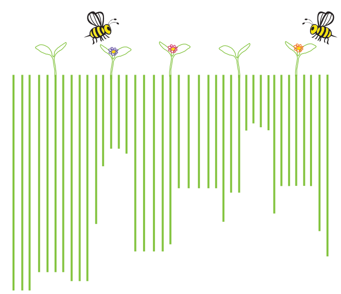
SAN FRANCISCO POLLINATOR TRAILS

creating a network of stepping stones for bees and butterflies across the city



A Senior Project by:
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Spring, 2012

SAN FRANCISCO POLLINATOR TRAILS

creating a network of stepping stones for bees and butterflies across the city

A senior project presented to the faculty of the landscape architecture program at the University of California, Davis in partial fulfillment of the requirements for the Degree of Bachelors of Science of Landscape Architecture.

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Abstract

Native bee and butterfly populations are struggling as urban development destroys their habitat. This project proposes a method for integrating native pollinator habitat into the dense urban fabric of San Francisco. Existing open green spaces were surveyed to determine their spacing and identify voids in vegetative cover as a way of locating the new network. The study also included researching native pollinator needs and how to use strategies such as green roofs and vegetated walls to provide nesting and foraging opportunities in compact areas. After analyzing the dispersal of green spaces, a site was chosen to create a unique bee and butterfly habitat at the center of a large gap in potential pollinator resources. The site design contains large curvilinear swaths of foraging plants covering the ground, crawling up the surrounding walls, and reaching the roof of the neighboring building. This design provides an engaging educational space where people can feel better connected to nature, while providing strategies for implementation on other city sites. The last step of the project laid out a network of stepping-stones to connect the designed habitat patch to the nearest existing green spaces. The spacing of these patches was determined using the foraging distance of target native bee species as a unit of measure, a strategy that can be duplicated on a citywide scale.

To my parents and sister for their tremendous love and support

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Preface

Since beginning my studies in landscape architecture I have been interested in fusing urban and ecological design. Ever since learning about wildlife I have thought about their importance, especially in thses times of climate change and massive urbanization. Habitat resources should especially be integrated into cities where the environment is harshest for native species' survival. I love the notion of creating spaces in cities that benefit both people and animals. Cities create harsh environments for native plant and animal species, and sensitively designed open spaces can help to bring nature back into the urban environment. At the same time these designs can improve the lives of city dwellers and help them understand the significance of the natural world even when living in a dense urban area.

This project integrated uban design with ecological planning, using the city of San Francisco as a study site for creating a stepping-stone corridor for native pollinators. I grew up in San Francisco, and in completing this project I was able to apply my personal knowledge of the city and include vegetation cover into an area that I have always noticed as exceedingly barren. In this project I was also able to research strategies like green roofs and living walls which I have found extremely interesting since noticing a grass-covered roof for the first time in 2006. In integrating these technologies into my design, I created a space that I feel is dynamic and rich in resources for native pollinator species, while providing a method for integrating habitat amongst dense built forms in the urban landscape.

Using native bees and butterflies as target populations in the city, I discovered a strategy for laying out habitat patches to make them feel more welcome in the city, while at the same time creating natural areas for humans in a district currently void of green open spaces. It is also a strategy that I believe can be applied on a much larger scale.

Introduction

This project aims to conceptualize the design of a comprehensive pollinator network across the urban matrix of San Francisco. Native bees and butterflies are struggling as urban development continues to spread, destroying their habitat resources. Creating a series of stepping stones across the city will assist their movement, while reintroducing natural elements into some of the most heavily urbanized parts of the city, offering a respite for wildlife, and the human population. The idea of integrating the city with nature acts as an underlying concept in the creation of pollinator habitat patches within a dense urban environment. This study progresses from the larger city scale to the design of a specific site and then zooms back out to connect the designed site to nearby green open spaces.

After selecting native bee and butterfly species and researching their habitat needs and maximum foraging ranges, it was possible to design a demonstration habitat patch as well as a surrounding network of stepping-stones. The location of the small-scale site was determined based on current dispersal of urban green spaces and the maximum distance that selected bees can travel. The site lands within the center of an industrial area and showcases a range of design strategies for providing pollinator habitat within dense cities, including diverse green roof plantings and vegetated wall sections. These habitat forms can be implemented on the proposed stepping-stones depending on their site conditions. The network of pollinator habitat patches fills a large gap in San Francisco's existing green space and helps to facilitate the movement of native pollinators across the harsh urban environment.

Nature and the City

The idea for this project arose from an interest in the complex relationship between the city and nature. Natural spaces within cities represent opportunities for wildlife to find refuge and valuable resources while also providing benefits to the urban population. There are documented advantages for people when they have the chance to interact with nature (Kuo, 2001), and in areas of cities currently void of green space there is opportunity to provide for urban populations of both people and animals.

Humans have officially become an "urban" species. As of 2010 over 50 percent of the world's population lives in cities, and this number continues to grow as the world's population continues to rise. Population projections predict that by 2030, 60 percent of people will live in cities, and that this will increase to 70 percent by 2050 (World Health Organization, 2012). Dense areas of cities will have to become denser as urban planners find ways to accommodate these large populations into cities. As a result, it seems likely that nature could become further excluded from our daily lives, quarantined to larger, established parks, instead of integrated into built areas. There is a scary version of the future where plant and animal biodiversity ceases to exist among dominating human influences, and people become completely excluded from nature.

There are many ways to combat this idea of a "concrete landscape." Designers can creatively infuse nature into urban settings, sometimes even using the physical structures of buildings as the substrate in which to grow native plants. Pieces of nature in dense cities conform to smaller and more disconnected spaces, but can still have potential for ecological renewal (Beatley, 2011). Some of these are small, unused lots or those waiting for delayed development to start. Other sites include medians and sidewalk strips, front and backyards in residential areas, and the walls and roofs of buildings themselves. Technology for planting vegetated roofs and walls has been around for a long time (Dunnett & Kingsbury, 2008), and the idea of using these types of technology intensively in an urbanized setting may have extreme benefits. They provide habitat, clean air, and clean water, in addition to economic and energy-saving benefits, and can also contribute a new aesthetic to cities. In addition, the increased vegetative cover of the city can provide connectivity for the movement of animals, and benefit the lives of people.

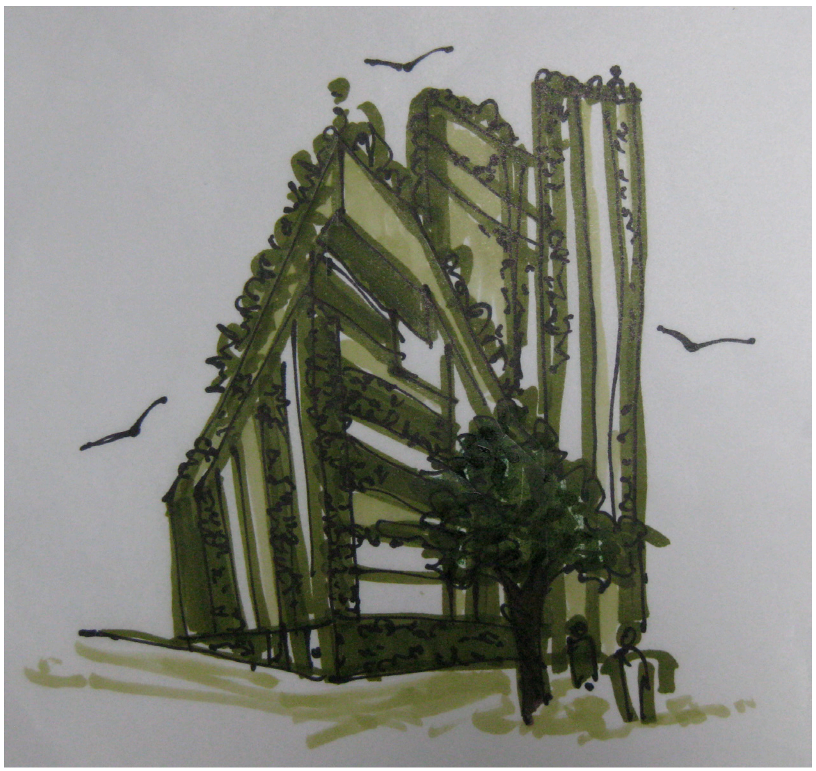


Fig. 1: A Vision of a Greener City
Levy, S., 2011

Fig. 2: Chicago City Hall Green Roof
Cook, D. & Jenshel, L., 2009

Innovative green spaces such as living roofs and vegetated walls have tremendous habitat implications. Roofs and facades are becoming a more common and practical place to foster natural habitats within the city environment (Beatley, 2011). Green roofs have great potential to act as wildlife stepping-stones across the urban matrix, creating small pieces of natural habitats on built structures. Since built-up areas usually interfere with existing natural habitats, green roofs can help minimize this disruption, creating much-needed corridors between larger habitats, while also providing visual green space linkages across. One of the most exciting aspects of planting vegetation on traditionally barren rooftops is creating habitat in a place that is usually void of life. There is a growing trend in the United States after European models to build green roofs as environments that support and conserve native habitats (Dunnett & Kingsbury, 2008). Extensive green roofs designed for their ecological benefits and not for human use have extreme potential for the establishment of native plant and animal communities as new, undisturbed habitat.

The construction of green roofs offers many environmental advantages for humans as well as animals, and these benefits can help to promote their installation. The presence of vegetation instead of the standard impermeable roof surface allows for natural management of stormwater through absorption by the plants. Green roofs are also able to insulate buildings, therefore significantly reducing their energy demands since they require less heating and air conditioning. The vegetation is also able to improve the surrounding urban environment by cleansing air and water of pollutants and cooling surrounding temperatures, lessening the urban heat island effect (Dunnett & Kingsbury, 2008). These environmental services that plants perform can help to regenerate natural habitats within cities, while improving the health of urban life.

One of the principle advantages of green roofs is their potential as constructed wildlife habitats. Stephan Brenneisen (2006) argues that the most important function of vegetated roofs is their ability to contribute to biodiversity preservation. He believes that green roofs should be seen from a regional perspective as a tool for ecological planning, instead of solely a strategy for energy conservation and aesthetic appeal.

Fig. 3: California Academy of Sciences Green Roof
Levy, S., 2012

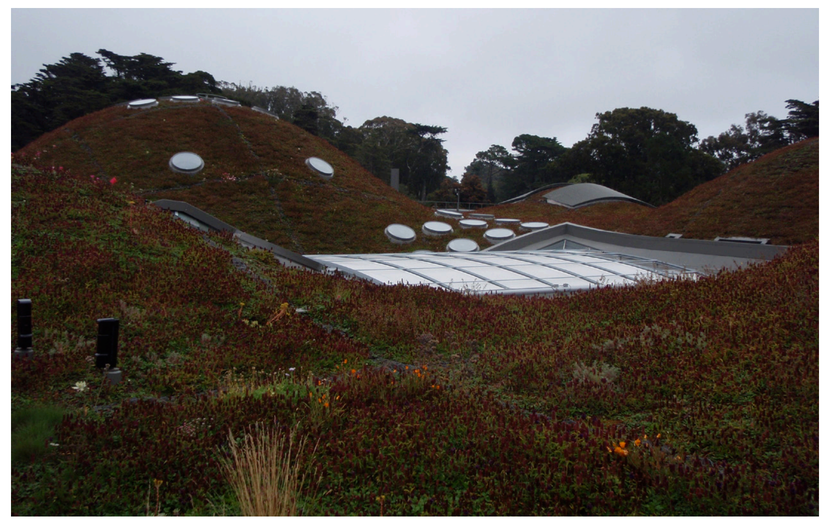


Fig. 4: Green Roof Detail
Levy, S., 2009

This belief is reflected in the principles of European urban planners. The main reason behind green roof construction in many European cities is their habitat value for native species, which is especially important in areas where development has destroyed valuable native sites (Dunnet, 2006). Rooftops have some of the natural features of exposed rocky habitats, and these types of environments can be enhanced to benefit more species through the construction of green roofs (Lundholm, 2006). These new habitats cannot accommodate all species because of their challenging locations at height that many animals cannot reach, but mobile species such as birds and insects can reach them and utilize their natural resources. These mobile species struggle in cities even though they can fly, and habitat created on rooftops can help them better negotiate an increasingly urbanized society.

Vertical vegetation schemes also have substantial potential to provide for wildlife species and can greatly improve the biodiversity of the city, while contributing environmental benefits similar to those that green roofs afford. The plants growing up or embedded in a vertical structure can provide food for both humans and animals, and can provide habitat and opportunities to protect small species (Dunnett & Kingsbury, 2008). Vertical gardens demonstrate a new view of plants where they can be seen from eye level or from below. Patrick Blanc has pursued the concept of living walls and developed a method of constructing them using a series of layers. He employs thin, lightweight felt as a growing substrate

Fig. 5: Patrick Blanc Green Wall, S.F.
Levy, 2012

Fig. 6: Living Wall Detail
Levy, 2012

over a supportive structure, and uses a gradient of plant sizes going from smaller herbaceous species at the base of the wall to larger shrubs near the top. Vertical gardens prove that barren walls don't have to inhibit biodiversity. Walls can instead be showcases of nature in the city (Blanc, 2011).

Using a combination of vertical and horizontal planes when designing vegetative spaces within cities creates three-dimensional environments where education is inherent as one finds him or herself immersed in an aesthetically and texturally unique environment. These installations are especially exciting in that they take advantage of spaces that would typically go unused in the city landscape. As the population and density of cities increases there will always be exterior walls and roofs so it is important to acknowledge and make use of these spaces and their potential for natural environments within a highly urbanized city.

New urban green spaces should be located to bridge gaps between existing parks and provide more continuous vegetated cover. Since cities have complex networks of roads and large expanses of dense, built areas, it is necessary to work with the fact that not all green spaces will be large areas, and that they may not be continuous throughout the urban matrix. This creates a unique pattern for a movement corridor for species to utilize. In addition to designing large spaces like parks, designers must work to establish connectivity between large patches of habitat. Wildlife movement corridors are extremely important for aiding animals and plants, and their design can help preserve and improve biodiversity in urban areas (Angold et al., 2005). Since urbanization takes away precious habitat, the creation of paths through which native species can move helps them survive in a human-altered environment. Laying out a network of wildlife corridors across a city's matrix is becoming increasingly influential in urban planning as a strategic tool for conserving native habitat.

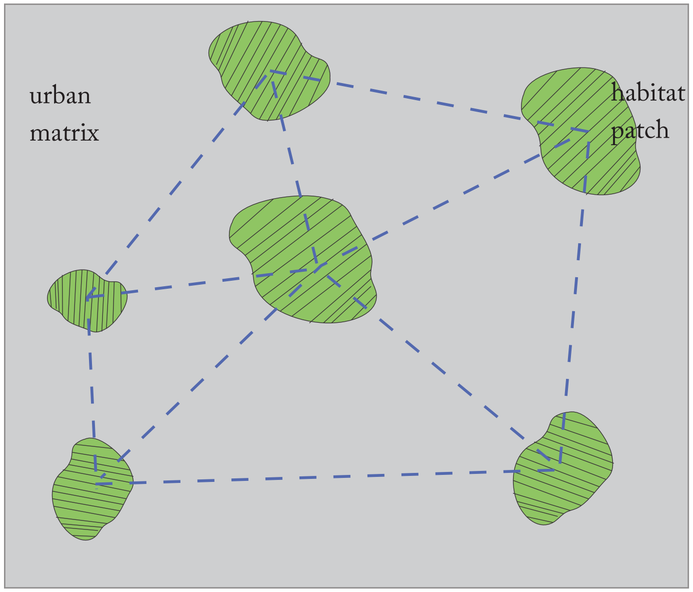


Fig. 7: Stepping Stones/Corridors Diagram.

These linear corridors connect habitats that were once joined, and along them there is a much higher level of plant and animal diversity than the surrounding built-up landscape. Since the nature in urban landscapes can become sparse and disjointed, linkages in the form of wildlife corridors should be incorporated in the planning process to dictate the distribution of green space throughout a city (Evans, 2007).

Small habitat patches can make up the nodes within a network of urban wildlife corridors, and also act as stepping-stones for species across a dangerous human-dominated environment. The small size of these patches can also contain some uncommon species not seen in larger habitats and can provide supplemental ecological benefits. To promote movement between patches, there should be similarly structured vegetation types in each of the small patches. In addition, visually oriented species can travel easier between patches when distance is reduced so that it is possible to see each successive stepping-stone along the wildlife corridor (Dramstad et al., 1996). With land in high demand for development within cities, it is necessary to look beyond traditional green spaces like parks and backyards to act as these habitat patches for native flora and fauna.

Pollinators

The disconnected green patches designed throughout a city have the potential to benefit some wildlife species, but since this lack of connectivity exists, it is necessary to plan for mobile animals that can utilize them with relative ease. In the case of this project there is a focus on native pollinators because these are species that can benefit from small, diverse vegetated spaces throughout the harsh urban matrix. Urbanization hurts pollinators by taking away habitat and replacing it with buildings and roads. At the same time, cities can provide opportunities for pollinators to do quite well. As a result of the random scattering of green spaces planted throughout the city, pollinators can often find some foraging resources although they are often distributed inconsistently across the landscape (Xerces, 2011). A more systematic network across the city, including areas already rich in resources has the potential to welcome urban pollinators, and give them a better chance of survival.

Providing for the needs of pollinators gives a framework for the idea of better integrating green space across the built landscape. Since flying birds and insects have the ability to navigate through anthropogenic landscapes, they will be able to scout out new habitat even within dense urban areas. If there were a better series of pollinator friendly green spaces filling in gaps between buildings and climbing across walls and over buildings, the diversity of plants and pollinator species would be even greater, helping populations return to the city landscape.

Creating connections to assist the movement of bees and butterflies across cities have implications for the targeted species as well as human populations. Where there are current gaps in natural spaces and resources for wildlife, this also indicates a void in green areas for urban dwellers. There are social indications to this lack of natural space, and its inclusion could help to revive very industrial or high-density neighborhoods. The inclusion of green spaces hosting a diverse range of plants can improve the psychological wellbeing of its human visitors while also helping the urban population by helping them feel better connected to the natural world (Fuller et al., 2007). Designing pollinator habitats throughout the city also allows for invaluable educational opportunities for city dwellers. People can see innovative design strategies for reintroducing native species, and can hopefully be inspired to continue the trend. In addition, the inclusion of spaces for pollinators can connect to city-wide movements to increase urban agriculture, and help increase the success of these small scale farming landscapes.

Pollinators are keystone species in most ecosystems because many plants and animals depend on them for their own survival. 200,000 different plant species worldwide rely on animal pollination for reproduction. These include both agricultural crops and wild plants that provide a source of food to many animal species. The activities of pollinating species lead not only to the production of foods, but also drinks, medicines, and fibers. There is a direct connection between diverse populations of pollinators and the health of nearby plant communities (Blaylock & Richards, 2009). While bees are some of the most important and efficient pollinators, other species such as butterflies, moths, humming birds, beetles, and bats feed on flowers and as a result help to spread their pollen from one plant to another.

Fig. 8: Honey Bee feeding from *Ceanothus,* UC Davis Bee Garden
Levy, S., 2012

Fig. 9: S.F. Hummingbird
Levy, S., 2012

Native Bees

The primary focus of this project is native bees. Bees are the most important group of pollinators because they deliberately gather pollen from the flowers they visit and take it back to feed their brood (Xerces, 2011). This differs from other pollinators like butterflies and hummingbirds that spread a small bit of pollen as a byproduct of feeding on nectar. Native bees are especially efficient at pollinating plants and are more effective at pollinating some plants than honeybees (Xerces, 2011). Habitat loss is especially detrimental for native bee species, as their historic foraging and nesting ranges are covered up by urban development. This makes them an ideal group to target and protect through new urban design projects.

Honeybees are generally well recognized as extremely important members of the insect population because of their valuable contribution to pollination. Their work has tremendous economic and environmental impact and their current struggles have major implications for humans, other animal species, and plant life. Honeybees though are a non-native species introduced from Europe, and are not the only important bee species facilitating plant reproduction. There are over 3,500 native bees that pollinate agricultural and wild plants, greatly contributing to the overall health of the environment (Blaylock & Richards, 2009). In fact, many native bees are more effective than honeybees in pollinating plants. The same design considerations that help support native bees can also help honeybees, but non-native bees may be a contributing factor to the declining population of native species (Xerces, 2011). Native bees are also easier to manage in an urban setting and are less likely to pose a threat to humans (Williams, 2012). Since most species are solitary, each female is the only one responsible for providing for her offspring, making her even less likely to risk her life by stinging a human.

One of the main challenges for bees in today's world is a lack of proper habitat. As a result of large-scale monoculture agricultural development there is a shortage of season-long food sources for bees (Spivak et al., 2011). An additional loss of natural habitat has resulted from increases in human populations in urban areas and the resulting sprawl that comes as these cities expand. Large declines in pollinator populations are taking place for unclear reasons, but a part of the reason is connected to the loss of precious habitat resources (Colla et al., 2009). Isolation from natural habitat causes the decline of 20 out of 22 native bee species (Williams, 2012). Urban development leads to habitat loss and the degradation and fragmentation of existing habitat. Places along rivers, and near bays or estuaries historically have high levels of biodiversity, but these are often the areas that become highly urbanized (Xerces, 2011). While not the only factor contributing to the decline of bee populations, habitat loss is something that can be considered when designing new urban projects. Landscape architects can increase habitat and public awareness to help reverse urban development's damaging affect on bees.

Solitary and social bees have varying amounts of contact with other members of their species. 90 percent of North American native bees are solitary. In these species, each female builds her own nest and takes care of it without help from others. In the typical lifecycle of these bees, the female first prepares balls of pollen and lays an egg on top of each. Then, the larvae eat the pollen provisioned for them in the balls before pupating and becoming adults (Xerces, 2011).

Social bees go through a similar lifecycle from larva to adult, but work closely with other members of their species in a way that differs from solitary bees. Social bees live in colonies where at least two females share a nest and the work of preparing it and feeding their offspring. In this system, one of the females becomes the egg-laying queen, and the others become the workers. Individual worker bees cannot reproduce or survive for a long time away from the support of the nest. In social bee species there is an innate sense of cooperation and organization and a highly developed division of labor exists (Xerces, 2011).

Fig. 10: Rooftop Honeybee Houses
farm1.static.flickr.com

Fig. 11: Artifical Nests for Tunnel Nesting Species (Bamboo)
urbanhedgerow.com

Fig. 12: A Ground-Nesting Bee
buzzybeegirl, 2008

Since the vast majority of North American bees lead solitary lives, it is most important to consider their needs when developing a landscape that aims to provide habitat for native pollinators. Some solitary bees will share a nesting location, but each female will have their own burrow within the site. In other cases, bee species will share a common entrance tunnel to their nest, with each female having her own brood cells within the nest. 30 percent of these solitary bees build nests inside of abandoned beetle burrows or other tunnels in dead trees. These species can also chew out space for their nests in the soft centers of twigs or stems in the landscape. Nests are often divided into cells with materials collected on foraging expeditions. The other 70 percent of solitary bees are ground-nesting species. They live in tunnels in the ground that they dig in bare or sparsely vegetated well-drained soil (Xerces, 2011). Ground-nesting bees can build their underground nests in different configurations ranging from short vertical tunnels to complicated branching systems. Specific bees have different requirements regarding their nesting substrate. Preferences can be for sand, clay, sandstone or rock, and some nest in flat ground while others use berms or even vertical cliffs (Thorp, 2012).

Specific Bee Species

This project specifically focuses on four native bee groups. These are bumblebees, leafcutter bees, mason bees, and digger bees. Bumblebees (genus *Bombus*) are a unique species that leads a semi-social life on a smaller scale than that of honeybee colonies. They are also special in that queen bumblebees can live up to a year, which is longer than most species. Bumblebees live in annual colonies created by a sole queen in the early spring when she wakes up from hibernation. At this point in the lifecycle the new queen builds wax pots where she lays her eggs and incubates them. When her daughters emerge as adults they take over the foraging duties for the nest as the queen continues to reproduce. In the autumn female and male bees leave to find mates. After their search, newly mated queens hibernate and the rest die. When females hibernate they burrow beneath leaf litter or several inches underground. As a result of their unique lifecycle, bumblebees are usually the first bees active in the early spring, and the last ones active in the fall (Xerces, 2011). Bumblebees require a foraging source for the longest period of the year when compared to other species, making them an important consideration when planning the plants for pollinator habitat.

Fig. 13: Bumble Bee
Hanson, G.

Fig. 14: Bumble Bee Nests
beneficialbugs.org

Leafcutter (genus *Megachile*) bees are a species of solitary bees with a tunnel-nesting habit. They get their name from the fact that they use pieces of leaves and petals that they cut from nearby plants to build their brood cells. Leafcutter bees are moderate to large in size (0.4 to 0.8 inches long) with stout bodies. They visit a large range of flowers to meet their foraging needs, and prefer leaves that are smooth on one side for wrapping their brood cells. The vast majority of North American species use pre-existing natural and artificial cavities for building their nests, covering the interior sides of their brood cells with oval pieces of leaves and petal, and closing the entrance with circular leaf pieces (Xerces, 2011).

Fig. 15: Leafcutter Bee
Plank, B., 2010

Fig. 16: Leafcutter Bee Nests
discoverwildlife.com

Fig. 17: Mason Bee Emerging from Nest
henreyleelucas, 2006

Fig. 18: Mason Bee
backyardfarmers.com

Mason bees are another species of bee "architects." They are tunnel nesters with similar lifestyles to leafcutter bees, constructing walls to separate brood cells in their nests. This study looks at two genera of mason bees, *Hoplitis*, and *Osmia*. Mason bees in the *Hoplitis* genus are small to medium in size (0.2 to 0.6 inches) and are often black. Bees in *Osmia* are small to large (0.2 to 0.8 inches), and are usually metallic. Both genera fly mostly in the spring and visit a wide variety of flowers. *Hoplitis* use pithy stems, holes in wood, and nests of other insects to build their nests. They divide brood cells with walls of chewed leaves, pebbles, sand, clay, and bits of wood. *Osmia* species historically nest in beetle tunnels in wood, but females will regularly use artificial nesting sites. Most North American species use mud as the primary material for dividing up their cells, and like leafcutter bees, they tightly close the entrance of their nests with additional layers of collected nesting materials (Xerces, 2011).

Digger bees are a group of ground nesting solitary bees. There are two focal genera for these bees as well, *Anthophora* and *Habropoda*, both of which are more prominent in the western states. Both genera are robust and hairy, and are usually gray in color. Members of *Anthophora* are small to large (0.25 to 1 inch), and are very fast flying bees. They visit a diverse range of flowers and have long tongues, which allow them to collect nectar from deep, complex flowers. These bees dig nests for themselves in either vertical banks or flat ground. Some species mark the entrances to their nests with mounds of soil, and the brood cells within are usually arranged vertically and lined with oil that helps to protect them from water. Bees in the Habropoda genus are similar, but have a more restrictive range with most species living along the west coast from British Columbia to Baja California, and prefer to nest in sandy soils (Xerces, 2011).

Fig. 19: Digger Bee
airoid, 2012

Fig. 20: Foraging Bee
Levy, S., 2012

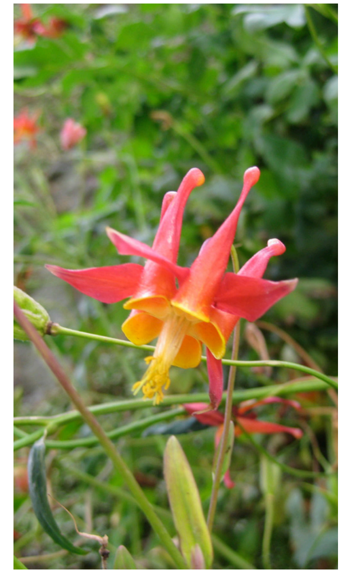


Fig. 21: Western Columbine
Levy, S., 2012

When bees of all species forage, they search for plants that can provide them with a source of nectar and pollen. The nectar gives them energy, and the pollen is brought back to the nest to feed the brood. Since flowers provide this source of nectar and pollen, a wide range of flowering plants is one factor facilitating the distribution of bee species. Bees benefit from plant diversity and a collection of natives that provide them with foraging opportunities, and supplies for their nesting habits in the case of leafcutter and some mason bee species. In ideal habitats the blooming periods of planted species overlap with one another to create a continuous bloom from early spring through the fall (Tonietto et al., 2011).

Butterflies

A secondary focus of this pollinator network is on butterflies. These insects are not as important for ecosystem ecology and stability as bees, but they are a species that can also recolonize areas of a city when the right resources are available to them to foster their health in the human environment. Butterflies require a lot of the same types of resources as bees. Successfully designed and executed native bee habitats offer foraging resources that butterflies can also use, and since butterflies are less particular than bees, they can easily be accommodated within these urban green spaces (Xerces, 2011). Butterfly adults feed on the nectar of plants, but since they do not specifically collect pollen from flowers they are rarely considered critical pollinators. One of the main purposes for considering butterflies in the design of sites along a bee network is to increase the public's excitement about such a project. Some people view bees in a negative light, fearing them as something dangerous when in fact they are just misunderstood. Butterflies on the other hand are well liked by most people, and their beauty is greatly appreciated. People are fascinated by butterflies and this is something that could increase interest in a pollinator network. Another reason for addressing the needs of butterflies in this project is to assist them in the harsh environment of the city. Butterflies are being affected by urbanization much like bees, as their foraging areas can be destroyed in the wake of new development in cities. Climate change is also burdening the butterfly population. The geographic ranges of some species have changed in response to changing climate, causing them to move northward, upslope, and coastwise in their migratory patterns (Shapiro & Manolis, 2007).

Similar to bees, butterflies have a very close relationship to plants. They recognize specific plants and depend on them as a source of food both in their larval and adult state. Butterflies lay their eggs on specific host plants and when young caterpillars emerge they only eat the leaves and flowers of these plants. This makes the selection of plant species an important consideration in the creation of butterfly habitat. Butterflies also need warm temperatures and sunlight to help them fly, and in the morning they like to sit on warm rocks, bricks, and gravel (Xerces, 2011). These requirements for sun and nourishing plants overlaps with the needs of bees, and allows for an integrated landscape that benefits them both.

Fig. 22: Anise Swallowtail
Fotolia

Fig. 23: Pacific Dotted Blue Butterfly
Wight, A., 2004

San Francisco Spatial Analysis

This project focuses on the city of San Francisco as a site for creating a network of vegetated landscape installations to fuse nature with the built environment in a more integrated and cohesive manner. Since the city of San Francisco is already highly urbanized, most of the green spaces in the city are small, but there are also some larger, diverse parks like Golden Gate Park (Beatley, 2011). San Francisco represents an example of a natural site that has been completely altered due to development. The city covers an area that was once a main coastal dune ecosystem, and is representative of a historically diverse site along the San Francisco Bay. Since its massive transformation to the urban center it is today many species including 3 dune butterflies are now extinct (Xerces, 2011).

The first step looks at the city as a whole to find the best site to set up a demonstration habitat patch for bees and butterflies. This location should be within a gap in current pollinator resources, and is only the first part of an eventual network. After designing the site scale within a barren San Francisco neighborhood, the project continues to look at connecting this new habitat into a series of stepping stones facilitating pollinator movement throughout the area.

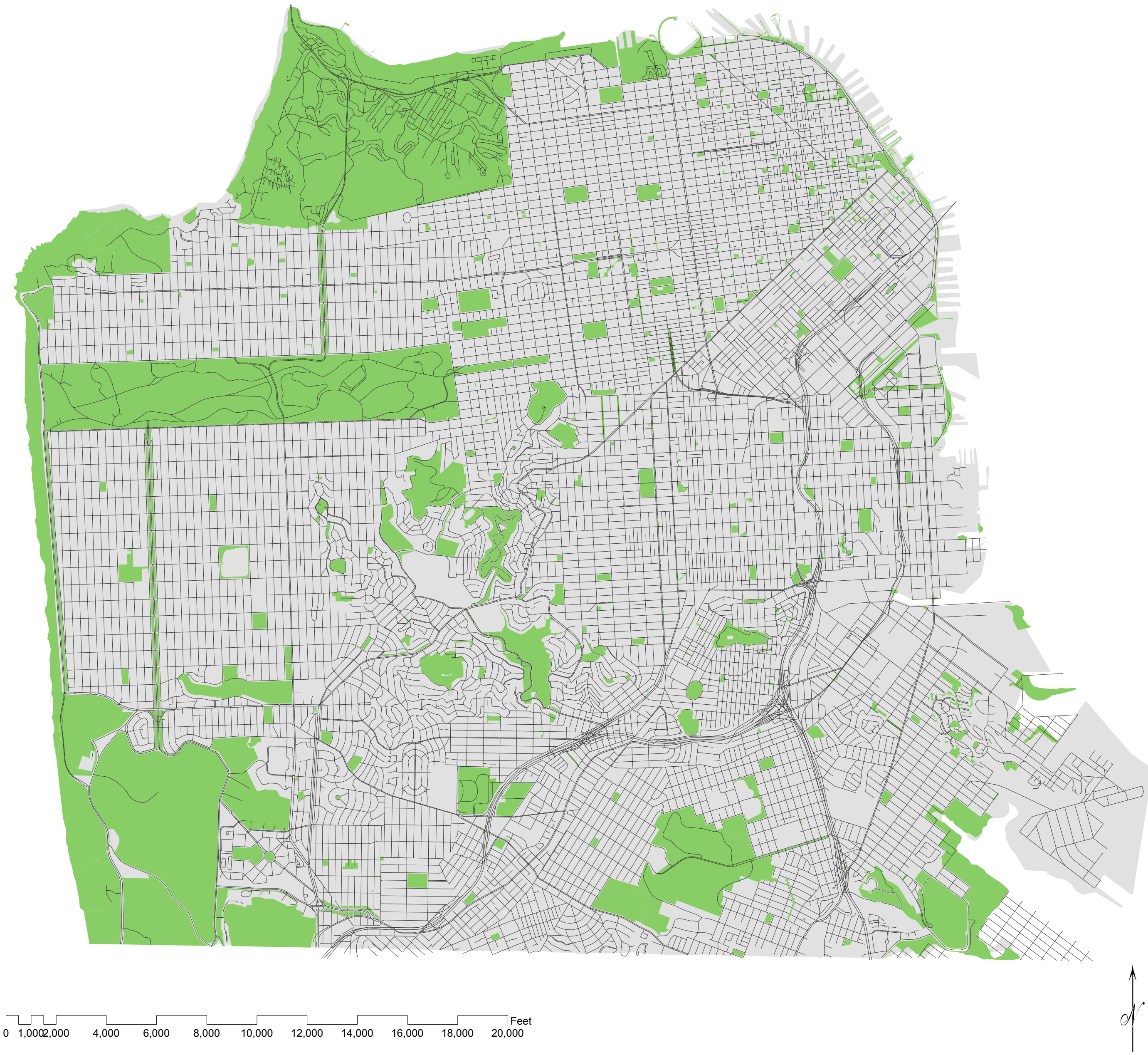


Fig. 24: Map of Open Green Spaces in S.F. data retrieved from: data.sfgov.org

In determining the ideal location for a template pollinator project it was important to first analyze the open space cover that exists in San Francisco. Mapping existing public open spaces provides a starting point for understanding the layout of green areas throughout the city (Fig. 24). Although many of the open spaces in the city are ambiguous, there are some larger parks that have existing source populations of pollinators. Golden Gate Park, Glen Canyon, and the Presidio are some of the largest expanses of open space in the city with wide ranges of native plant species providing sources of nectar and pollen for bees and butterflies.

In order to design a comprehensive and effective network for pollinators to navigate, the most important consideration is the distance that species can travel between feeding and nesting sites. This distance determines how well pollinators will be able to reach new patch habitats within the city (Greenleaf et al., 2007). Since bees are the most important group of pollinators for the purpose of this proposed network and can travel overall shorter distances than butterflies, they are the main consideration for the distancing of stepping stones. If the new components of the network are spaced too far apart from one another, it makes it challenging for some species to reach them and altogether impossible for others. Foraging distance creates a useful unit of measure for distributing stepping stones rich in pollinator habitat resources.

The distance that a bee species is able to travel is usually strongly correlated to its body size. (Greenleaf et al., 2007). As a result of their differences in size, the focal bee species of this network have slightly different foraging ranges that they can travel. The bumblebee is the largest of the selected native bees, and can therefore travel the farthest. Bumblebees can fly for over a mile between plants and their nests (Xerces, 2011), making them the easiest to accommodate. Leafcutter, mason, and digger bees can travel a moderate distance in relation to other native bees. The maximum foraging distance of these species falls between 1200 and 1500 feet (Xerces, 2011), necessitating the introduction of closer patches to accommodate their resource needs while traversing the city.

Fig. 25: Bumblebee in Flight
Frith. B.

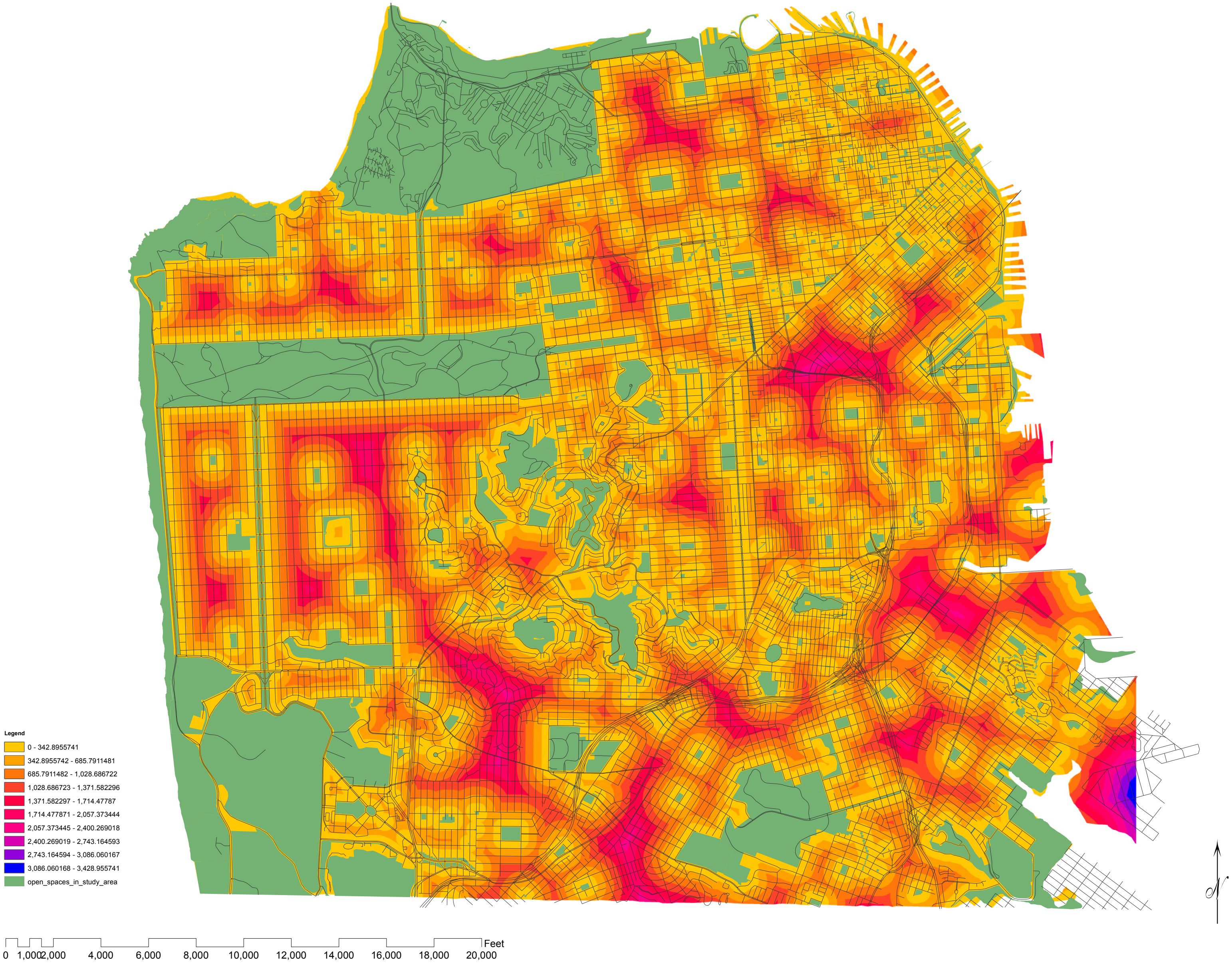


Fig. 26: Distance Analysis from Green Spaces
data retrieved from:data.sfgov.org

In systematically laying out a pollinator network using information about foraging distance, the first step was to take the existing open spaces in San Francisco and use those to find the gaps in vegetated coverage across the city. This was possible through a Euclidean distance analysis on the existing open spaces in the city to find the areas farthest away from possible resources (Fig. 26). It is necessary to acknowledge that not all of the public open spaces in San Francisco contain resources that meet the needs of bee and butterfly populations, but it is a start to understanding the pattern of green space distribution throughout the city.

Through the creation of this distance map of the city, areas over 1,000 feet from existing open spaces stand out, requiring further analysis to determine their impact and potential for moving pollinator species. After looking at aerial maps of the city, and visiting some of the areas in the indicated voids, it was possible to classify gaps based on how challenging they may be for pollinators to traverse. Upon closer observation a great deal of the open space voids, especially those on the western side of the city had greater vegetative cover than the map indicated. This is because these land in very residential neighborhoods where the majority of houses have backyards that form their own corridors in the center of each block. In other cases, the gaps found through the distance analysis highlighted areas that are truly barren and seemingly inhospitable for native wildlife.

Fig. 27: Sunset Neighborhood with Backyards
googlemaps, 2012

Fig. 28: Dense Neighborhood without Vegetative Cover
googlemaps, 2012

Demonstration Site

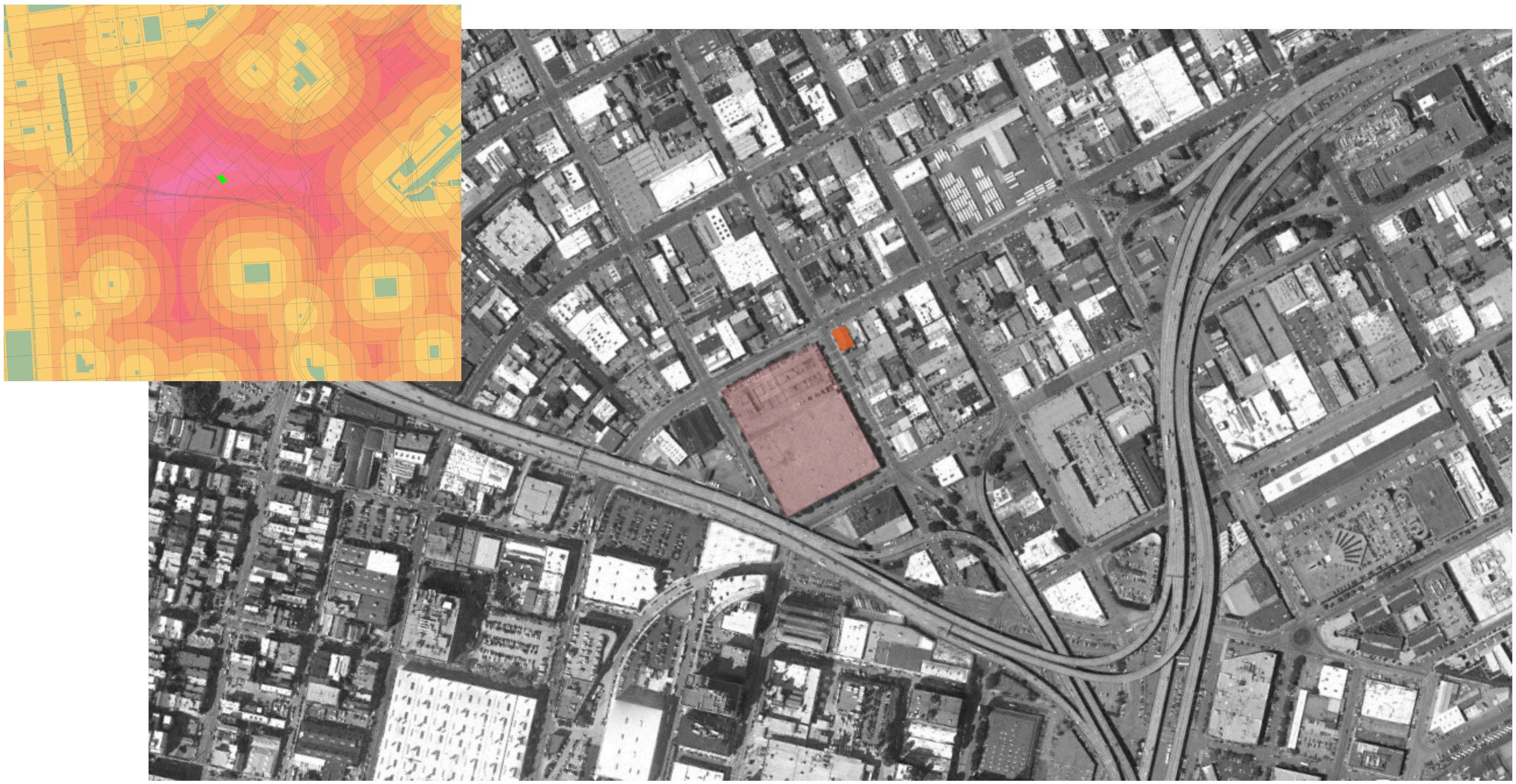


Fig. 29: Site Highlighted in Orange
googlemaps, 2012

Fig. 30: Site at intersection of Harrison and 10th
Levy, S., 2012

The specific site selected for a template pollinator habitat is at the corner of Harrison Street and 10th Street on the edge of the South of Market (SOMA) neighborhood. This small corner lot lands in the center of a large void in green space in the city, and is in a fairly industrial neighborhood. The demonstration site encompasses not only the vacant land on the ground but also the two adjacent building walls on the northern and eastern sides of the lot. In addition, the roof of the northern building is designed to create additional, undisturbed habitat resources.

Fig. 31: Site, Elevated View
Levy, M., 2012

Fig. 32: Path through Howard and Langton Mini Park
Levy, S., 2012

Fig. 33-34: Possible Pollinator Plants
Levy, S., 2012

When examining the green open spaces in the neighborhood, a great deal of pollinator plants were found, validating the potential of the demonstration site for attracting native pollinators and contributing to the overall movement of bees and butterflies throughout the city. Two specific nearby parks demonstrated plant resources that could indicate the presence of a source population of bees. The first of these is Howard and Langton Mini Park located about 2000 feet from the Harrison and 10th site. This space acts as a community garden for neighbors in the SOMA area and contains a lush and diverse mix of plants.

The second park that demonstrated potential for hosting an existing source of pollinators is Franklin Square located about 2170 feet from the site. While a large expanse of this park contains monotonous fields, the bordering planted area contains pollinator plants including *Echium candicans* (Pride of Madeira), *Callistemon sp.* (Bottlebrush), *Arbustus unedo* (Strawberry tree), and *Foeniculum vulgare* (Fennel).

Fig. 35: Pride of Madeira and Bottlebrush in Franklin Square
Levy, S., 2012

The selected project site has high visibility for the urban human population, as it is located in the middle of an area with a lot of commercial businesses frequently visited by a range of city residents. The closest main "attraction" is the San Francisco Costco Wholesale Market, which is located across 10th Street, taking up an entire city block. As a result of this visibility there is great potential for educational outreach, and the design aims to catch the eye of passersby while also providing a space to escape from the harsh barren surroundings. This location represents a good example of an empty place in the city without nature for animals or humans to interact with in their everyday lives. Another aspect of the physical and social environment surrounding the site is the large, 5-lane street passing on either side. This increases the site's visibility while also establishing the potential benefit that a space like this could provide as such a vast contrast from existing infrastructure.

Fig. 36: Costco
Levy, S., 2012

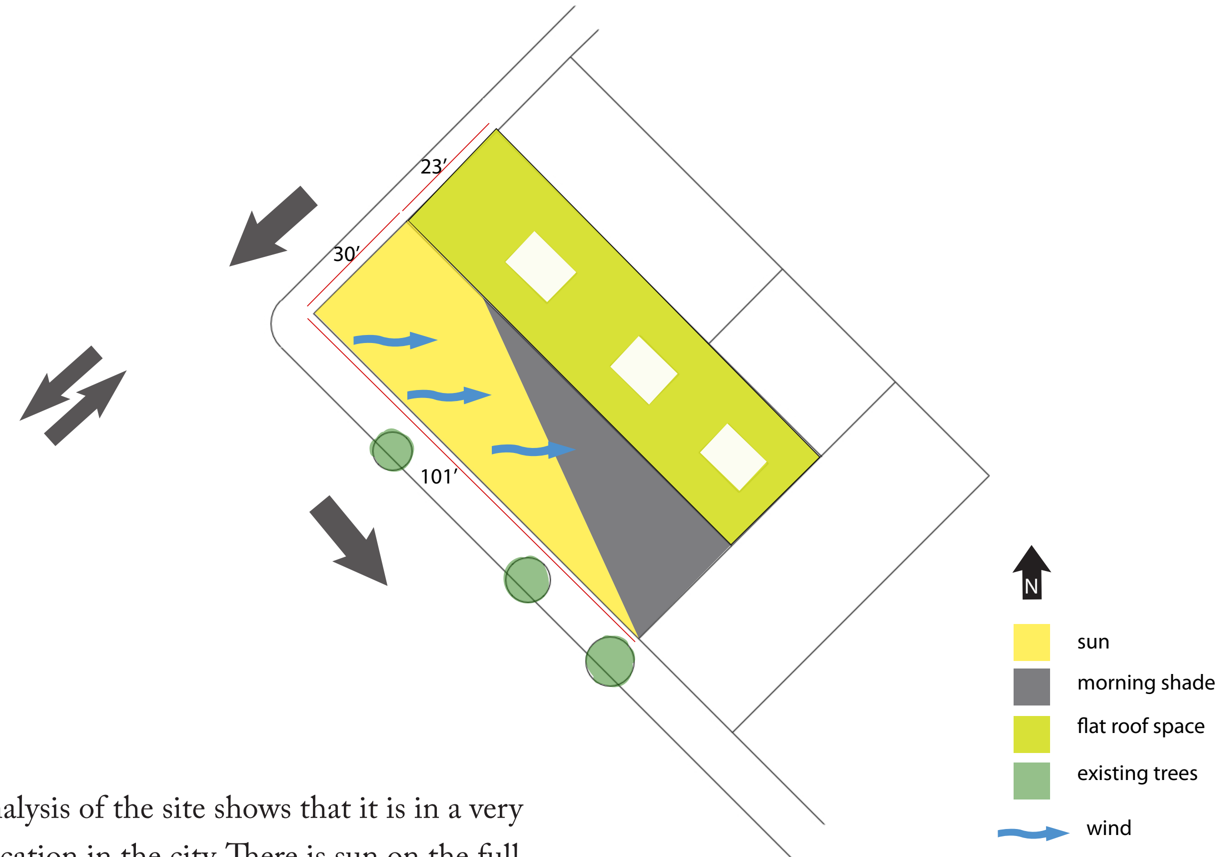


Fig. 37: Site Analysis

Climatic analysis of the site shows that it is in a very warm and sunny location in the city. There is sun on the full site for most of the day, which is beneficial for both bees and butterflies (Xerces, 2011). There is no vegetation currently with the exception of a few small street trees adjacent to the lot. The sunny conditions allow for a wide range of plants to be used in conjunction to provide a diverse range of resources for intended pollinator users.

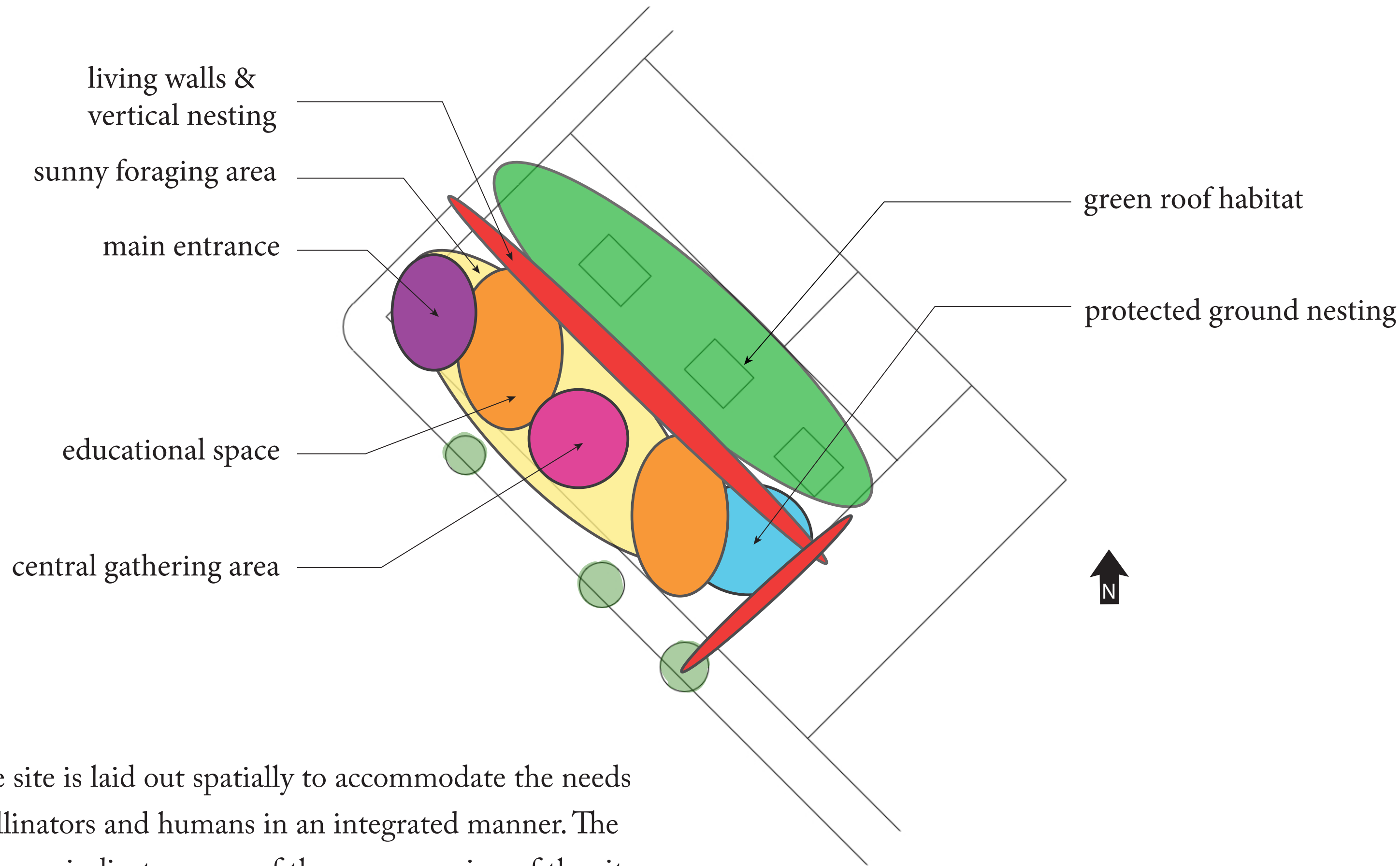


Fig. 38: Bubble Diagram

The site is laid out spatially to accommodate the needs of both pollinators and humans in an integrated manner. The bubble diagram indicates some of the programming of the site and its placement. The main entrance for the pollinator garden is at the corner of Harrison and 10th to attract the most visitors to the site. Areas are indicated for green roof and vertical habitat, as well as sunny foraging spaces and protected nesting on the ground. There are also educational spaces, and a central gathering area laid out for attracting human visitors.

The final site plan addresses the habitat needs of the target pollinator species and integrates them in a dynamic design. Pollinator plants are planted in large abstracted forms on the ground plane that continue up the walls that surround the space and onto the neighboring roof. The diverse range of plants included on the site have a combined bloom period that lasts through the year and especially concentrates in the most active time of year in the lifecycle of bees and butterflies. Included in the plant palette are specific host plants for species of butterflies common to San Francisco to utilize for laying their eggs and nourishing caterpillars. In the appendix is a list of proposed plants for the site showing their color and bloom period. Most plants are designed in groups at least 3 feet in diameter to maximize their value for pollinators, but there are no strict boundaries between species. In addition to the curvilinear planted spaces there is a semicircular native meadow and wildflower area. Native grassy areas can supply habitat for butterflies and nesting opportunities for bumble bees (Xerces, 2011), while the wildflowers are another source of nectar and pollen.

Nesting needs are also accounted for in the design. Spaces for ground nesting bees are incorporated amongst the planted areas in the form of mounds at varying heights to accommodate bees with different nesting preferences. These spaces are unmulched and partially bare, and some of them are more protected to allow bees to overwinter and hibernate within them. There are also some nesting mounds on the site

Fig. 39: Vertical Nesting Structure
urbanhedgerow.com

Fig. 40: Vegetated Wall Detail
Levy, S., 2012

Fig. 41: Mounding on Green Roof
Levy, S., 2012

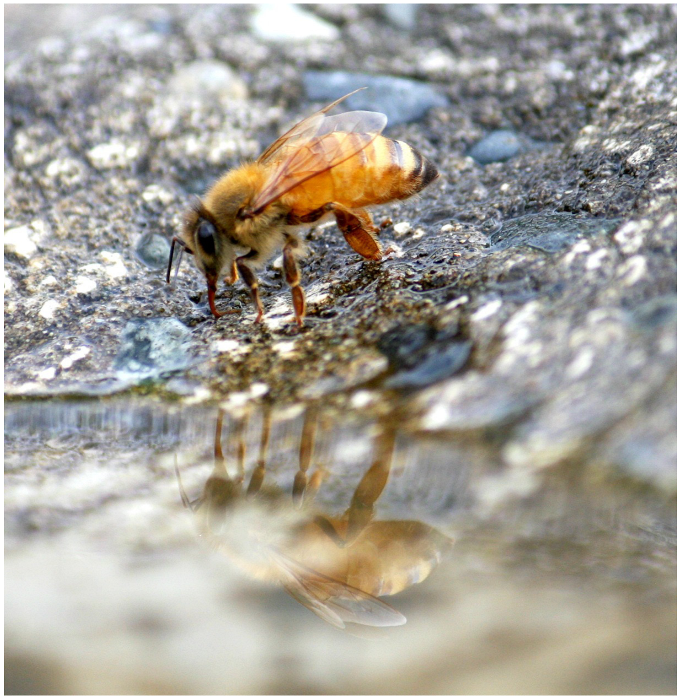


Fig. 42: Bee Drinking Water
Lee, J. 2012

that are less exposed to human circulation paths for more sensitive species. Artificial tubular nesting is provided on the south-facing wall adjacent to the lot. Nesting tubes within mounted structures vary in diameter, allowing bees of different sizes to occupy them. Surrounding the tubular nesting structures with native foraging plants will provide bees with a convenient source of pollen and nectar, and can moderate the climate surrounding the nest.

A couple of other considerations in creating a comprehensive habitat for native pollinators are designing a source of water for bees, and spaces for bees and butterflies to rest in the sun. Within the site plan is a bee-inspired water feature based on their drinking needs. Bees prefer to keep their feet dry and drink from a thin, calm film of water. The feature in the design has an uneven stone surface with some areas standing above the water level for bees to put their feet on. The water circulates through a system that provides a slow drip to replenish the available film. Rocks are placed around the site to provide warm surfaces for bees and butterflies, and some areas of mud can become a source of nesting supplies for mason bees.

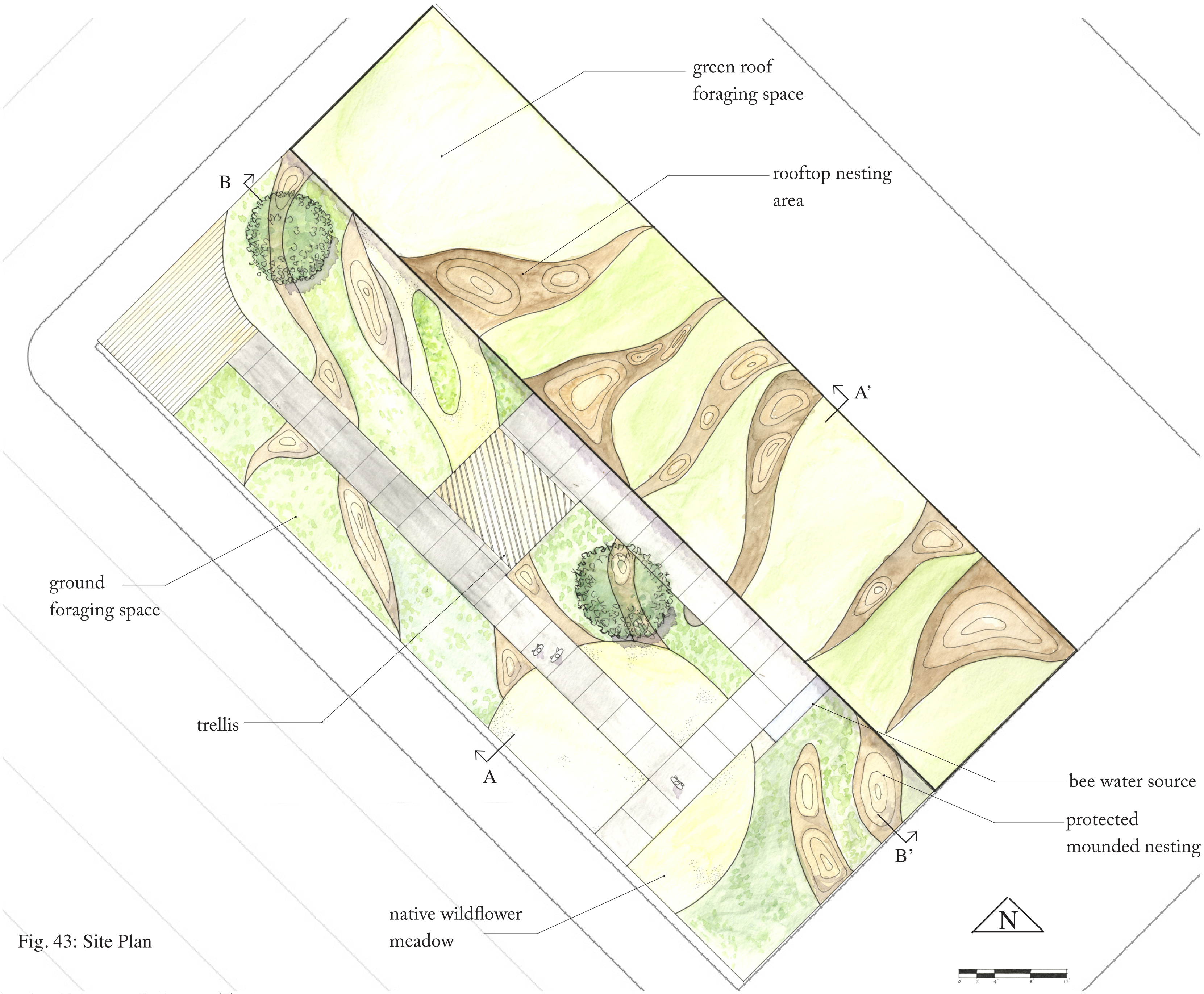


Fig. 43: Site Plan

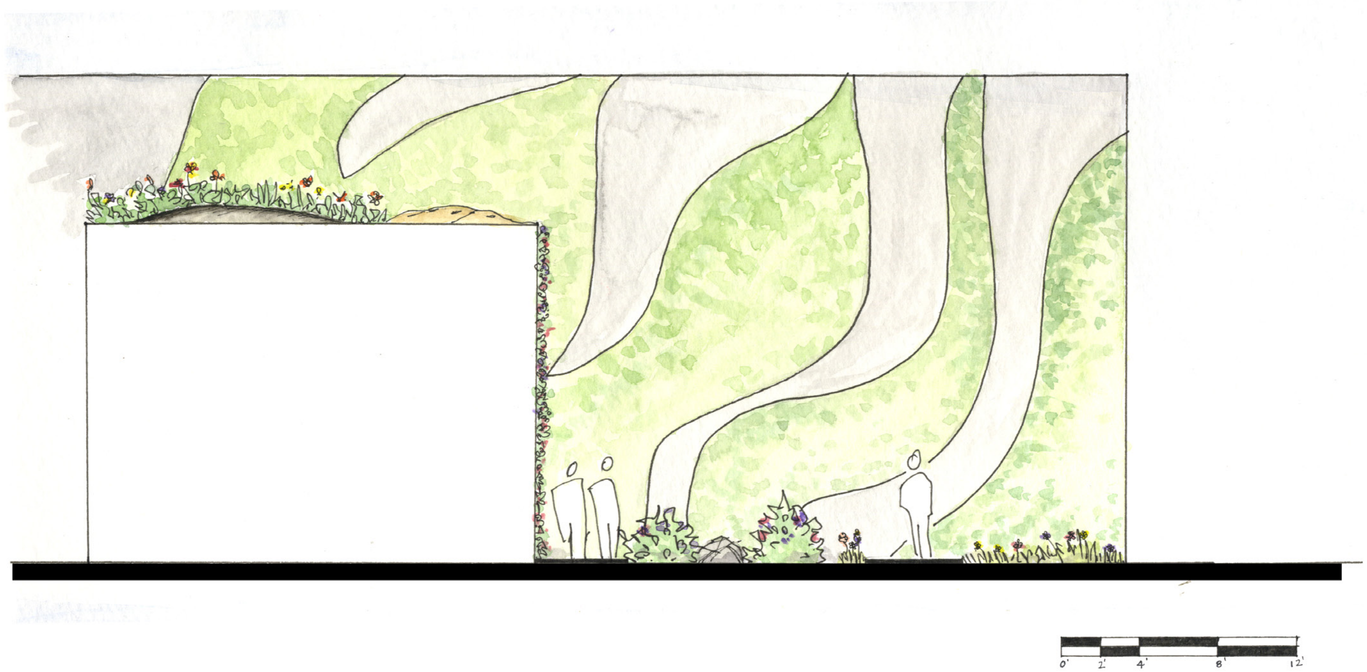


Fig. 44: Section-Elevation AA’

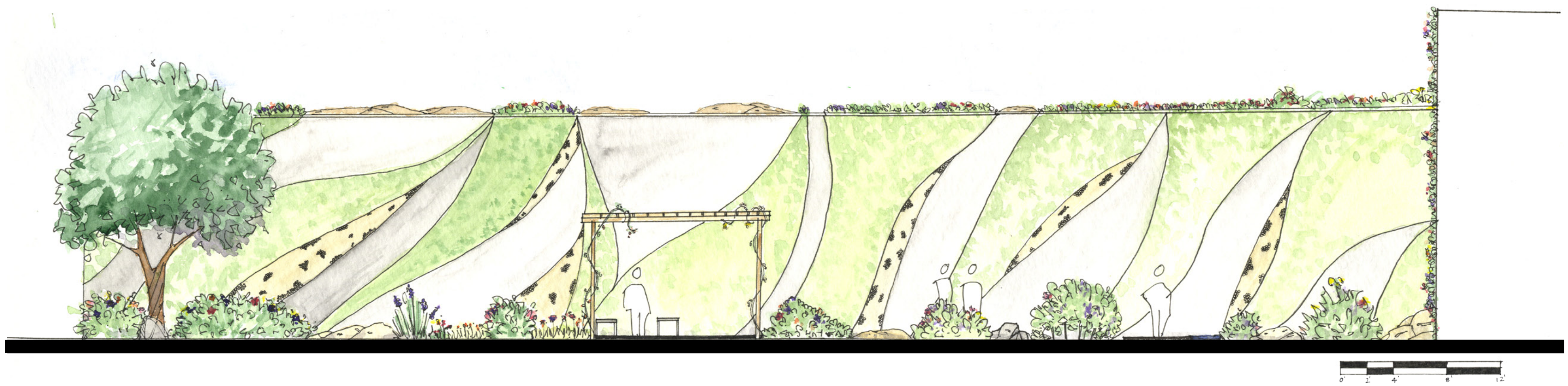


Fig. 45: Section-Elevation BB’

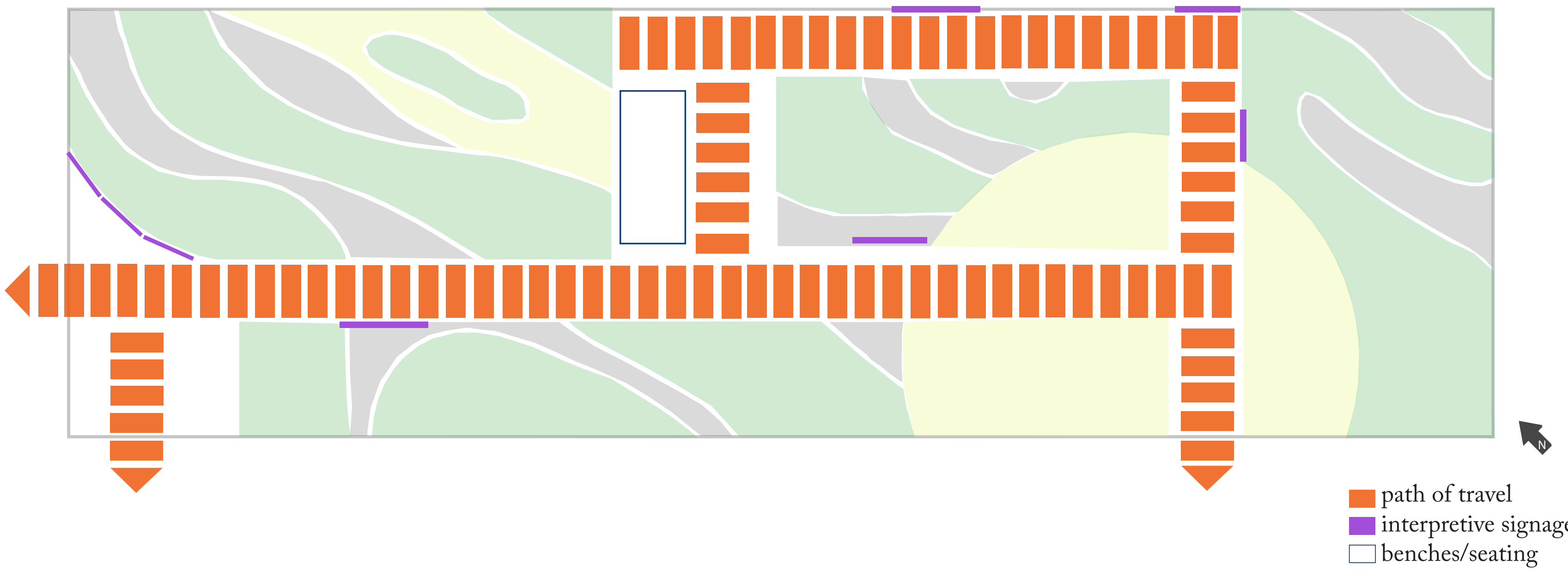


Fig. 46: Circulation and Signage

In addition to meeting the needs of native pollinators, the site is intended as a space for city residents to experience. There is a circulation path running through the site, giving pedestrians a choice to experience the pollinator habitat instead of the main sidewalk. There is an offshoot of the path going through a covered seating area and continuing along the northern vegetated façade. This lets people touch the plants and interact with the unique vertical element. The site also includes signage so people can learn about native pollinators and their environmental significance. They can also discover strategies for encouraging bees and butterflies to return their own neighborhoods, and in that way increasing the spread of a pollinator resource network.

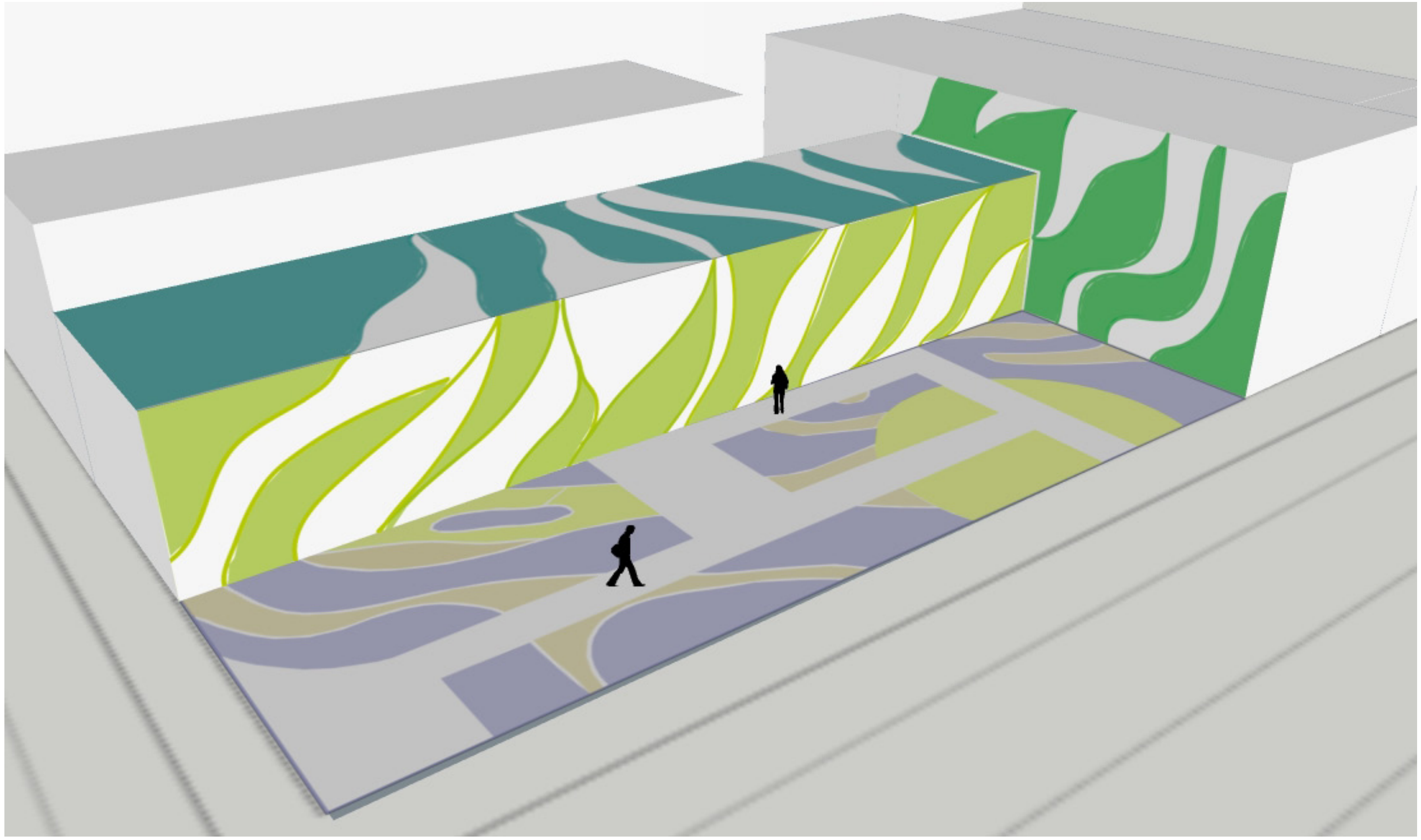


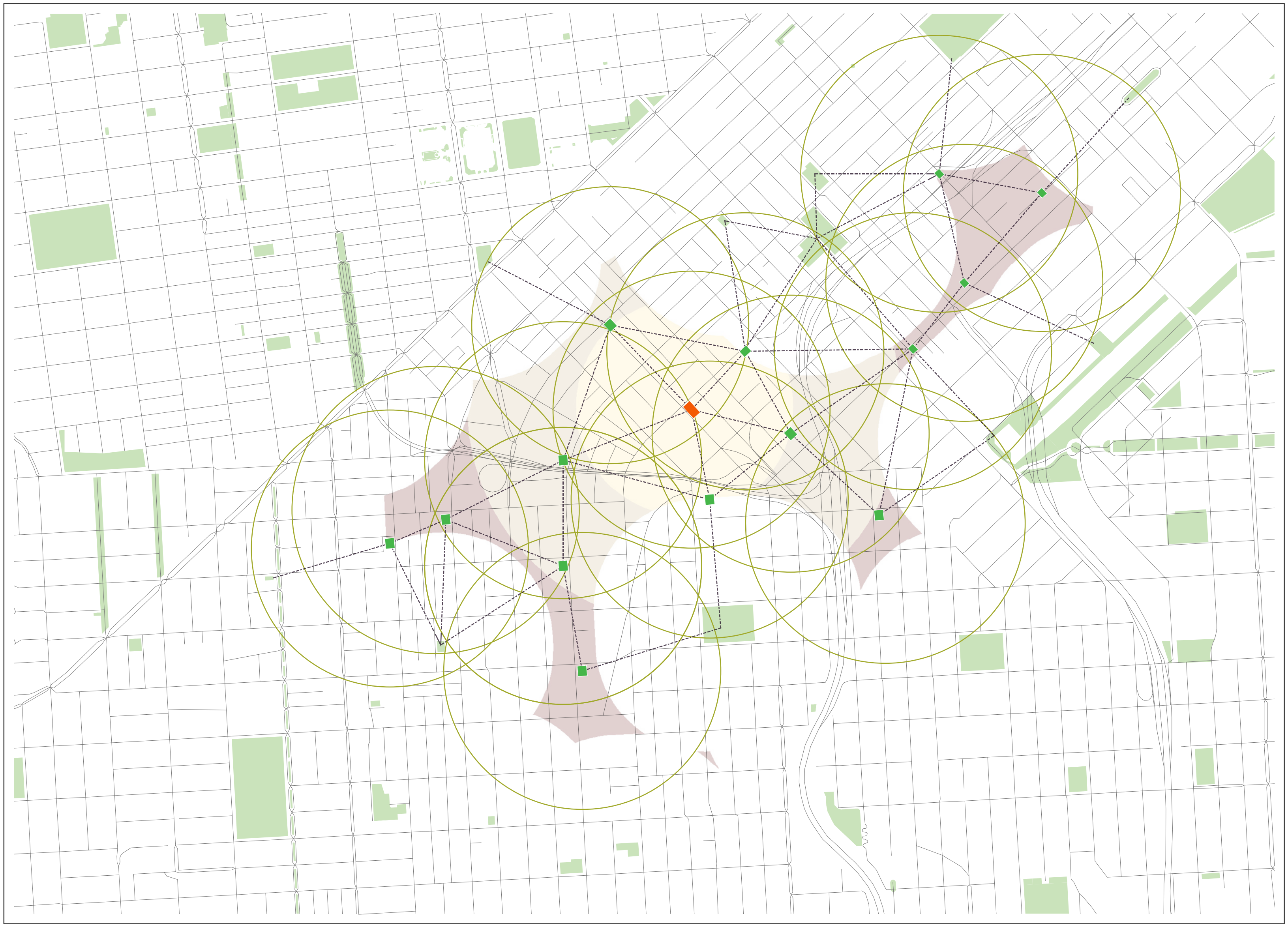
Fig. 47: Concept Model

The most unique aspect of this designed pollinator patch is its three-dimensionality aimed to provide an innovative template for how to utilize different open spaces in cities while being aesthetically provocative. The site utilizes three different types of surfaces: the ground, two vertical walls, and a higher-level horizontal plane on the roof. The walls and roof contain some of the same native plants that are in the planted areas on the ground as well as more drought-tolerant *Sedum* species. To increase the biodiversity of the living roof, the substrate varies in depth and composition. This allows more native plant species to thrive, and provides more nesting opportunities for ground nesting bees. Additionally, there are elements such as small logs and rocks to serve as resting places for bees and butterflies and to serve as additional nesting. The overall layering of pollinator habitat creates an intriguing atmosphere and displays a new aesthetic for talking about the integration of landscape and building.

A Stepping Stone Network

The designed site acts as only one small piece of a much larger vision for a more connected network of pollinator habitat throughout San Francisco. One smaller scale extension to the project would be to utilize the overwhelmingly large area occupied by the Costco across the street. Throughout the parking lot is a series of bare trellises and something as simple as covering these structures with a diverse mixture of flowering vines could provide a large source of foraging habitat for native pollinators. An even bigger opportunity pertaining to the Costco site concerns the building itself. The roof is flat and this massive area could become a living roof with a variety of habitats for bees, butterflies, as well as space for larger species including birds to nest and feed.

Moving outward from the site it is important to further consider its connectivity to nearby existing green space. Taking 1200 to 1500 feet as the lowest estimated foraging distance range of the targeted bee species, another distance analysis was performed on this area of the city. This narrowed down the void in green space to the large patch surrounding the project site. Since the designed lot is close to the center of this gap it is located too far away from possible source habitats to be well-used by the smaller members of the targeted native bee species. In order to aid these species in reaching the new project site it was necessary to introduce a series of stepping-stones. Further Euclidean distance measures taking the new project site into consideration as a green open space makes it possible to identify where these habitat patches should be established to create a movement corridor for bees and butterflies. The end result is a proposed stepping-stones with a distance of 1200 to 1500 feet separating them.



■	demostration site	■	< 1200 ft from site, > 1200 ft from existing green space
■	stepping-stone	■	1200-2400 ft from site, > 1200 ft from existing green space
■	existing green space	■	> 2400 ft from site, > 1200 ft from existing green space

0 400 800 1,600 2,400 3,200 Feet

N

Fig. 47: Proposed Stepping-Stone Network
Orginal Data from data.sfgov.org

The proposed sites along the network to be used as stepping-stones can incorporate a number of the strategies displayed in the design of the demonstration site. The 10th and Harrison project includes vertical and horizontal habitats that integrate both nesting and foraging resources at and above ground level. The strategies for planted walls and roofs can be used in creating pollinator habitat in areas that don't necessarily have land to spare at ground level. Plant species can vary from site to site as long as bloom continuity is a goal of all new patch projects.

From here a long-term master plan can be conceptualized to fully integrate built and natural space within the city of San Francisco. This vision can also be used in other cities to combat pollinator habitat loss resulting from continued urbanization.

Conclusion

In conceptualizing a network for pollinators across the city of San Francisco, this project aims to better understand how to assist urban populations of native bees and butterflies. Through analyzing the spacing of open green spaces in the city and the areas with less vegetative cover, gaps in resources become clear. In these areas it is possible to design patches of habitat to act as stepping-stones for pollinator species between rich foraging and nesting sites.

A demonstration site is located in the center of an extremely barren area of San Francisco within the SOMA neighborhood. It is designed using a combination of a small lot, the two walls surrounding it, and a neighboring roof to provide elements that can be integrated into future stepping-stones. The vegetated walls and roof that also contain nesting resources showcase an approach to integrating pollinator habitat even amongst dense urban areas where the only available space is not on the ground plane.

Using the estimated foraging distance of moderately sized native bees as a measure for spacing habitat patches informs the design of a stepping stone network through the current concrete landscape of the study area. This provides a method for strategically implementing pollinator habitat in barren areas to fill voids in open space throughout the city.

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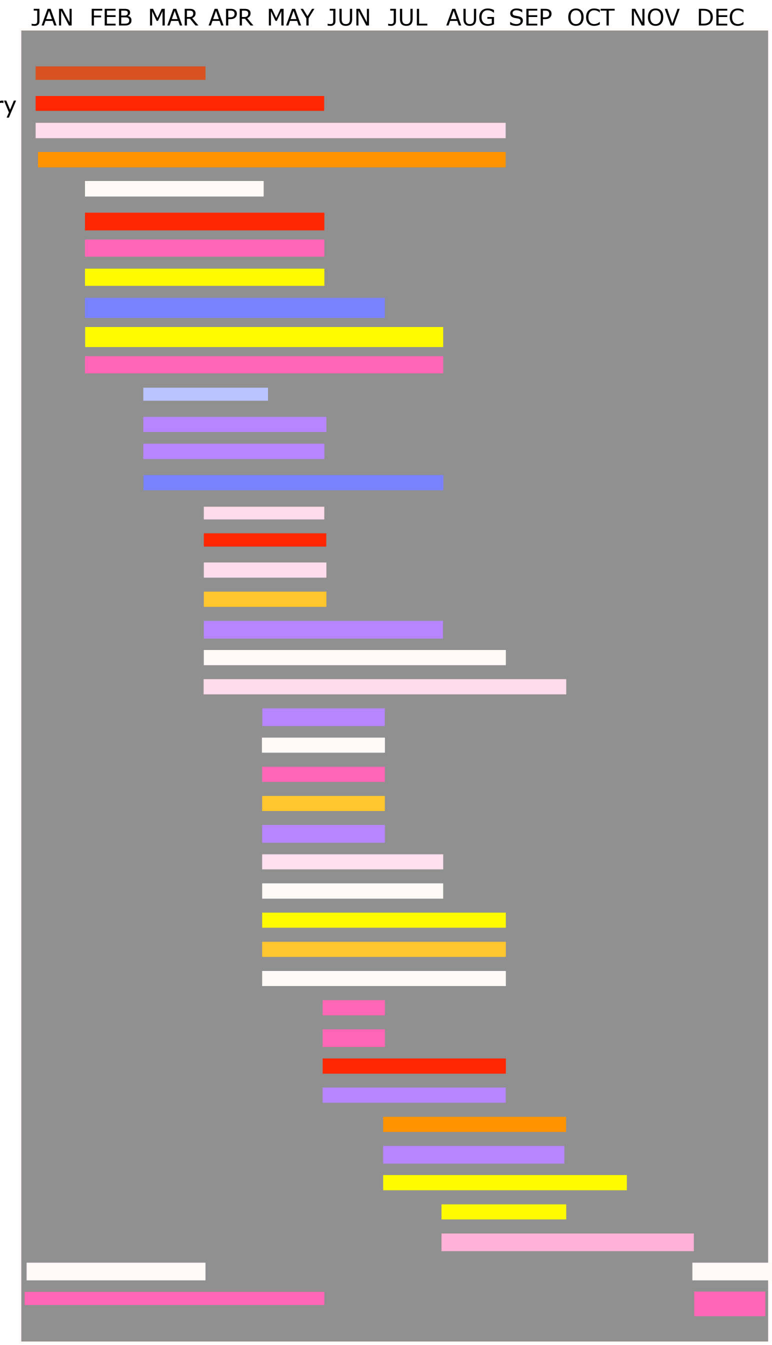
Appendix 1: Plant List

SCIENTIFIC NAME	COMMON NAME
Aristolochia californica	California Pipevine
Ribes speciosum	Fucshia Flowering Gooseberry
Erigeron glaucus	Seaside Daisy
Eschscholzia californica	California Poppy
Cardamine californica	Native Milkmaids
Aquilegia formosa	Western Columbine
Cercis occidentalis	Western Redbud
Ranunculus californicus	California Buttercups
Ceanothus thyrsiflorus	Blue Blossom
Cleome lutea	Bladderpod
Malva assurgentiflora	Island Mallow
Gilia tricolor	Bird's Eye
Phacelia tanacetifolia	Lacy Phacelia
Lupinus albifrons	Silver Lupine
Borago officinalis	Borage
Arbutus 'Marina'	Marina Madrone
Penstemon eatonii	Firecracker Penstemon
Arctostaphylos edmundsii	Little Sur Manzanita
Ribes aureum	Golden Currant
Lavandula angustifolia	Lavender
Achillea millefolium	Common Yarrow
Eriogonum fasciculatum	California Buckwheat
Salvia leucophylla	Purple Sage
Salvia mellifera	Black Sage
Rosa californica	California Rose
Wyethia mollis	Mule's Ear
Eriodictyon californicum	Yerba Santa
Aesculus californica	California Buckeye
Adenostoma fasciculatum	Chamise
Sedum spathulifolium	Yellow Stonecrop
Eriophyllum lanatum	Woolly Sunflower
Eriogonum nudum	Nude Buckwheat
Asclepias californica	California Milkweed
Rhus integrifolia	Lemonade Berry
Heteromeles arbutifolia	Toyon
Monardella villosa	Coyote Mint
Mimulus aurantiacus	Sticky Monkey Flower
Aster novae-angliae	Purple Dome
Ericameria nauseosa	Rabbitbrush
Solidago californica	California Goldenrod
Sedum "Autumn Joy"	Autumn Stonecrop
Garrya elliptica	Silk Tassel Bush
Ribes malvaceum	Chapparal Currant



Appendix 2

Plants for Use in the Meadow
(see chart to left for bloom)

Erigeron glaucus
Eschscholzia californica
Lubinus albifrons
Borago officinalis
Penstemon eatonii
Achillea millefolium
Wyethia mollis
Eriodictyon californicum

Stipa pulchra (purple needle grass)

Target Butterfly Species

Eight species of butterflies identified for inclusion into the network based on their presense in San Francisco:
Anise Swallowtail (Papilio zelicaon)
Sara Orange-Tip (Antocharis sara)
Tailed Copper (Lycaena arota)
Dotted Blue (Euphilotes enoptes)
Northern Checkerspot (Chlosyne palla)
California Tortoiseshell (Nymphalis californica)
Painted Lady (Vanessa cardui)
West Coast Lady (Vanessa cardui).