). I held on to this dream for as long as I could, but after reading more about green walls and microclimates, and the plant species themselves, it became obvious that my research was going a different direction.

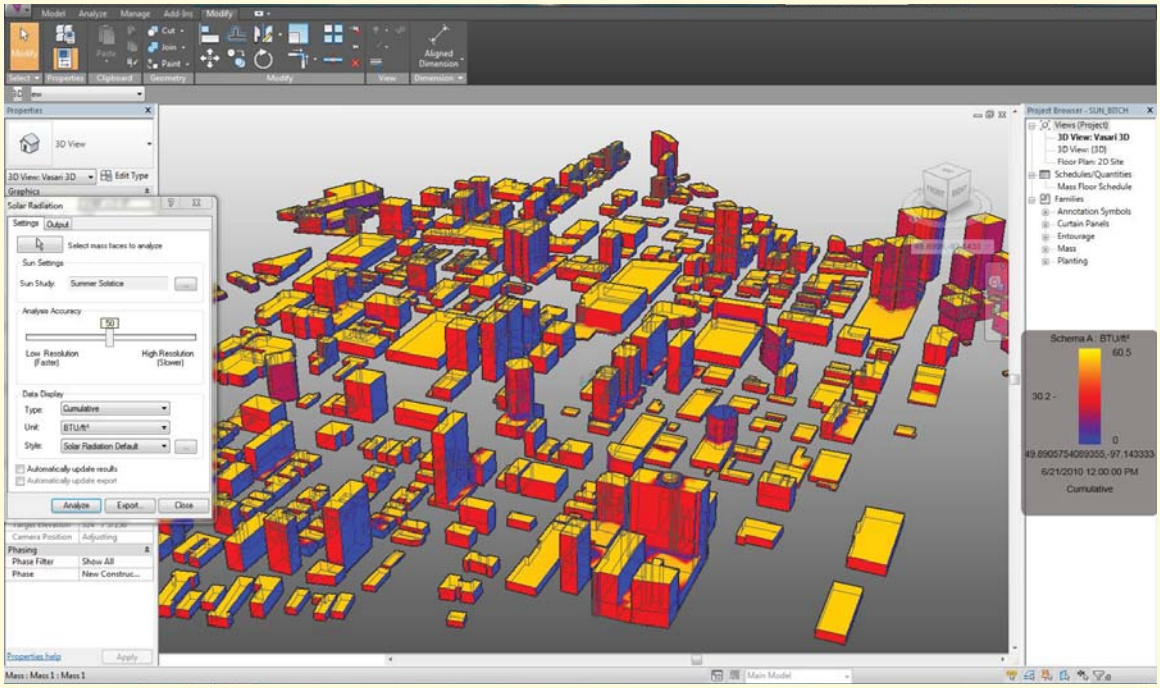


Figure 10.02: Solar analysis of facades.

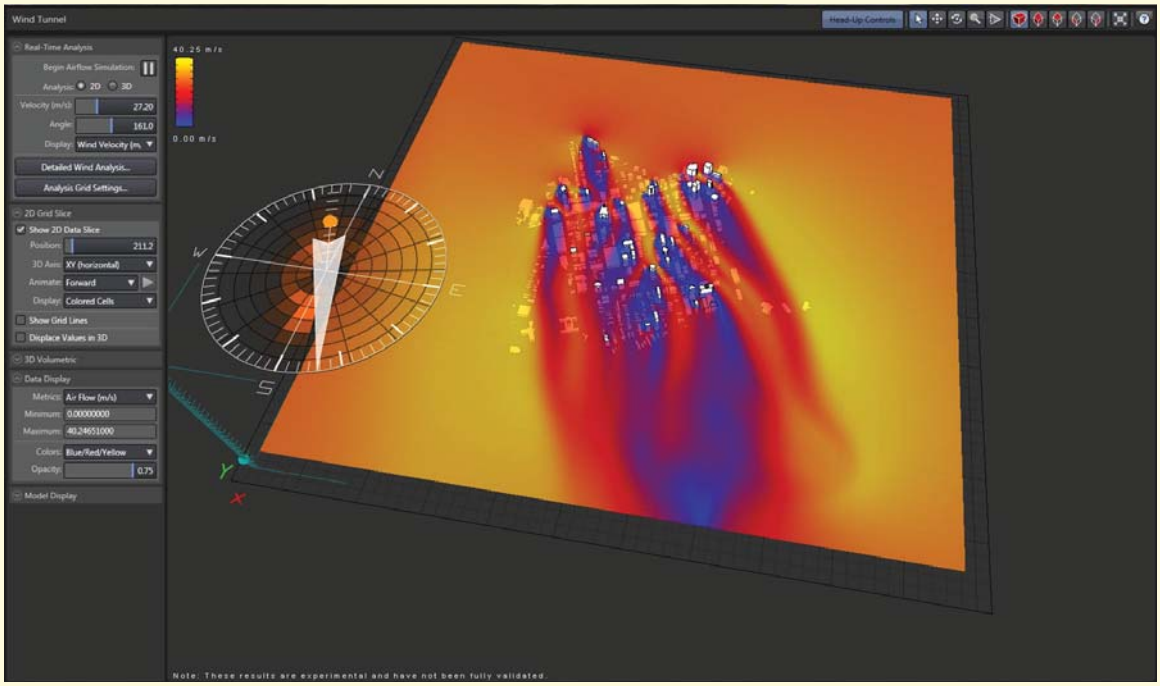


Figure 10.03: Wind analysis of Downtown Winnipeg with western facing facades with less wind exposure highlighted.

10.2 Sun and Wind Exposure/ Location

Downtown Winnipeg was selected because vertical gardening is most suited to areas where traditional horizontal gardens are not an option. This is usually due to lack of space. Downtown Winnipeg is a relatively dense urban area where density will continue to increase over time. It is desirable to integrate gardens in places that are currently unused, like walls, while keeping open lots available for future development.

For my exploration of sun and wind exposure I ran computerized wind simulations at different heights and sun path analyses on the downtown, seen in figures 10.02 and 10.03. These were done to isolate facades exposed to a suitable amount of direct light, while also relatively isolated from the wind. The west-facing cliffs I had visited in Ontario and Manitoba had the highest level of plant diversity, so I focused mostly on finding western facades. Though north facing walls were found in wall ecology studies to be the most diverse, western walls in cold climates will have slightly longer growing seasons due to heat absorbed by the sun.

10.3 Container Size/ Soil Requirement

Another aspect explored in depth was the container size each plant needed. Because most endemic prairie plants have very long roots, it is probably not advisable to grow many of these plants in containers. I have selected those which I predict have the best chance at survival based on their lifespan, and predicted survival in pots for multiple seasons, and their general hardiness. It is estimated that the size of the container (chosen based on the size of the root mass of each plant) will be large enough for plant survival to be many seasons. Some plants will do very well initially and then die off once competition and limited rootspace stresses them too much. The plant pallet has been designed to incorporate different species of different lifespans, shapes, textures and tolerance for competition. The worst case scenario would be for all of the plants to die in the first year.

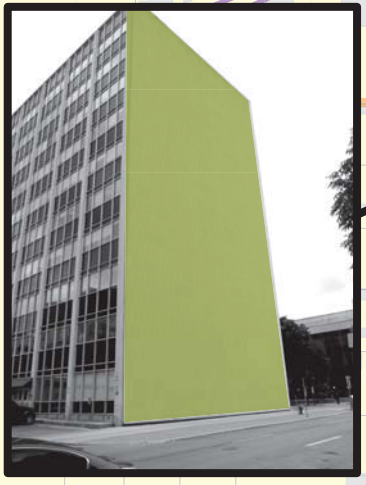
It was often suggested to me during my design process that perhaps annuals would be a simpler choice. I agree they would be easier to plan for, as they would be replaced every year, however my desire was to create a garden that was based on Manitoba plant communities, to enrich downtown plant diversity. Once testing of the design is completed, if it is completely unfeasible to use the plants outlined herein, then annual plants can be planted.

10.4 Winnipeg Winters

The winter season is another aspect that I struggled with for a long time. I had to choose between creating a greenhouse for the vertical garden, and insulating or removing it for the winter. For the scope of the practicum, it is assumed that native plants can be successfully overwintered in containers in zone 2b. Further testing is required, but if the plant is allowed to freeze solid, then kept frozen and insulated for the duration of the winter, it is assumed the plant will survive. It is critical that the plant not be exposed directly to warming sunlight, to prevent accidental waking of the plant in the middle of a sunny winter day.

SHELTERED WALLS AT 12 m. HEIGHT

(40', 3.1 storeys)



PORTAGE AVE.

DONALD ST.

MEMORIAL BLVD

BROADWAY AVE.

Figure 10.04: Protected Facades at 12m. (40' or 3.1 storeys) in Elevation.

Figure 10.05: Potential sites for green walls in Winnipeg.

10.5 Potential Sites

During the initial search for sites I found thirty possibilities (see figure 10.05). I narrowed the list down to two through an evaluation of the age of the building (and whether it was a designated historic site), its protection from strong downtown wind currents, its material composition, the condition and size of the facade, its accessibility, proximity to nearby attractions and transit, and its degree of visibility.

The two facades chosen for further development were selected primarily for their materiality, protection from wind, and south-west exposure. One was a highly modified 1920's brick veneered concrete building (333 St. Mary Ave, now known as City Place, originally the Eaton Mail Order Catalogue building, then Eaton Place), and a concrete building with a metal skin (229 Fort St., Winnipeg Square). It had been decided early on that the vertical garden design would be added to an existing facade, in order to improve existing environments and not depend on new construction. Designed as an additional element, it could also be added to new construction as easily as retro-fits.

It was important that the chosen site be highly visible within the downtown, both to visitors and those who live or work there. I also wanted the gardens to be visually accessible. Ideally the gardens would be close enough to eye level so that people walking by could see individual plants. However, I knew that I would have to elevate the gardens somewhat from street level, because of malicious acts that occur to plants in the downtown. Plants get pulled out of their planters, peed on, and used as ashtrays. I decided that the garden would have the best chance of survival if it was not within reach of a person of average height. I had also discovered in my research that above 8 stories in height, additional design considerations must be made for vegetation (Peck et al., 1999, p. 4) so I determined that the garden would range from 2m above grade to an 8 story maximum.

Designs envisioned for each of the facades will be reviewed in the following sections. Each site inspired different scenarios with different aspects to consider. Lists of advantages and difficulties were created for each design to determine which one was persued.

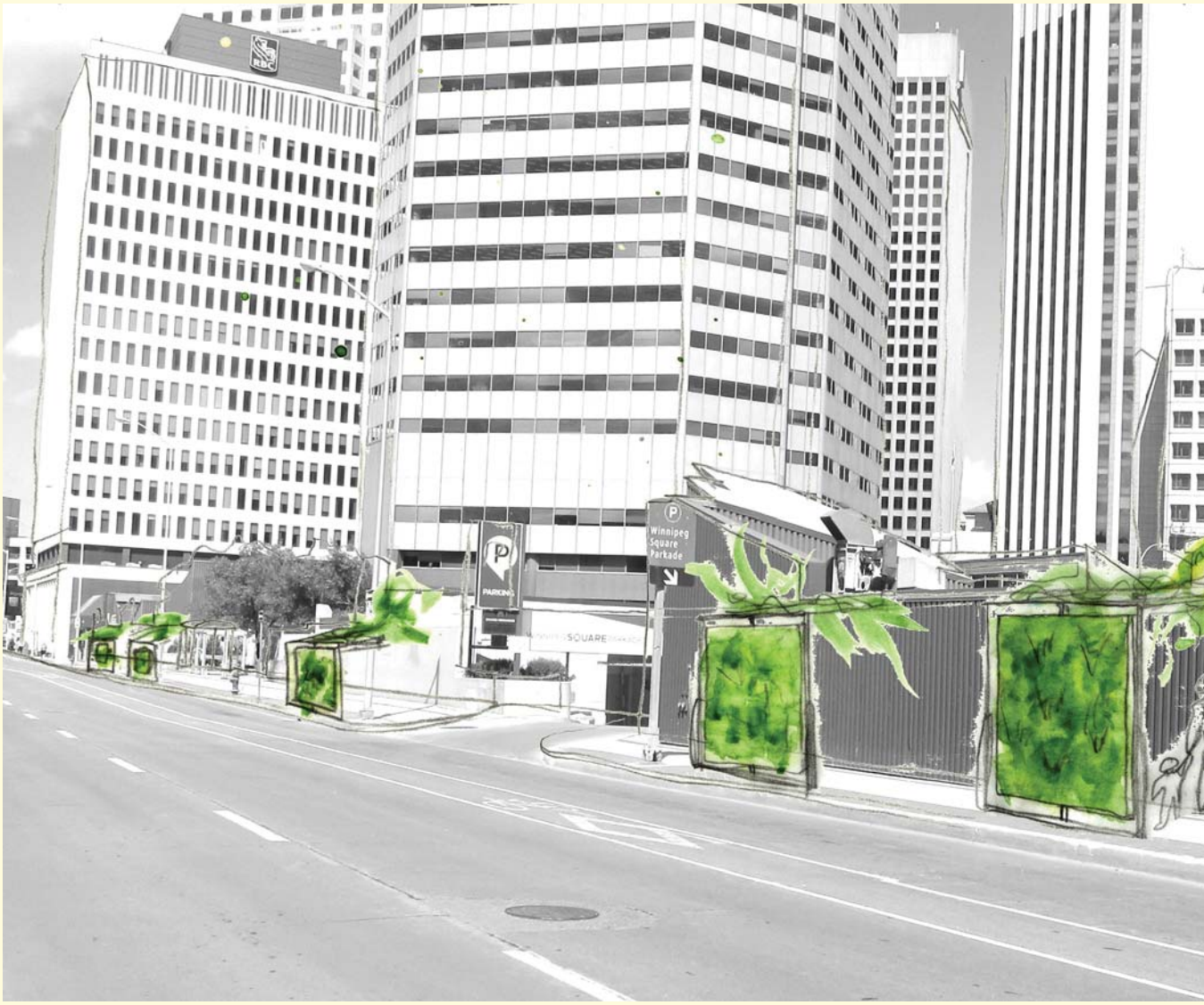


Figure 10.06: Rotating Panels in front of Winnipeg Square.

10.6 Design Sketch #1: Rotating Wall

Inspired by a vertical garden design found in India called the *Jaaga Vertical Garden* (Jaaga, n.d.), the 'rotating wall' concept is a narrow greening tool that could be used on streets where there is not enough space for trees. The design is based on a rotating component, a frame, and a trellis. The frame would be bolted into the concrete sidewalk, and a barrel would be cut in half and put on a rotating mechanism in the middle of the frame. The barrel would be insulated and planted. A trellis would extend from the frame to the nearest building, allowing a canopy of vines to develop over top of the sidewalk, providing shade for pedestrians. During the summer, the barrels could be turned at will, but during the winter they would be locked in place with the plants facing the sidewalk, to protect them from salt spray.

Advantages (3):
- Reacts and adapts to winter by turning,
- Vines will cover the sidewalk,
- Can easily be covered or wrapped for winter.

Figure 10.07: Location of Winnipeg Square.

Figure 10.08: Model of rotating panel.

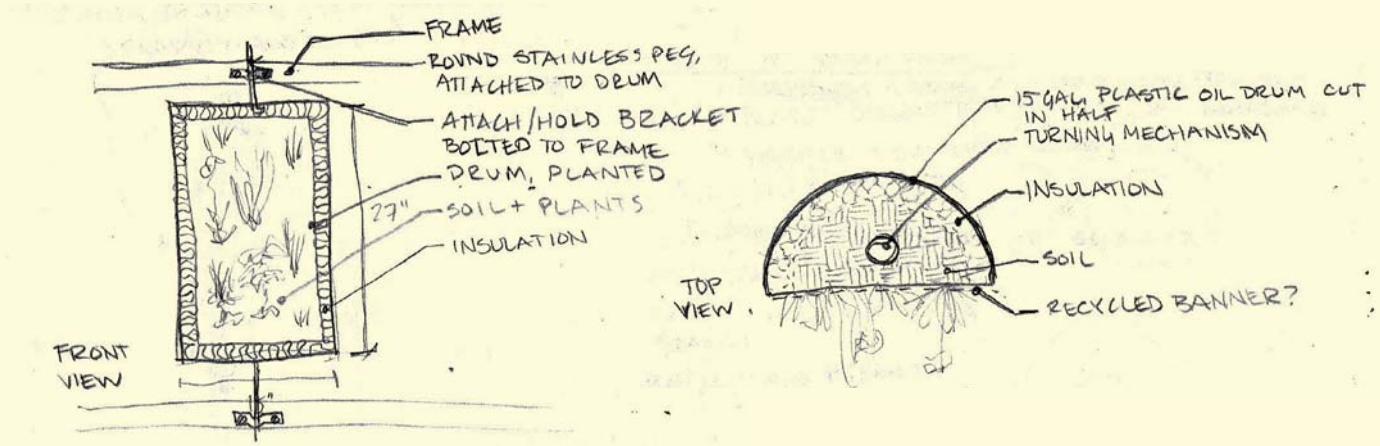


Figure 10.09: Sketches of rotating panel.

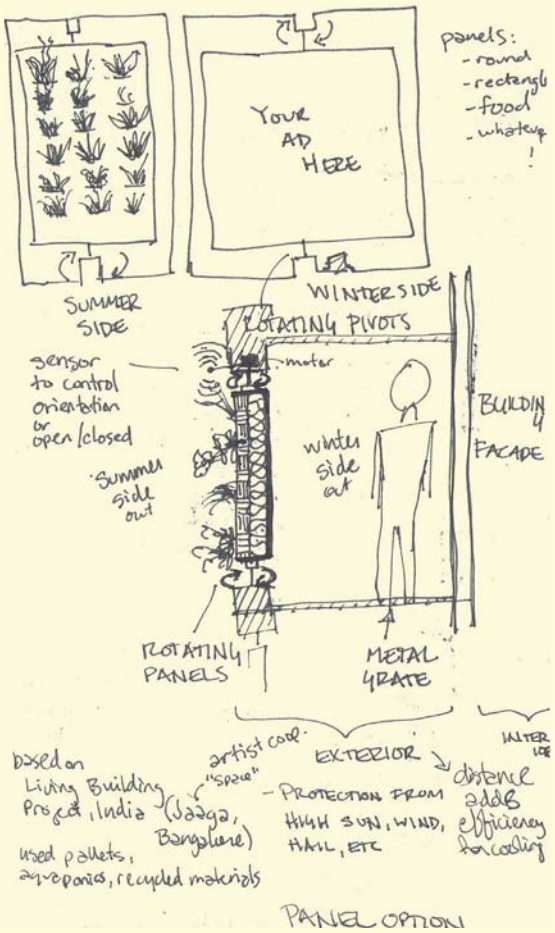


Figure 10.10: Sketches of rotating panel.

Difficulties (7):
- Irrigating a rotating planter would be complicated,
- The panels would be large and require heavy machinery to be moved,
- The design does not allow for variation in soil depth and type within a single module,
- The wall would only be vegetated on one side, but both are actively visible,
- Size of the garden does not lend itself well to the plant community gradient proposal developed in response to the microclimate of a Winnipeg vertical garden,
- Individual plants would be difficult to remove.

Due to the difficulties listed this idea was not pursued. In the end a similar design was installed successfully at the US Pavilion at the Milan 2015 Expo, so the difficulties listed above were able to be surpassed.

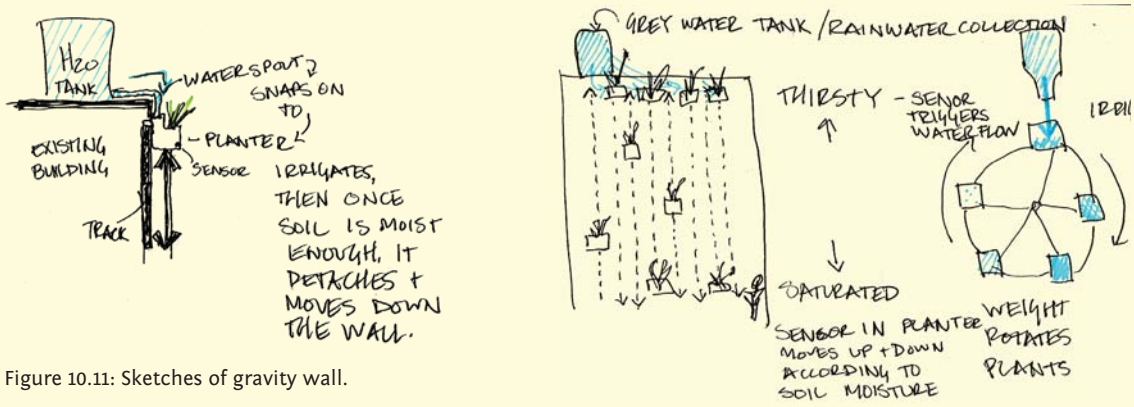


Figure 10.11: Sketches of gravity wall.

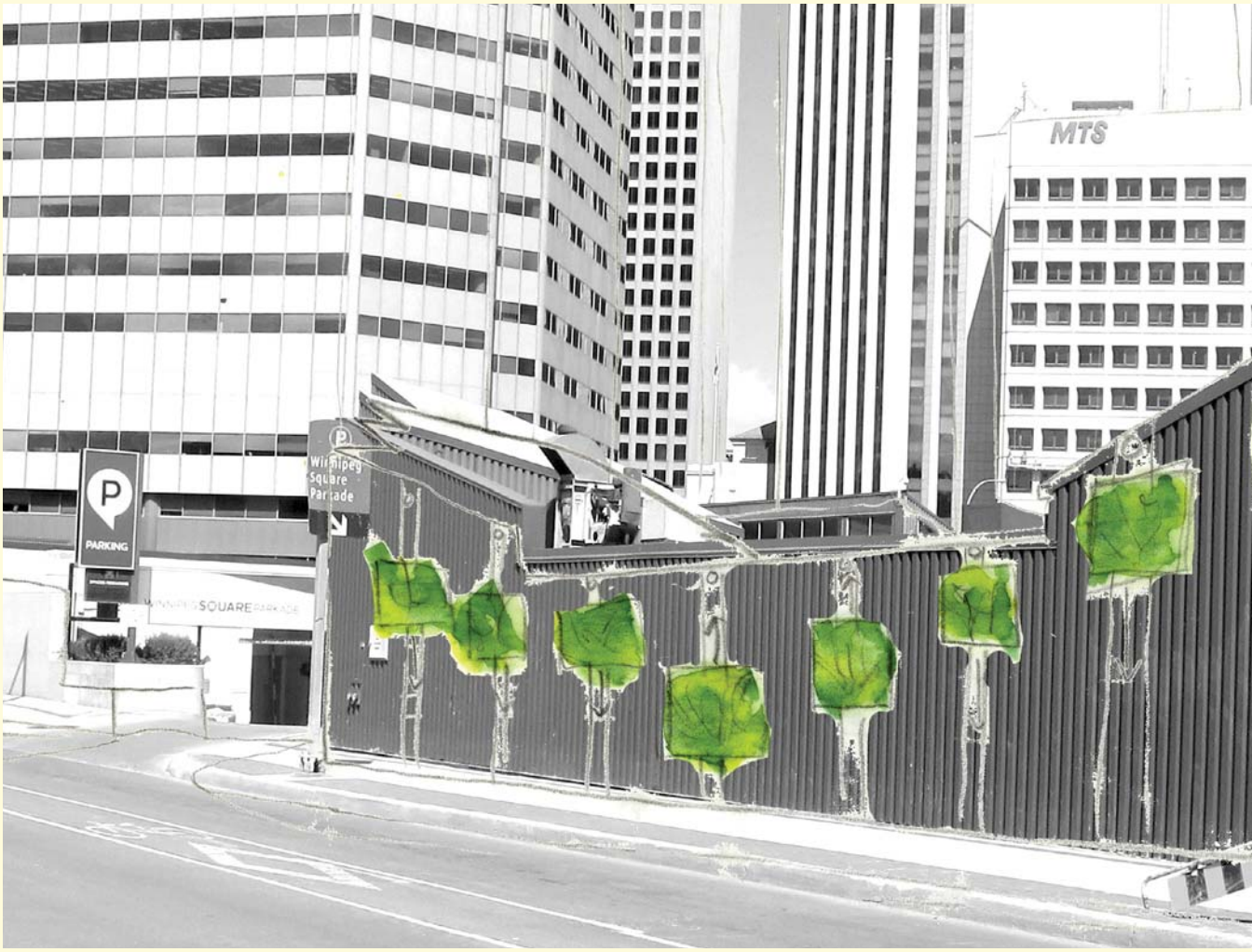


Figure 10.13: Gravity wall on Winnipeg Square.

Figure 10.12: Location of Winnipeg Square.

10.7 Design Sketch #2: Gravity Wall

The gravity wall was developed in response to the moisture conditions of a vertical garden. Individual planter units would be on a counter weight pulley system so that when they were dry (and light) they would be self propelled to the top of the wall, where they would plug into an irrigation spigot. Once they were fully saturated, the added weight of the water would then ease them downward, where they would once again start their ascent when water began to evaporate.
This garden would create a dynamic visual representation of the moisture level of the garden, and would give passers-by an insight into how a vertical garden works.

Advantages (2):
- Interactive/ showcases internal phenomena,
- Provides a dynamic lesson in physics and moisture requirements for plants.

Difficulties (4):
- Could be read as a novelty item, or a game rather than an educational opportunity,
- Essentially only demonstrates one aspect of vertical gardens: plants need water,
- Would cover a relatively small portion of the wall,
- Plug in irrigation system would be complex.

Through discussions with committee members it was decided that this was not the strongest idea, so others were pursued.

Figure 10.14: Cliff recreation on Winnipeg Square.

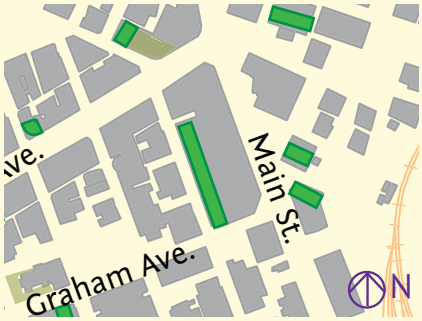


Figure 10.15: Location of Winnipeg Square.

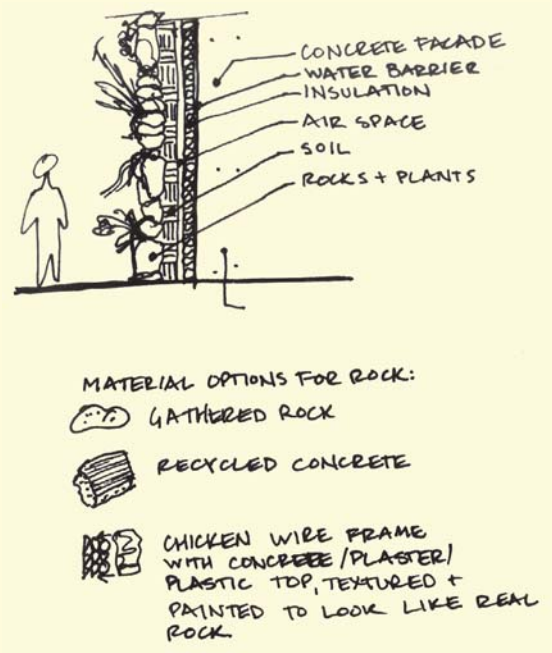


Figure 10.16: Sketch of cliff wall.

10.8 Design Sketch #3: The Cliff Wall

This wall design recreates an artificial cliff in the city. Inspired by cliffs in the city of Hull that appear to be built into the urban fabric (see Boulevard Maisonneuve cliff case study on pages 96-97), this wall would be an analogue cliff, using concrete as rock and only cliff dwelling plants.

Advantages (2):
- Direct translation of cliff research,
- Irrigation system could be simply water poured over the face, similar to a fountain.

Difficulties (4):
- Translation of cliff research was deemed to be too literal as intentions were to create something new instead of a recreation,
- Weight would be extremely heavy,
- Width would have to be fairly thick,
- Would be relegated to bottom of building,
- Responds only to one habitat template.

This proposal was dismissed fairly early on due to the fact that the recreation of a plant community was not the desired outcome.

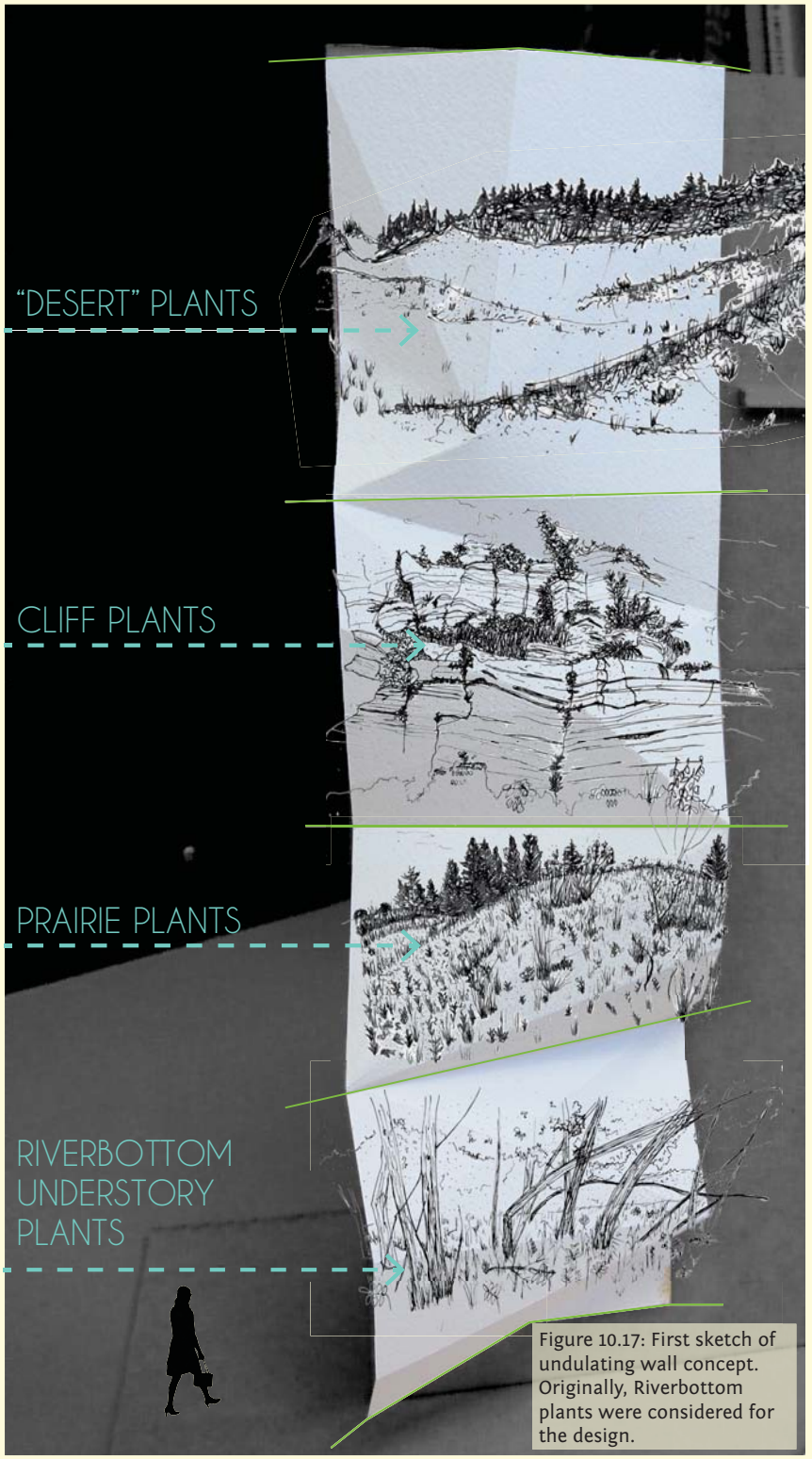


Figure 10.17: First sketch of undulating wall concept. Originally, Riverbottom plants were considered for the design.

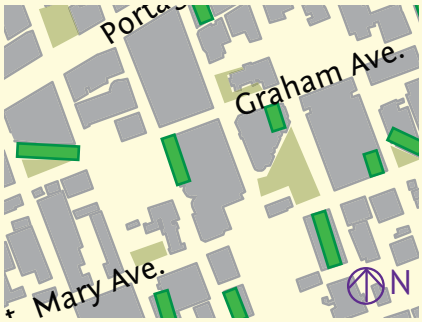


Figure 10.18: Location of City Place

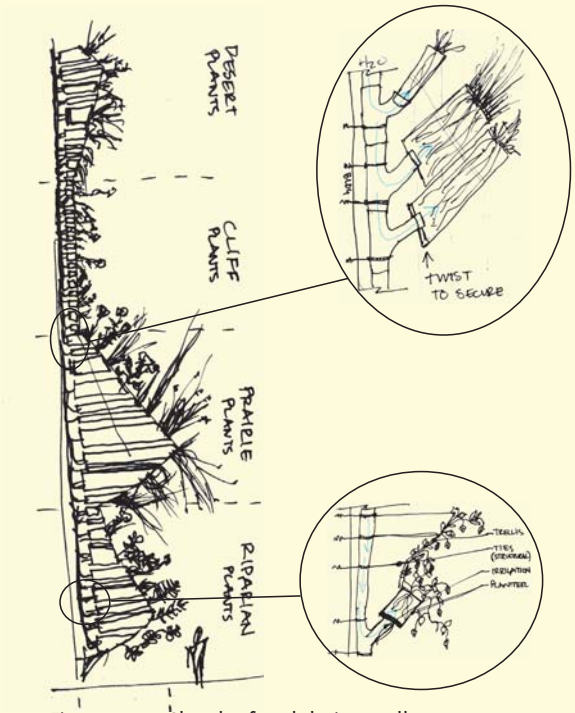


Figure 10.19: Sketch of undulating wall.

Figure 10.20: Sketch of undulating wall.

10.9 Design sketch #4: The Undulating Wall

This proposal was based on considerations of plant root mass in selected habitat templates. The 'containers' are structured to create a series of unique microclimates for plants. Each plant has its own module or pot, and be easily removed if necessary.

Advantages (5):
- Responds to each plant community studied, in terms moisture, soil type and quantity,
- Undulation of the face of the garden will create more microclimates and unique niches for plants and insects,
- Because each plant is contained in a separate container, it would be easier in theory to prevent invasive species from taking over,
- Undulation could provide interesting opportunities for human interaction,
- Clear translation of research.

Difficulties (3):
- Structure would be complex and very expensive,
- Access for maintenance would need to be from the exterior, and special equipment and trained personnel would be necessary,
- Irrigation system and re-circulation would be complex.

This sketch had more advantages than difficulties, so it was selected for refinement.

Figure 11.01: Concept rendering, green wall, City Place.

11. DESIGN PROPOSAL

The Undulating Wall sketch design (see chapter 10, section 9) was chosen for final refinement because it directly responds to all research criteria leading up to the design. From the shape, to the size of plant openings, to materials and plant pallet, everything has a reason stemming from research.

11.1 Location

The final location selected is the west facade of City Place, along Hargrave Street. The building has undergone a series of repairs and retrofits, not the least of which includes the recent addition of large clerestory windows and an entrance on the west side. This renovation was managed by Number Ten Architecture, who were generous enough to share their working drawings of the building. The plans came with a disclaimer: due to the amount of renovations, the inner structure varies quite a bit. Drawings do not necessarily reliably convey existing conditions. For this design, I am assuming that the structure of the bays where the gardens are to be placed are reinforced concrete walls.

City Place's Hargrave facade was chosen because of its identification during the neighbourhood analysis as a relatively wind-free spot downtown. Its also has excellent openings or "blank spots" (areas currently covered with stucco panels). It is centrally located and highly visible. Located in the heart of the Sports, Hospitality and Entertainment District (S.H.E.D.), City Place is adjacent to MTS Centre, Millennium library and beside what is arguably the central hub of rapid transit in Winnipeg. I admire the exterior of the building for its pragmatic and careful use of brick and the simple, yet elegant, cornice and limestone veneers. Having lived four blocks away, I was often far enough away to appreciate the beauty of the building as a whole, but when directly beside it the structure felt, as it continues to feel, somewhat underwhelming. I enjoy the nooks on the first floor with their angled brick base- they are wonderful wind shelters along Graham and Donald during blustery winter months.

The building's physical connection to its surroundings is limited. Entrances exist on all sides of the building, but are disguised

Figure 11.02: City Place

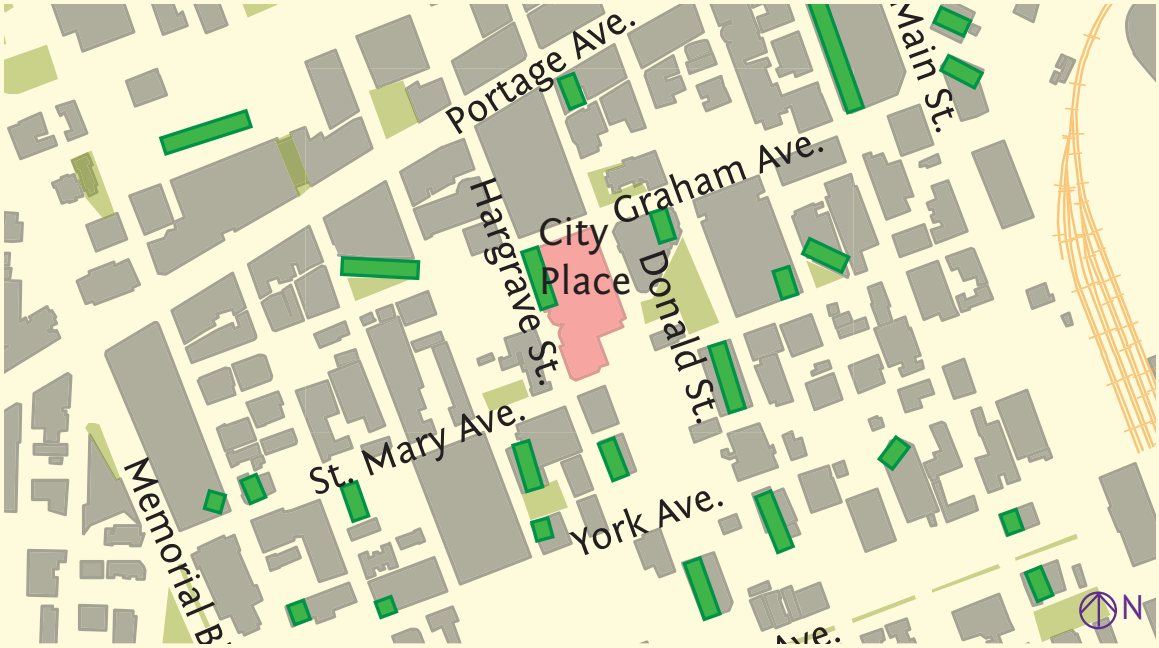


Figure 11.03: Location of City Place within the downtown fabric.

within the uniformity of the facades. Underutilisation of such prime street facing real estate is striking. The first couple of floors of the building have turned their backs to the street, with main entrances and shops opening to the interior court. Street-side walls are not used to show merchandise, or to provide views into the building as they were historically, but are simply used as barriers. Above, the offices belonging to Manitoba Public Insurance have windows that look down to the streets, but these seem to be the only true connection to the outside except for the entrances. A mechanical room is located in the north-west corner of the third floor. This choice of location is surprising to me. The north-west corner faces one of the busiest transit corridors in the city, which provides excellent opportunities for streetside connections and views in and out of City Place. Such transparency would help to draw people in while they wait for their next bus.

The City Place building and location provide opportunities to connect to the greater community and to increase the profile of the tenants. Using vertical gardens to highlight entrances and increase interest will provide an economic boost to the tenants, and give them the opportunity to capitalize on a more "green" image.

Figure 11.04: Refined design rendering.


CIBC Banking Centre

Figure 11.05: Rainwater collection and irrigation system.

11.2 Design Structure/Form/Material

The garden is a retrofit design that could be added to an existing building. It is a unique structure that would be made using a mold and various recycled products. For the purpose of this practicum, the assumption is that the structure of City Place is robust enough to hold the garden, which is comprised mostly of lightweight materials. The garden will be located on the second floor of the facade, above existing signage for tenants. The gardens will feature mostly hearty Manitoba plants, whose relative abundances will change over time.

The search for suitable materials for the design began with visits to recycling depots such as the Habitat for Humanity Re-store. I was browsing through the plumbing section, when I saw PVC pipes. Having worked in plumbing briefly before, I was somewhat familiar with the parts offered. PVC pipe come comes in standard diameters (a very wide variety - from 2" to 20") and there are restrictors, angle connections, and caps manufactured to fit all the diameters offered. PVC seemed like a good option, for a while. The different diameters and lengths could be correlated to the size of the plant (and, more importantly, its root mass). This material however would be difficult to stack at an angle, is very heavy, and does not provide the

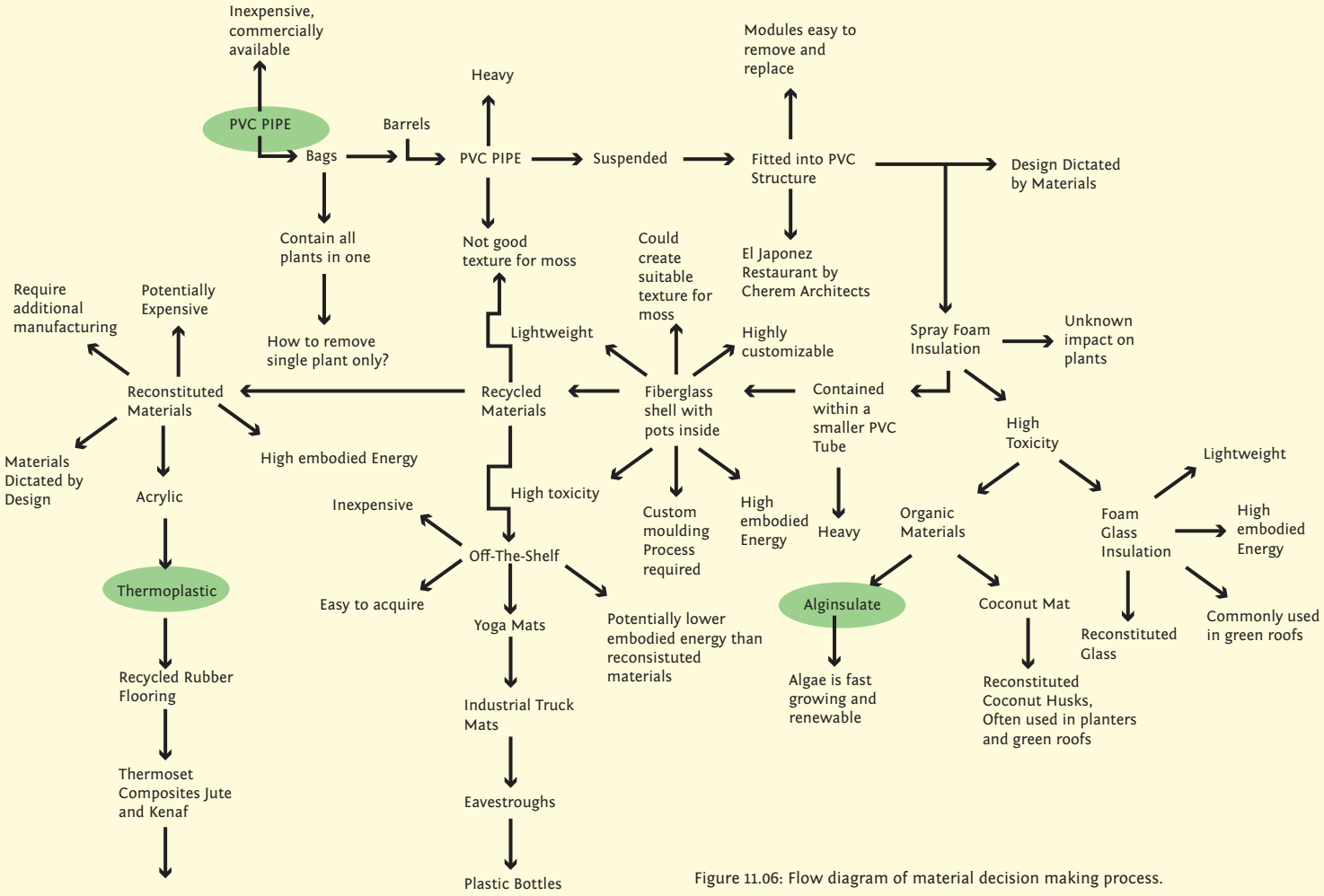
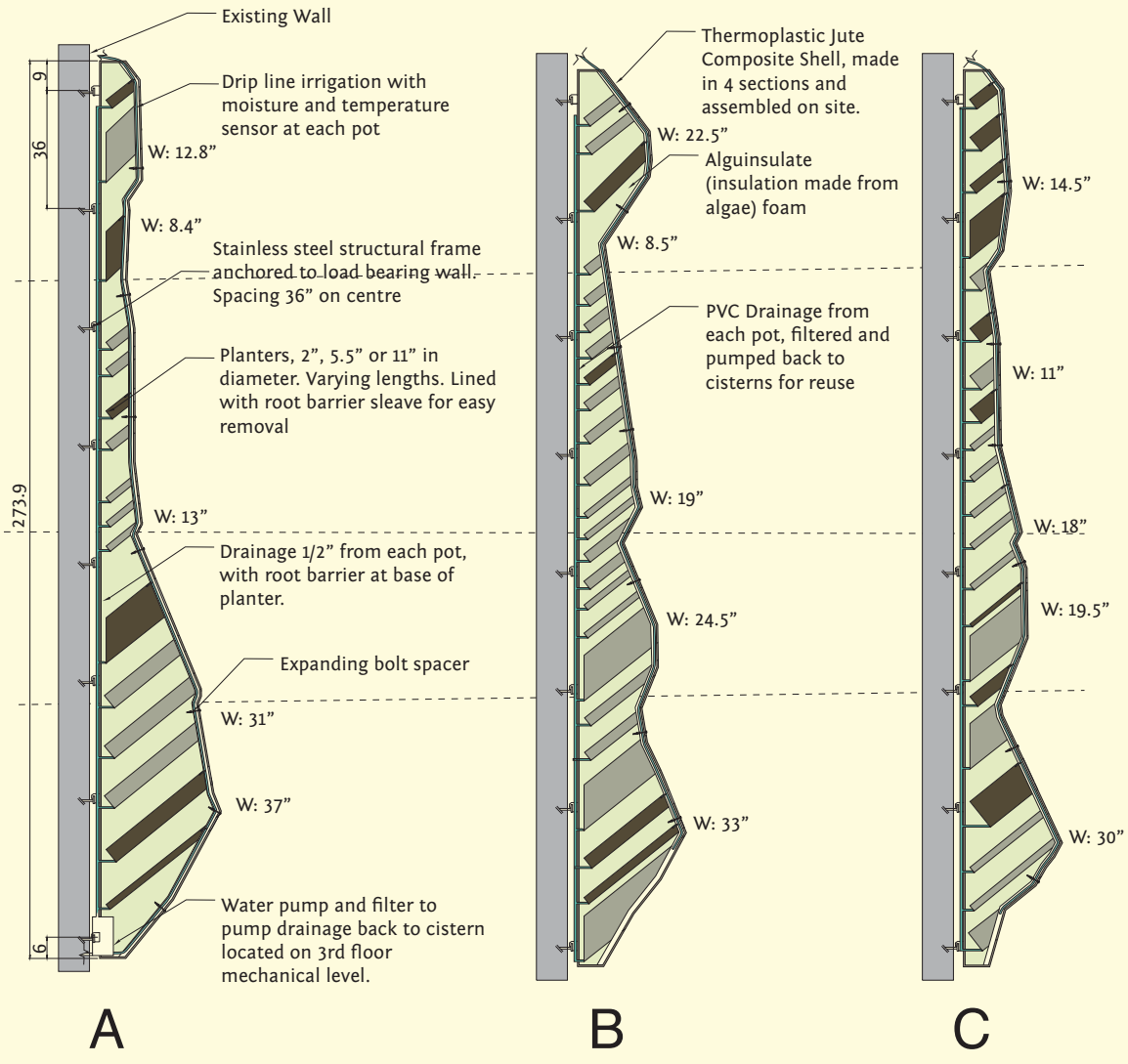


Figure 11.06: Flow diagram of material decision making process.

texture necessary to host the lichen and moss desired to colonise the project, so alternatives were investigated. PVC is still used in the final design, but its role is to provide formwork for the planters, while other materials are sprayed around them (see figure 11.07).

The final structure is comprised of 4 unique panels as seen in figure 11.07 and 11.08, that together create a dynamic, undulating form. Panels fit into each other, forming one cohesive garden. The garden has been scaled to fit into each existing bay of the City Place building, allowing flexibility for installation in any of the bays. With changes to the plant pallet, panels could also be installed on the northern and eastern facades if desired.

Materials highlighted in figure 11.06 have been selected for their lightness, as well as being either recycled or otherwise environmentally friendly. The exterior shell is made from reinforced thermoplastic jute for structural stability. Recycled PVC pipes are retained as the formwork for the openings of plants. Alginsulate foam is used as an insulating material around plants. Due to high temperature fluctuation found on facades, an insulative membrane is necessary. Alginsulate, a material currently in development by Dr. Michael Narodoslawsky at the University of Technology Graz in Austria (Verpackungs Zentrum Graz, 2013) is an insulative foam made from algae, through a process that does not produce any harmful substances .



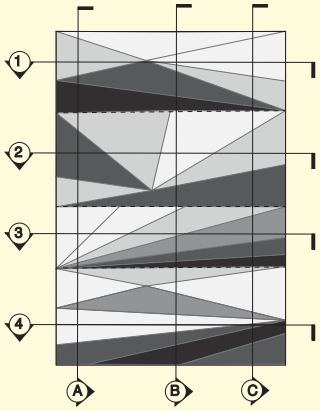


Figure 11.07: Sections showing orientation and relative size of planters and materials used.

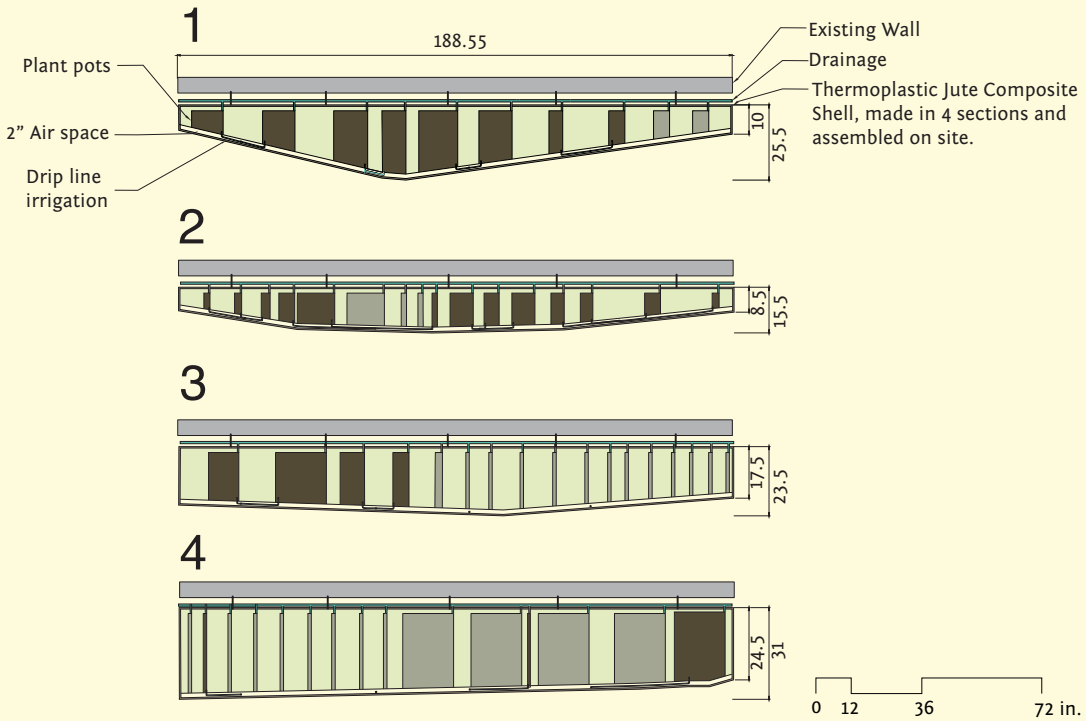


Figure 11.08: Sections showing depth of each community area.

The exterior thermoplastic jute face will have three different sized openings for the plants. The size and spread of each plant determines what the opening size is. The face will be a light colour, with a high albedo so solar heat will be somewhat mitigated. Over time, it is intended that moss and lichen will colonise the face of the jute, providing more visual interest. Lightweight soil designed for green roof applications, which has a fully saturated weight of 60 lbs/sq. ft. (292.6 kg/m^2), instead of the typical 100 lbs/sq. ft. (1597 kg/m^2), will be used (Peck and Kuhn, n.d., p. 11). This growing medium was used on the Vancouver Public Library green roof (p.11).

Water will be gathered for irrigation from rainfall on the roof (see figure 11.05) and stored in cisterns on the mechanical floor of City Place. Rainwater will be filtered as it enters the cistern. Once water has circulated through the garden, it will be piped into a secondary cistern where it will once more be filtered. Upon completion of the second filtering, the water will be transfered back to the first cistern, to go through the garden again. This will reduce runoff from the City Place site, as well as the amount of water in the combined sewer system downtown. This could be a critical detail for Winnipeg, because during times when the sewers reach capacity, raw sewage overflows directly into either the Red or Assiniboine Rivers. This occurs several times a year. In times of drought, city water will be used to irrigate but only when absolutely necessary.

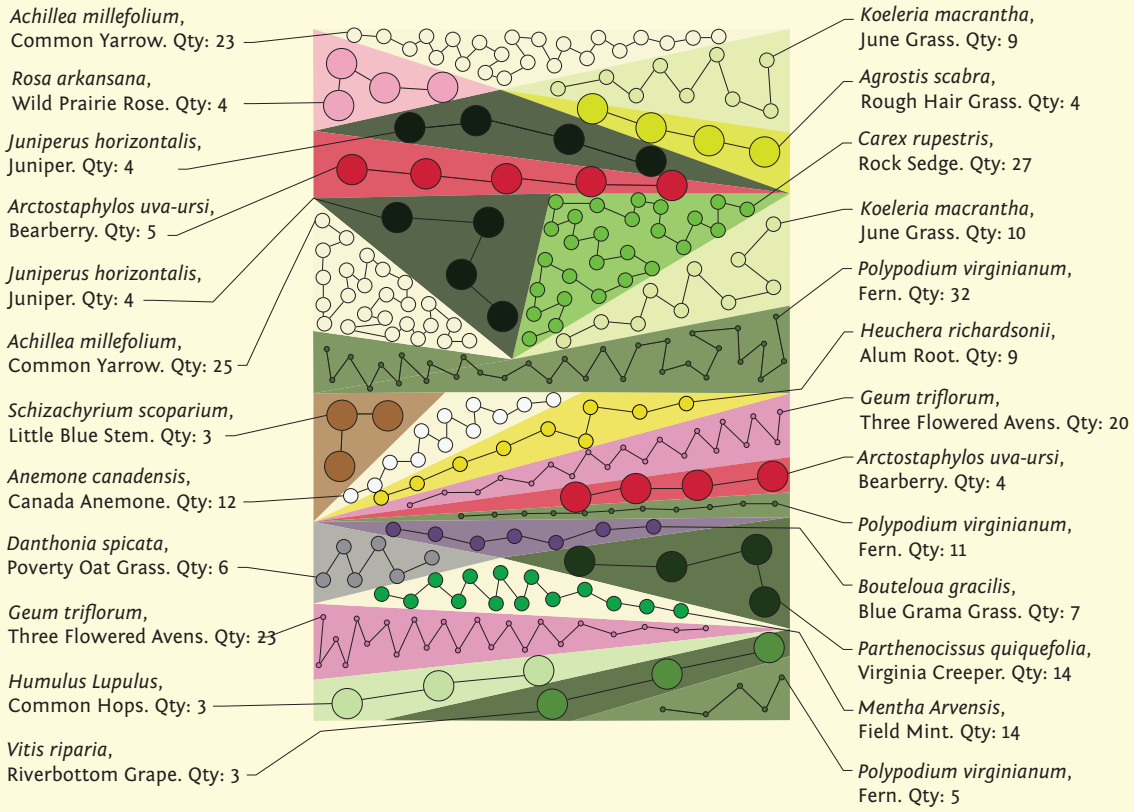


Figure 11.09: Plant Pallet as planted.

11.3 Plant Pallet and Habitat Potential

The plant pallet, shown in figure 11.09, is comprised of plants found in four of the communities studied: cliffs, prairies, sand dunes, and prairie potholes. From these communities, one fern, one sedge, four shrubs (including two subshrubs), three vines, five wildflowers, and six grasses were selected. These plants are predicted to be able to thrive in the microclimate of a wall, and most are able to grow in full sun or shade. Plants range from medium sized shrubs to grasses and small herbaceous plants. Smaller species are more numerous, and it is assumed that they will be visible from street level due to their increased numbers. Stainless steel trellis cables will be suspended vertically on the columns of City Place, giving vines and climbers a secured area to spread within. Vines will need to be pruned regularly to prevent excessive growth.

The plant list was first developed during the research phase, when a list was kept of the plants most often mentioned as growing well on cliffs or walls. This list was then combined with the preliminary list I had developed during the *Vertical Gardens* Reading Course (Urben-Imbeault, 2012, p. 24-34).

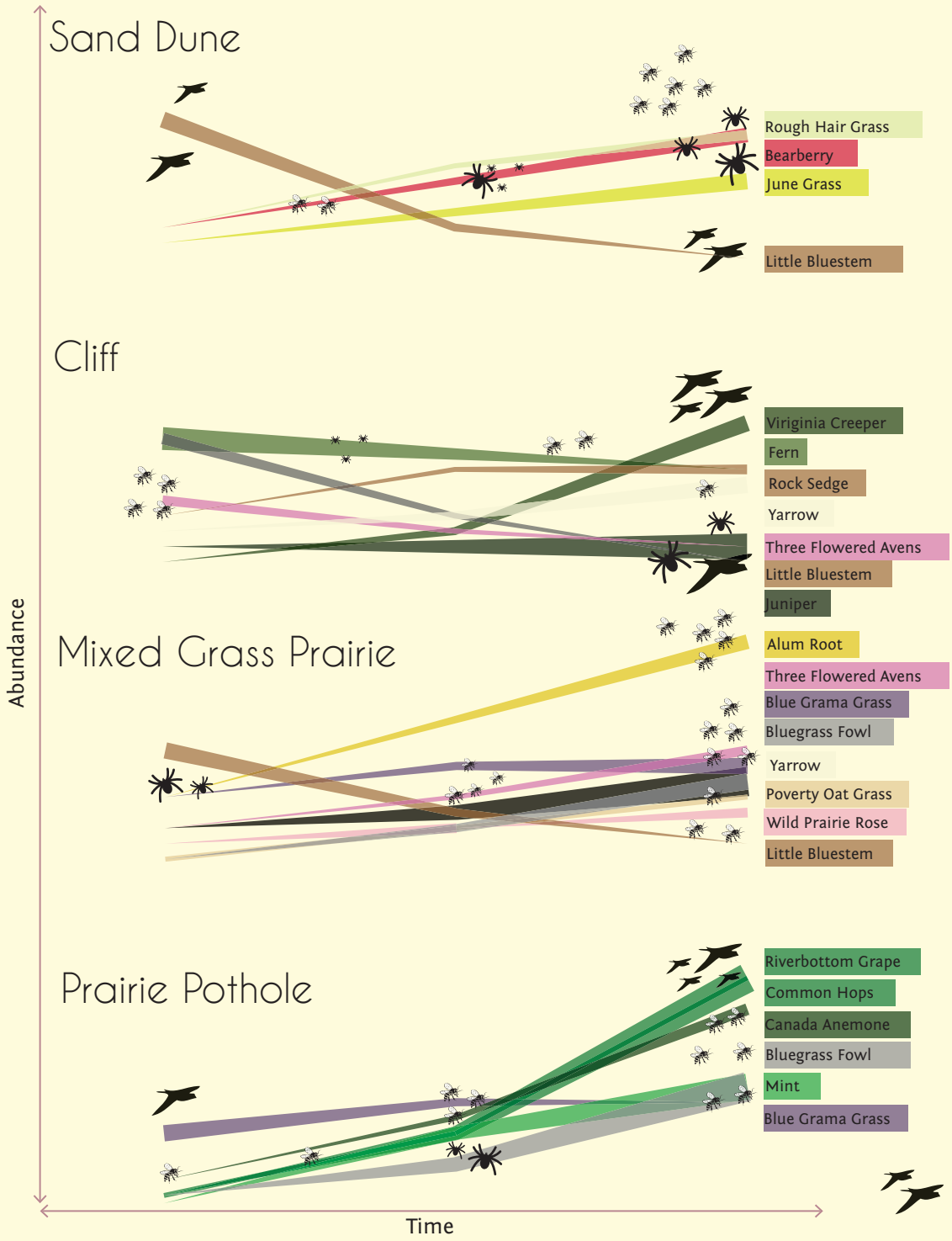


Figure 11.10: Planned plant abundance and change over time. Analysis is based on quadratic sampling methods that sample the spread of plant, and does not necessarily accurately represent the quantity.

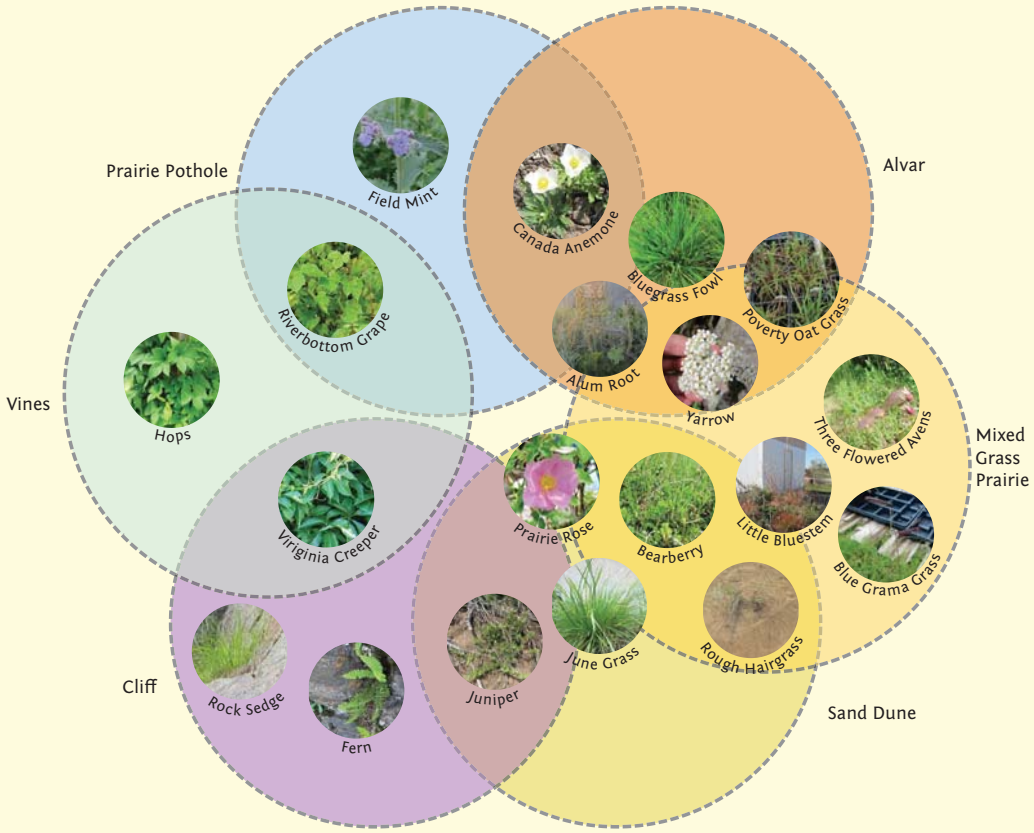


Figure 11.11: Plant pallet showing origin communities. Plants located between or in 2 circles are present in both communities. Many of the plants used are present in multiple communities, so the community in which it is most abundant determined its placement in the figure.

Through consultation with committee members that are plant experts, recommended plants were added and others removed. Each plant was then evaluated based on a series of criteria, with one point given for the following requirements satisfied;

- Appropriate size to be viewed from street level, but also small enough to grow to maturity in a container,
- Able to grow in sun and shade,
- Hardiness/tolerances of pollution, salt
- Moisture requirement,
- Winter interest,
- Bonus: Other (varies) examples include food for birds, cover for insects or larvae, flower colour and bloom time, texture, edible for human consumption.

Any plant that did not receive a rating of 4 or higher was removed from the list. Those that remain are the best of the originally selected plants for Manitoban vertical gardens.

The majority of these plants provide food or nesting materials for various species of birds, butterflies and bees. As such, nesting will be encouraged by the garden, and will bring more diversity to the downtown, which does not currently have such a high plant diversity

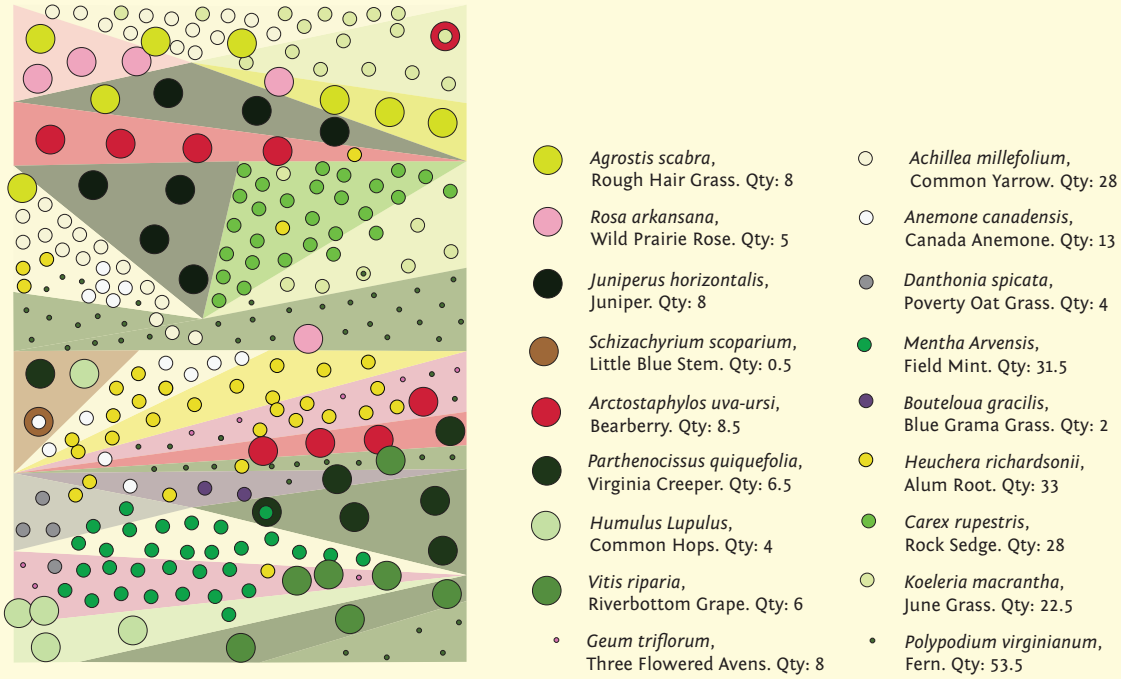


Figure 11.12: Possible plant abundance in future.

as would attract such a variety of species. Larval habitat will be provided for solitary bees who nest in holes in wood. Hollow bamboo will be inserted in some of the smaller holes in the front face not occupied by plants. The bees' colonization will be instigated by design. Their presence in the garden will help ensure plant health is maintained.

The garden will undergo succession over time. Plants have been chosen for their different roles and behaviours in the succession process. Initially, planting will be clean and orderly, plants will be organised so that one plant will grow on each plane of the garden. Over time, it is expected that the composition of plants will change, evolving into a less structured composition. Some species will be lost entirely, while others will need to be managed so they do not take over the whole garden. New plants will grow from seed or droppings brought to the garden by wind, animal or bird. Some of these plants will need to be removed; others, such as lichen and moss, will be encouraged. Removal of individual plants will be facilitated by geotextile linings in each pot, allowing the plant to be easily removed from the garden.

Figure 11.13: Vertical garden covered with a tarp for the winter.


CIBC Banking Centre
cityplace

11.4 Adaptive management

Adaptive management is a method used in situations where the outcome is not fully known or predictable. It relies on study over time to develop new strategies that adapt and respond to changes in the system. Adaptive management can be very useful to ensure planting remains robust and healthy.

The vertical garden will require adaptive maintenance. Plant growth, rigour and overall health will be monitored. Sensors will be required to monitor soil moisture, and ensure irrigation is regular. Materials will be checked to ensure they are not broken or hindering the success of the garden. Systems will be monitored by a team of professionals, from various industries. Monitoring of certain aspects will occur daily (eg. soil moisture), while others will occur monthly or as needed (eg. plant health, overall structural monitoring). If plant mortality rises above a couple plants a month, detailed analysis of the system will need to be undertaken to determine causation. It is recommended that both design and construction professionals meet to inspect and discuss their findings if and when issues arise. Solutions will be proposed and implemented as soon as authorisation is given from the owner and designer of the vertical garden.

A single bay of the design will need to be built and installed in a location where it can easily be monitored before it can be installed at City Place. Monitoring will occur for a minimum of three years before a report will be compiled on the information gathered. This report will aid in the re-evaluation and potential redesign of the vertical garden. The final iteration, after recommended revisions from the report are made, would be installed on City Place. Once the garden is installed, adaptive management will still be necessary, but most major discoveries or failures should have been resolved through the initial monitoring phase. The opportunity to fund the project will be presented to the tenants of City Place. It is estimated that larger companies in City Place such as Manitoba Public Insurance (the current owner), CIBC and the Manitoba Liquor Mart may each be interested in sponsoring a green wall. Provincial and federal funding will also be sought as there are a few government grants for which the project would qualify.

11.5 Winter Garden

During the winter the garden will be wrapped with a brightly coloured tarp to protect plants from wind, dessication and drastic temperature changes. This wrapping, combined with insulation and air spaces, will shelter plants well from drastic changes in temperature, which are the biggest threat to plants on a wall during the winter. It is unknown if the tarp cover will be necessary; further testing is required. If plants are able to survive winter without being covered, the garden will remain visible throughout the year.

Conclusion

The structure and design of the vertical garden is site specific in every way possible, from plant choice to overall form. A unique assemblage is created that respects and responds to the site and community in which it is located. The green wall design can be installed at different locations in Winnipeg, however revisions at each site will be necessary to ensure health of the plants.

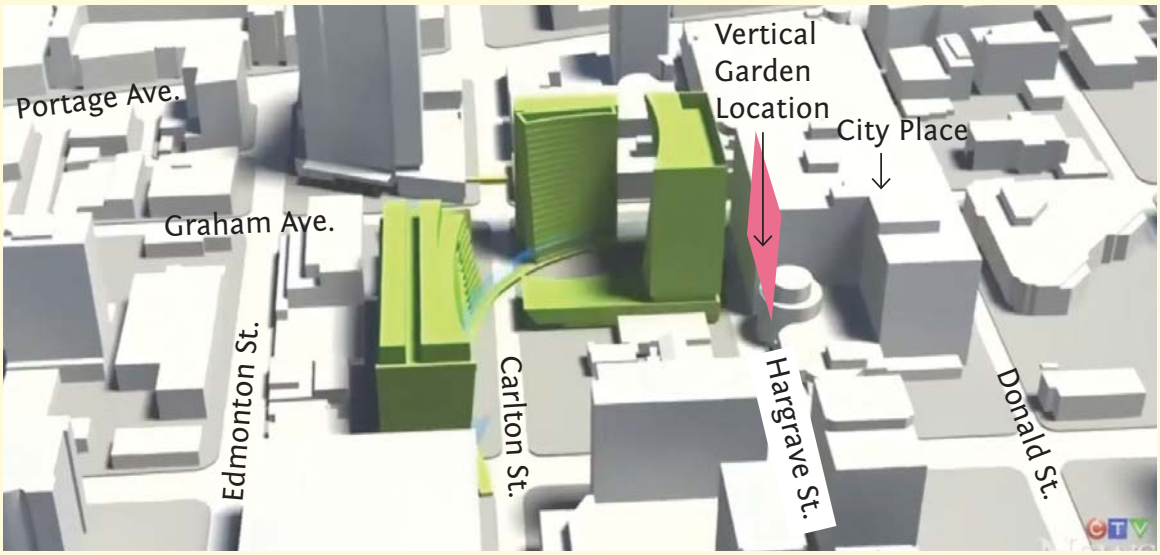


Figure 12.01**: Planned development of True North Square.

12. CONCLUSION

The Undulating Wall at City Place will bring excitement and dynamism to the burgeoning S.H.E.D. in Winnipeg. Its undulating geometric forms create a point of interest and fascination in the neighbourhood. By using native plants from Manitoban habitat templates, a connection to the larger regional landscape will be established, and will provide new habitat opportunities for bees, birds, and butterflies. Recycled or natural materials will be used for many parts of the design, while keeping weight to a minimum. Adaptive management will be employed to monitor and adjust maintenance procedures as appropriate.

Changes happen in sites, especially in cities. There are many plans proposed for the S.H.E.D. The site at City Place will be greatly affected by the True North Square development. It features a 20 storey mixed use building located directly beside the City Place Hargrave facade, where the vertical garden was planned. This will change the facade's solar exposure, creating one more similar to a northern facing wall. Most of the plants chosen for the vertical garden proposed here will be able to adapt to these new conditions, as they are able to grow in both direct sun and shade. Some plants may need to be removed or replaced after construction is completed. Geotextile sleeves will facilitate the removal of individual plants. Humidity levels will increase due to the increase in shade, which will reduce the amount of irrigation lost to evaporation. Wind currents will change drastically and digital analysis will need to be undertaken to determine whether additional modifications are necessary. Ultimately, as with all landscape projects, the design will be affected by all changes in the area. Designers should always plan for change and unforeseen complexities.

This practicum provides a knowledge base for cold climate vertical garden enthusiasts to anticipate growing conditions, external influences and ideal scenarios for vertical gardens in urban neighbourhoods. There are still many things that remain unknown in the field, and further research is recommended. On the following spread a brief list of aspects that should be explored in the future is included.

- Detailed scientific analyses of vertical gardens that include comparative climate and UHI data, details about species of plants used and why, depth and kind of growth media, solar orientation, wind exposure, and frequency and type of irrigation.

- Comparative analysis of different kinds of vegetation used in green walls for different locations and scenarios. Eg. for a given situation would succulents or grasses be the most appropriate choice?

- Compare heating and cooling trends in hydroponic versus soil systems.

- Comparative analysis of heating and cooling models based on data from a single green wall to an entire building covered in plants.

- Qualitative and quantitative studies of failed vertical gardens.

- Publishing of construction standards and codes for vertical gardens.

- Studies of animal and invertebrate colonization of vertical gardens.

- Studies of VOC reduction/emission from plants used in green walls.

- Study of the suitability of volcanic, arctic, epiphytic and mountain cliff plant communities for vertical growth.

- Comparison of successful vertical garden to healthy street tree (in terms of the amount of shade, pollution and dust control, biodiversity and habitat provided)

- Quantity and quality of food producing plants in vertical gardens versus traditional gardens on grade.

- Correlation of vertical garden diversity to overall success or other attributes.

- Further investigation of ideal urban canyon configuration and location for successful vertical gardens in urban centres. Cartographic modeling, and/or the development of scripts to analyse locations in massing models could be developed.

- Potential for vertical gardens to increase the lifespan of a building wall.

- Development of recommended plant lists for vertical gardens in various climates.

- Increase positive awareness of vertical gardens in designers, contractors and the general public.

- Increase number of grants and incentives available for vertical gardens. Adding vertical gardens to programs like LEED (Leadership in Energy and Environmental Design) and adding supplemental landscape-based point systems like the *Seattle Green Factor* will greatly increase the prevalence of vertical gardens.

- Translation of existing texts, such as the German *FLL*, into a variety of languages.

- Further study of the percentage of cover of cliff communities, including vegetation type, plant type, species richness, number of species, weedy or native.

- Further testing of green walls in Canada.

- Research of how much soil is needed to overwinter a mature native plant in a container. If insulation is needed, how much? Will a simple tarp cover suffice or is accumulated snow on top and sides necessary?

- The creation of a modular (flexible) vertical garden design for cold climates that could be easily adapted to a variety of sites.

- Studies on the mortality rates of plants in containers in Winnipeg.

- Architectural and structural analysis of Winnipeg walls best suited to host vertical gardens.

FIGURES

All figures are the original work of the author, unless otherwise noted.
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Front End:

1: Vertical garden idea web.
2: Garden design at City Place.
3, 4: Design drawings for modular hydroponic vertical garden, made for LA Studio 7.
5, 6, 7, 8: DIY vertical garden experiments with recycled drawers, and different growth media.

Chapter 1: Introduction

No figures

Chapter 2: A Short History of Vertical Gardening

2.00: Grape Vines provide shade and fruits on a Greek restaurant patio on Ellice Avenue in Winnipeg.
2.02*: Vinalia, the Roman wine harvest festival was celebrated when grapes were harvested in ancient Greece. Image *Vintage at Cherchell Roman mosaic* retrieved from Wikimedia, http://en.wikipedia.org/wiki/Vinalia#/media/File:Vendanges_romaines_%C3%A0_Cherchell.jpg
Image in the public domain.
2.03: Recent resurges in the popularity of vertical gardening have spurred many new innovations in the field.
2.04**: Vertical garden by Patrick Blanc, Paris. Image by Maria Zbigniewicz.

Chapter 3: Types of Vertical Gardens

3.01: Vines growing at the University of Manitoba.
3.02: Green retaining wall system by Hurcules.
3.04**: Soil based panel system in Victoria. Image by Nefeli Mitrovgenis.
3.05 Felt hydroponic garden in Toronto.

3.06: Felt biofilter in Toronto.
3.07: Types of vertical gardens vary mostly due to the kind of media they grow in.
3.08 Vines at the University of Toronto
3.09: Vines at the University of Toronto
3.10: Self-Clinging Climbers Image adapted from Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) (2000). *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau Richtlimie für die Planning, Ausführung und Pflege von Fassadenbegrünungen*. Bonn: Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. - FLL (p. 17)
3.11: Support Climbers Image adapted from Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) (2000). *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau Richtlimie für die Planning, Ausführung und Pflege von Fassadenbegrünungen*. Bonn: Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. - FLL (p. 17)
3.11: Support Climbers
3.12: ARTLab steel trellis.
3.13 Vines squeeze between a building and a sidewalk in Costa Rica.
3.14: Close up of Virginia creeper growing on the ARTLab trellis.
3.15: Dead vines still cling to a brutalist structure at the University of Toronto.
3.16: Close up of different vines growing on a brick masonry wall at the University of Toronto.
3.17: Espaliered tree.
3.18: DIY style garden made from recycled materials.
3.19: Commercially available soil bearing system that can be bought pre-planted or plant-free.
3.20: Green Over Grey's green wall system installed in a cafe in Toronto.
3.21: Felt Growing medium with water collection tray at bottom of hydroponic garden, Toronto.
3.22: Living Wall Biofilter at Sun Life Financial in Toronto.

Chapter 4: Benefits of Vertical Gardening

4.01 & 4.02: Plants commonly used for indoor vertical gardens. Richardson Building Green Wall.
4.03 & 4.04: Details of growing media and plants in biofilters.
4.05: Nedlaw™ Biowall, Sun Life Financial, Toronto.
4.06 & 4.07: With a widespread application of green skins in the form of green walls and roofs, temperature variations (the UHI) of cities will fluctuate less, resulting in happier residents.
4.08: Dust and pollution accumulate on the leaves of plants in urban environments. Carbon is also sequestered through the photosynthetic process.
4.09 & 4.10: Stormwater runoff can be minimized with the use of widespread vegetative skins on buildings.
4.11 & 4.12: Vegetation can help to reduce noise reverberation.
4.13: Integrating native vegetation into urban centres will help bring nature into cities.
4.14: People admiring a living wall biofilter in the Richardson Building, Toronto.

Chapter 5: Difficulties Associated with Vertical Gardens

5.01**: Failing green wall, Vancouver. Image by Fernando Velarde Trejo and Tove Hall.

Chapter 6: Microclimate of a Vertical Garden

6.01: Wall microclimates vary tremendously in disturbance, moisture levels and solar exposure. The top of the wall will generally have increased disturbance from wind, and be exposed to more sun, whereas the bottom of the wall will have increased disturbance from people, animals and cars, and be exposed to less sun. Because of these factors and due to gravity, moisture levels at the bottom of the wall are usually the highest, while the top of the wall is relatively dry.

6.02: Located directly beside the Granville bridge freeway in Vancouver, this garden is perfectly located to capture unwanted dust from the freeway.

Chapter 7: Regional and Neighbourhood Climates in Winnipeg

7.01*: Location of Winnipeg, Manitoba. Vector Image Source: *H1N1 Canada map.svg* Uploaded by Wikimedia user Fonadier. Canada vector https://en.wikipedia.org/wiki/2009_flu_pandemic_in_Canada#/media/File:H1N1_Canada_map.svg
Used under Creative Commons License: http://creativecommons.org/licenses/by/3.0/
Changes: Colour, labels, and location of Winnipeg.

7.02: Winnipeg's regional climate, cold continental. Numbers shown are maximums and minimums collected throughout the last 100 years.
Weather data adapted from http://WeatherSpark.com/averages/28187/Winnipeg-Manitoba-Canada/

7.03: Map of Winnipeg's downtown core. (see Map Metadata section for map data source)
Statistics retrieved from:
Data marked with ** is from: Statistics Canada (1996) *Downtown Neighbourhood Profile* Retrieved from winnipeg.ca/census1996/default.stm
Data marked with * is from: Statistics Canada (2006) *Downtown Neighbourhood Profile* Retrieved from http://winnipeg.ca/Census/2006/City%20of%20Winnipeg/Downtown%20Winnipeg/Downtown%20Winnipeg.pdf

7.04: Screen shot showing boundary layer of downtown Winnipeg.

7.05: Shade analysis of downtown Winnipeg.

Chapter 8: Foundations

8.01: Roadside cliffs in the Cloud Forest of central Costa Rica.

8.02: Corktown Commons, Toronto. Design by Michael Van Valkenburg Associates

8.03: Weeds growing in a crack in the pavement.

8.04: Similar geometry and material composition make a naturally formed canyon similar to an urban streetscape.

8.05: Plants growing on a wall in Britain. Image by Maria Zbigniewicz

8.06: Colonisation of a steel wall by plants on a southern facing street-side retaining wall, Toronto.

8.07: Unplanned colonisation of a steel wall by plants on a southern facing street-side retaining wall, Toronto. Note species of yarrow, nightshade and grasses.

Chapter 9: Suitable Habitat Templates for Winnipeg

9.01: Habitat template sketches.

9.02*: Locations of habitat templates. Vector of Canada Source: *H1N1 Canada map.svg* Uploaded by Wikimedia user Fonadier Canada vector https://en.wikipedia.org/wiki/2009_flu_pandemic_in_Canada#/media/File:H1N1_Canada_map.svg
Used under Creative Commons License: http://creativecommons.org/licenses/by/3.0/
Changes: Crop to Manitoba only, colour, and added habitat locations, capital city label and locations.

9.03: Influences observed on cliffs include: 1) wind exposure, 2) drainage from surrounding area, 3) disturbance from people, animals, and other natural occurrences 4) nearby waterbodies (increased humidity levels), 5) solar exposure and 6)regional context both in terms of flora and fauna communities and whether located in a city or in a rural area.

9.04: Variance in disturbance from rock climbing shown in pink, Lily Pond rock wall.

9.05: Ground water drips from moss in a crack in the Lily Pond rock wall.

9.06: Composition of a small cliff in Major's Hill park, Ottawa.

9.07: Appearance of the same cliff shown in Figure 9.06 without dissection layers.

9.08: Large roadside cliff in Kenora, Ontario.

9.09: Large roadside cliff in Rockliffe Park, Ottawa, Ontario.

9.10: Case Study: Major's Hill Rock Wall 1 (see Map Metadata section for map data source)

9.11: Case Study: Major's Hill Rock Wall 2 (see Map Metadata section for map data source)

9.12: Case Study: Nepean Point Rock Wall (see Map Metadata section for map data source)

9.13: Case Study: Boulevard Maisonneuve Rock Wall (see Map Metadata section for map data source)

9.14: Case Study: Whiteshell Provincial Park Roadside Wall (see Map Metadata section for map data source)

9.15: Case Study: Lily Pond Rock Wall (see Map Metadata section for map data source)

9.16: Pika, Ochotona princeps

9.17: A rare glimpse of what a natural talus would look like. Roadside, CR.

9.18: Alvar on the edge of the Whiteshell region of Manitoba.

9.19: Sand dunes in the Sandy Lands at Spruce Woods Park, Manitoba

9.20 & 9.21: Sand dunes at Spruce Woods.

9.22**: Mixed grass prairie in Manitoba. Image by Maria Zbigniewicz.

9.23: Sand blowout at the Sandy Lands.

9.24**: Prairie Potholes in the Minnedosa area. Image by Gord Goldsborough.

9.25: Cliff with groundwater flow encouraging plant growth.

Chapter 10: Design Parameters

10.01: Map featuring the S.H.E.D. in Winnipeg, and the downtown context (see Map Metadata section for map data source)
10.02: Solar analysis of facades.
10.03: Wind analysis of Downtown Winnipeg with western facing facades with less wind exposure highlighted.
10.04: Protected Facades at 12m (40', 3.1 storeys) in Elevation (see Map Metadata section for map data source)
10.05: Potential locations for vertical gardens in downtown Winnipeg. (see Map Metadata section for map data source)
10.06: Rotating Panels in front of Winnipeg Square.
10.07: Location of Winnipeg Square. (see Map Metadata section for map data source)
10.08: Model of rotating panel.
10.09: Sketches of rotating panel.
10.10: Sketches of rotating panel.
10.11: Sketches of gravity wall.
10.12: Gravity wall on Winnipeg Square. (see Map Metadata section for map data source)
10.13: Location of Winnipeg Square.
10.14: Cliff recreation on Winnipeg Square.
10.15: Location of Winnipeg Square. (see Map Metadata section for map data source)
10.16: Sketch of cliff wall.
10.17: Sketch of undulating wall.
10.18: Location of City Place (see Map Metadata section for map data source)
10.19: Sketch of undulating wall.
10.20: Sketch of undulating wall.

Chapter 11: Design Proposal

11.01: Initial concept rendering.
11.02: City Place
11.03: Location of City Place within the downtown fabric. (see Map Metadata section for map data source)
11.04: Refined design rendering.
11.05: Rainwater collection and irrigation system
11.06: Flow diagram of material decision making process.
11.07: Sections showing orientation and relative size of planters.
11.08: Sections showing depth of each community area.
11.09: Plant Pallet as planted.
11.10: Planned plant abundance and change over time. Based on quadratic sampling which samples the spread of plant, not necessarily quantity.

11.11: Plant pallet showing origin communities. Plants located between or in 2 circles are present in both communities. Many of the plants used are present in multiple communities, so the community in which it is most abundant determined its placement in the figure.
11.12: Possible plant abundance in future.
11.13: Vertical garden covered with a tarp for the winter.

Chapter 12: Conclusion

12.01**: Planned development of True North Centre. Capture from True North promotional video. http://winnipeg.ctvnews.ca/video?clipId=544781
Used with permission from Susan Olsen, Executive Assistant & Manager, Office Administration, True North Sports & Entertainment Limited. Direct number: 204-926-5556

MAP METADATA

All maps have been adapted from GIS Shapefiles or created from aerial images that are available to the public through various geographic information websites. Associated authors have been listed where available by city and figure number.

All data was manipulated using the following software:

ArcGIS [GIS software]. Version 10.2 Redlands, CA: Environmental Systems Research Institute, Inc., 2012.

Adobe Illustrator [Illustration Software]. Version CS6 San Jose, CA: Adobe Systems Inc., 2012.

The following layers were used in every map:

Water:

Government of Canada; Natural Resources Canada; Earth Sciences Sector; Canada Centre for Mapping and Earth Observation (2015). *National Hydro Network (NHN)* (catographic line file) http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/33c52131-4ebf-41c2-bd47-88a68fb0218c.html

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Roads:

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The following layers are listed by location and figure number:

Winnipeg, Manitoba:

Associated figures: 7.02, 10.01, 10.04, 10.05, 10.07, 10.12, 10.15, 10.18, 11.03

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Created in Illustrator.

Ottawa, Ontario:

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Rivers, Roads, Building Footprints:

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This practicum is a reference for vertical gardeners in cold climates. Winnipeg, Manitoba is explored, however findings may be applied to other cities in similar climates. First, the history of vertical gardening is discussed, then the types of vertical gardens currently on the market are described. These can be classified into two categories: soil bearing or non-soil bearing. Most designs are modular pre-planted systems that can be attached to any wall, as long as it satisfies the structural requirements recommended by the manufacturer. The benefits of vertical gardening have been shown to be rather extensive, covering a wide range of areas. Aesthetic improvement, reduction of the Urban Heat Island (UHI) effect, improvement of air quality, stormwater absorption, noise reduction, native habitat integration, reduction of heating and cooling costs for buildings, food production, marketing, and biophilia are all benefits explored in detail. Difficulties associated with vertical gardening are discussed, specifically the lack of knowledge and awareness of vertical gardens, lack of empirical evidence (or missing details in existing research), overall cost and lack of financial incentives, lack of industry codes, and various associated risks. Design framework exists within microclimate conditions unique to vertical gardens, as well as neighbourhood and regional (micro) climates. Theories relating to the study of green walls covered include the human ecosystem model, urban reconciliation ecology, habitat templating, the urban cliff hypothesis, and wall ecology. Suitable habitat templates identified for vertical gardens in Winnipeg are cliffs, sand dunes, alvars, mixed grass prairie and prairie potholes. Design parameters to be followed for vertical garden design in Winnipeg are to ensure that lightweight materials are used, to provide insulation to protect plants from sudden temperature changes, to choose plants that grow in the region and are adapted to grow in areas with limited soil, increased wind, varying degrees of sunlight (depending on orientation), and increased pollution and salt spray depending on location.